

RAINFALL AND AFRICA'S GROWTH TRAGEDY*

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Abstract

We examine the role of the general decline in rainfall in sub-Saharan African nations in their poor growth performance relative to other developing countries. To do so we use a new cross-country panel climatic data set in an economic growth framework. Our results show that rainfall has been a significant determinant of poor economic growth for Africa, but not for other developing 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 9 and 23 per cent (i.e., between 374 and 787 dollars per capita) of today's gap in African GDP per capita relative to the rest of the developing world.

* We would like to thank Mark Cassidy, Oliver Morissey and Jesus Anton for fruitful earlier discussions on the topic. We are also grateful to comments by participants at seminars given at University of Birmingham, CSAE, and the Eighth Annual Conference on Econometric Modelling for Africa. The second author gratefully acknowledges financial support from the *National Research Fund of Luxembourg*. Any remaining errors are ours alone. This paper was written before the first author started working at the European Commission. The opinion expressed in this paper belong to the authors only and should not be attributed to the institutions they are affiliated to.

Section I – Introduction

The poor performance of sub-Saharan Africa during the second half of the last century has and continues to receive a considerable amount of attention in the economics literature, see Collier and Gunning (1999a, 1999b) and Artadi and Sala-i-Martin (2004) for comprehensive reviews.¹ In the 1960s there was widespread optimism about its future – relatively high growth rates in the first half of the 20th century meant that it had already surpassed per capita GDP of many Asian countries and increasing political self-determination seemed to provide much 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 down and by the 1980s even resulted in economic contraction. While Africa's growth rates have recently begun to normalise again, the disastrous performance over more than twenty years has now 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 and Gunning (1999a, 1999b). In essence the theories can be categorised into those arising from political 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 and Ndulu (1996), Knack and Keefer (1995), Mauro (1995). These range from poor fiscal, exchange rate, and trade policies, and badly functioning financial and labour markets, to the lack of sufficient democracy

¹ As is conventional in essentially all of the literature on this topic, we focus on the relative growth performance of sub-Saharan Africa as the North African countries of 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 the sequel, we will interchangeably refer to Africa for sub-Saharan African countries (SSA), and to non-sub-Saharan (NSSA) countries for all other developing countries.

and good governance; see Collier and 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 and Dollar (1997)), low population density, the lack of diversification of Africa’s exports (Sachs and Warner (1997)), and ethno-linguistic diversity (Easterly and Levine (1997)), as well as the landlocked geography and tropical climates prominent of many African nations (Bloom and Sachs (1998)).

One other aspect of Africa that is increasingly more frequently referred to, but has as of yet not been evaluated empirically as a potential determinant of Africa’s poor performance, is the distinct change in rainfall patterns that has taken place since the 1960s. In particular, while there is a general awareness of a number of severe droughts over the period, it has only relatively recently been noted that rainfall in Africa has also in general been on a decline since its relative peak in the 1960s; see, for instance, 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, Africa is much more reliant than other countries on hydro-power for electricity generation. Moreover, severe changes in rainfall may arguably also have had an impact on other factors in Africa, such as demographic trends and investment.

In this paper we explicitly investigate for the first time the role that changes in rainfall have had on Africa’s relative economic performance.² In particular, we use a

² O’Connell and Ndulu (2000) do include a measure of the number of dry years, measured as the number of years in which rainfall was one standard deviation below its mean level of the 1941-1960 period, in a cross-country growth regression of African countries and find this variable to significantly negatively affect growth rates. While this result is indicative of the importance of rainfall for Africa there are two reasons why it did not enable the authors to draw further conclusions regarding African performance relative to other countries. Firstly, without access to comparable data for other developing countries the authors were unable to evaluate the importance of rainfall in the relative economic performance context, which is the focus of the current paper. Secondly, due to their alternative data source the authors use a different

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. More importantly, in a cross-country panel growth regression framework results indicate that rainfall has only had a significant impact on growth 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 be between around 9 and 23 per cent lower (i.e., the gap would be reduced by between 374 and 787 dollars per capita), 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 summary statistics. A discussion about the estimated specification is provided in Section IV. The results of our econometric analysis are given in Section V. Evidences of the importance of our identified channels are explored in Section VI. Using these results hypothetical growth scenarios under more benevolent rainfall conditions are explored in Section VII. The last section provides concluding remarks.

Section II: Rainfall and economic growth in Africa: A Conceptual Framework³

Changes in rainfall could potentially have a wide array of economic implications anywhere in the developing world. Historically, however, shortages in rainfall in Africa seem to have been associated with particularly damaging consequences. This particular

measure of rainfall namely the number of dry and non-dry years, which may not capture the full extent of the impact of rain.

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

sensitivity to rainfall seems at least in part to rest on features specific to Africa. We briefly identify the potential channels through which rainfall is likely to have affected sub-Saharan Africa (SSA) below.

A. Agriculture

The most direct impact of rainfall on Africa is certainly on the agricultural sector, since water is an important input into agricultural production. 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 per cent 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 per cent in the rest of the developing world.

However, even apart from the importance of agriculture per se, there are other aspects of the SSA continent that are likely to make the SSA agricultural sector very 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, i.e., mostly the tropics around the equator, are humid throughout the year. While there is substantial rainfall during the wet season(s) in the sub-humid regions located to the north and south of the tropics, there is almost no rain during the much longer dry season(s). Further poleward 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. As the name suggests, arid areas receive little direct water.

It is also important to point out that while the African continent has several large water basins and rivers and there is, as just noted, 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, even within the arid and semi-arid areas there is little water runoff as drier soil absorbs more moisture. As a matter of fact, the average runoff of about 15% is lower than in any other continent and extremely sensitive to changes in rainfall. Reibsame (1989), for example, estimates that in Southern Africa a reduction of 10 per cent in precipitation would lead to a fall of more than 50 per cent 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 per cent of arable land in SSA is irrigated, compared to nearly a fifth in other developing countries.

As becomes apparent, the areas outside the tropics are extremely reliant on rainfall for moisture.⁴ The availability of water from rainfall depends in turn on the rate of evapotranspiration, i.e., on the amount of water that remains in the soil after what is evaporated and what is transpired by plants as a part of their metabolic processes. The rate of this is particularly high in SSA, in part because high temperatures increase the water-holding capacity of the air. Moreover, recent trends in desertifications 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 inter-annual soil water storage. The UN, for example, estimates that desertification has reduced the potential vegetative productivity by 25 per cent for nearly a quarter of Africa's land area, see UNEP (1997). Land-surface and atmosphere conditions may thus interact positively as a feedback mechanism leading to a further decrease in precipitation.

⁴ As a matter of fact, today around 60 per cent of African countries are considered to be vulnerable to drought and 30 per cent extremely so, see Benson and Clay (1998).

The geographical variation of availability of water just described can be in turn 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 of 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 characterised by grasses of low digestibility. Since livestock are directly dependent on grass quantity, rainfall variations in the semi-arid and arid areas, have, in turn, direct consequences on livestock production.⁵ Specifically, it has been shown that the link between rainfall and animal numbers is approximately linear; see IPCC (2001).

Agricultural practices themselves have often added to the water shortage problem in Africa more than anywhere else due to the fact that farmers are often not owners of the land they work on, so that the preservation of natural resources is generally viewed as a secondary objective. In addition, pressures represented by increasing populations and changing technology add to the problem of land deterioration related to agricultural practices, see for example Drechsel et al. (2001). Besides, problems associated with land use through, for example, deforestation, can translate into increased erosion. Another illustration of environment-damaging agricultural practices is the intense use of fertilizer in low-quality lands. As yields increase, so will water consumption, thus creating a vicious circle, see Gomme and Petrassi (1996).

⁵ One should also note that apart from animal products, domestic livestock often also serve as source of draft power in SSA.

Finally, it is important to consider how the agricultural sector in SSA may have directly responded to shortages in rainfall. One could argue that one response to losses in agricultural production to falls in rainfall that could dampen their effects may, at least in the short run, be an adjustment of prices. However, since most of African agricultural products are for export and African countries tend to be price takers on the world commodities market, a loss in production is unlikely to have any effect on prices for most agricultural products for most countries; see Deaton (1999) and Reilly et al (1994). Over the more longer run farmers and governments may adopt technologies and production techniques that take the climatic changes into account and thus reduce its impact. However, as noted by the IPCC (2001), relative to for example the Asian regions, adaptation in SSA has been minimal.⁶ For example, Molua (2002) found that in Cameroon only little more than half of farmers modified their farming practises to suit prevailing climatic conditions and that this mostly involved using inferior indigenous techniques to do so. Moreover, as noted by Jagtap and Chan (2000), farmers in SSA tend to employ rudimentary non-scientific means of predicting large fluctuations in rainfall.

B. Urbanization

An important direct consequence of effects of shortages of rainfall on the agricultural sector is urbanization. More specifically, variation in rainfall may result in permanent internal population movements. As a matter of fact, Krokfors (1995) notes that migration is an important demographic response to environmental stress in Africa. Thus, severe and prolonged shortages of rainfall and consequent losses in income generated from agricultural production may cause substantial movements of the population from rural to urban areas. The potential importance of this is suggested by the fact that SSA's rate of urbanization has grown by more than 140 per cent since the

⁶ Nevertheless, it must be emphasized that human adaptation to long-run changes in Africa is not well understood; see IPCC (2001).

1960s and that estimates show that roughly half of this urban growth has been due to rural-urban migration. For instance, during the drought period in the mid-1980s there was substantial rural-urban migration in a number of the Sahelian states; see Kelley (1991).

In this regard, the movement of people from rural to urban areas due to rainfall shortages may have negative effects on growth as it may lead to what has become known as over-urbanization, a concept noted back as early as Davis and Golden (1954) and famously modelled from a urban-rural wage perspective by Harris and Todaro (1970). Particularly, with regard to Africa it has now been estimated that urban centres are indeed not serving as engines of growth as they do in many other developing countries; see World Bank (2000) and Fay and Opal (2000).

C. Population Size

In its severest cases, extended shortages of rainfall can have non-negligible impacts on the size of the population in SSA countries. For example, one of the severest droughts between 1968 and 1973 in the Sahel caused around 250,000 deaths. Also, the long drought in the early 1970s in Ethiopia resulted in nearly 300,000 dead. One should note, that while this may be a direct consequence of starvation or dehydration, there may also be indirect effects, since shortages in rainfall can affect both its quantity and quality, see World Bank (2003). For instance, some devastating diseases such as typhoid, cholera, and schistosomiasis are directly linked to water scarcity and quality; see, for example, the study by Spalding-Fecher and Moodley (2002) on the economic consequences of malaria in South Africa and its relationship to rainfall variation.

D. Energy Production

Rainfall can also significantly affect the energy sector in SSA as energy supply in many of its countries now relies heavily on water as both a direct and an indirect source of energy production; see Magadza (1996). Over the last 50 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 per cent of total power generation in Africa compared to the relatively stable average of 34 per cent in other developing countries. Additionally, water also serves as an important secondary input for thermal power generation as a cooling device and is needed in huge 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 very sensitive to changes in precipitations. One of the reasons for this 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. As a matter of fact, there is evidence that shows that the African major rivers' performance is significantly lower than that of other areas in the world.⁷ 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 significant loss of as much as 30% of total hydropower energy from the Kariba dam, which supplies power to Zambia and Zimbabwe; see Magadza (1996).

Finally, the effect of a fall in precipitation may not only reduce generation capacity, but could also retard the construction of new and more productive plants. It may also cause negative effects on investment projects as installations are often costly and the huge investments they require become less profitable as rainfall decreases, see Harrison and Withington (2001, 2002a, 2002b).

⁷ 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).

E. Investment

Rainfall shortages may also have effects on investment as the insurance capacity of households is extremely limited; see Christiansen et al (2002). More specifically, as noted earlier, changes in rainfall are likely to cause greater precautionary savings and thus divert funds from potential investment in Africa in order to smooth consumption levels. For example, Rosenzweig and Binswanger (1993) find that uninsured weather risk leads farmers to select asset portfolios that are less sensitive to rainfall but are also less profitable. Related to this, prolonged shortages in rainfall may also have consequences for investment in human capital by affecting the extent of child labour; see, for example, Bhalotra and Heady (2000).

Section III – Primary Data and Summary Statistics

The primary data used for the purpose of the paper is derived from a number of sources, and we describe these and the definitions of all our variables in greater detail in the Data Appendix. Our first main variable of interest is the country-wide measure of rainfall taken from the Inter-Governmental Panel on Climate Change (IPCC) data set and available over the period 1901-1998. We normalised this rainfall measure by the long-term mean annual rainfall in each country prior to 1960. It should be noted that a similar normalisation has also been used by the FAO; see Gommers and Petrassi (1996). This normalisation was primarily done since we are interested in shortages relative to long-term trends rather than just yearly movement in levels. Typically, as shown by Nicholson (2001) for Africa, long-term trends in rainfall seem to move in very long cycles lasting several decades. One should note that the cut-off point of 1960 was chosen in view of this being the beginning of the sample period of our econometric analysis.

One other aspect with regard to our rainfall measure that deserves discussion, because it has plagued many studies examining other potential determinants of Africa's poor growth performance, is the question of its 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. Moreover, as just noted, earlier historical data suggests that rainfall naturally moves through long cycles of relative troughs and peaks, and that a cycle similar to the one over the 20th century seems to have also occurred in the 19th century.

Our second main variable of interest is economic wealth. As a measure of economic wealth 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.⁸ We graph the normalised rainfall, taking 1960 as the base year, mean series of economic wealth for sub-Saharan African and other non-sub-Saharan developing countries in Figure 1.⁹ 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 the early 1970s. It then rose significantly in the late 1970s and particularly in the 1980s, but appears to have stabilised in the latter half of the 1990s.

Figures 2 and 3 depict the long-term trends in our normalised rainfall measure for the same groups, shown as five year moving averages given their high inter-annual variability.¹⁰ As can be seen, while variable, the mean rainfall in SSA remained roughly

⁸ See the Data Appendix for further details on the groups as well as the definitional criteria.

⁹ The mean real GDP per capita, in 1996 \$US, was 1457 and 2611 for Sub-Saharan African and other developing countries, respectively.

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

constant during the first part of the 20th century until the late 1950s, when it peaked. However, since this peak, rainfall has been on a clear downward trend. As a matter of fact, apart from a peak in 1980, mean rainfall has been for the most part lower than during the first 60 years of the century. These trends suggest that there has been an important change in the trend of rainfall in SSA since about roughly the late 1970s. Figure 3 shows, in contrast, that average annual rainfall in NSSA displays no such trend.

In order to give some graphical indication of how the observed rainfall patterns 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 onwards simultaneously in Figure 4. This reveals that the two series seem to move very 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 5.

Section IV – Econometric Specification

The graphical trends just depicted seem to suggest that SSA’s relatively poor growth performance has gone hand in hand with movements in mean precipitation. In contrast, no such trend 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 augmented Solow growth model in the spirit of Mankiw et al (1992) where we assume that the stock of water available is an additional (to labour and capital) factor input. More precisely, countries are postulated to follow a Cobb-Douglas production function as follows:

$$Y = AK^\alpha W^\beta L^{1-\alpha-\beta} \tag{1}$$

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.

where Y , A , K , L , and W are output, exogenous technological progress, the capital stock, population, and the stock of water, respectively, and $0 < \alpha < 1$, $0 < \beta < 1$ and $\alpha + \beta < 1$. It can be shown that under certain assumptions such a production function will have a steady state output per capita growth rate that will depend on the rates of factor of accumulation and that convergence to this steady state will depend on the distance from it; see Durlauf and Quah (2000). The empirical specification of such steady state growth convergence is usually constructed using a log-linear approximation around the steady state of output per capita:

$$GR_{i,t-j \rightarrow t} = \beta_1 + \beta_2 \log(y_{i,t-j}) + \varepsilon_{it} \quad (2)$$

where y is the output per capita, GR is the GDP per capita growth rate for country i over the period $t-j$ to t measured as $\log(y_t) - \log(y_{t-j})$, and ε is a random error term. The specification in (2) predicts conditional convergence in the sense that a lower starting value of per capita income level (which also captures the initial stock of production factors) tends to generate a higher per capita growth rate, which should be reflected in a negative estimate of β_2 . One should note, however, that such a notion of absolute convergence assumes structurally similar economies with the same rates of factor accumulation. In contrast, the large empirical literature on determinants of economic growth rates within this framework, however, has shown that there are cross-country differences in the rates of factor accumulation and many other aspects that may affect the rates of factor accumulation, hence suggesting conditional, rather than absolute, convergence. Particularly, with regard to this paper, we assume that water may be an important factor input in both agricultural and non-agricultural economic activity which may differ across countries and time. Thus one would like to control for the rate of accumulation of this and other possible determinants of ‘conditional’ convergence as follows:

$$GR_{i,t-j \rightarrow t} = \beta_1 + \beta_2 \log(y_{i,t-j}) + \beta_3 w_{i,t-j \rightarrow t} + \beta_4 X_{i,t-j} + \varepsilon_{it} \quad (3)$$

where w is a proxy of the rate of accumulation in the water stock and X is a vector that includes changes in other factors of accumulation (such as the investment rate and population growth rate) and other determinants of these.¹¹ In terms of measuring w one would ideally like to have a measure of the available stock of water for each period for each country to then calculate its change. A comprehensive and reliable measure of this, unsurprisingly, currently does not exist.¹² However, the water balance model, a fundamental concept in the hydrology literature based on Newton's law of motion and the first law of thermodynamics, states that the change in the water stock between any two time periods is (see Dingman, 2001):

$$\Delta W = I - O \quad (4)$$

where ΔW , I , and O are the change in the water stock, the inflow, and outflow of the Water stock over any period $t-1$ to t , where I and O are due the natural hydrological cycle and (possibly) augmented by man made facilities (such as irrigation systems). Important natural inflow factors include rainfall and ground water inflow, while natural extractions consist largely of evapotranspiration and groundwater outflow.¹³ Unfortunately, in terms of measuring the change in the water stock, the only information available to us is rainfall and we thus for our empirical analysis have to assume that changes in rainfall will adequately capture changes in the overall stock.¹⁴

¹¹ One should note that such 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 et al (1997), Barro (1997), Easterly and Levine (1997), and Masters and McMillan (2001).

¹² Moreover, there is considerable controversy of how such should be measured; see, for instance, Lawrence et al (2002).

¹³ One should note that this basic water balance equation serves, for example, as the underlying model of the Nicholson (1997) study of the water balance over Africa, Sumarjo Gatot et al (2001)'s analysis of rainfall harvesting in Indonesia, and Guenter and Bonstert's (2002) study of water availability in Brazil. Also note that the general water balance model has also been utilised to determine water availability for hydropower; see Harrison and Whittington (2002b).

¹⁴ For discussion of the link between evapotranspiration, rainfall, and runoff in terms of soil moisture see Dickinson et al (2003).

With this water balance and our economic growth model in mind, convergence to the steady state growth rate over any time period will be determined by initial GDP per capita, changes in the water stock as proxied by rainfall and other country differences that might determine the steady state growth rate. Moreover, in terms of showing what since Easterly and Levine's (1997) seminal paper has become known as the African growth tragedy within the economic convergence empirical growth framework, authors have normally included a zero-one type dummy that take on the value of one when a country is located in the SSA region.¹⁵ The coefficient on this variable has consistently been found to be significantly negative and referred to as the African growth tragedy. For purposes of this paper, we thus estimate the following for the pooled sample of SSA and NSSA countries:

$$GR_{i,t-j \rightarrow t} = \beta_1 + \beta_2 \log(y_{i,t-j}) + \beta_3 X_{i,t-j} + \beta_4 SSA_i + \beta_5 RAIN_{i,t-j} + \beta_6 SSA_i * RAIN_{i,t-j} + \gamma_t + \mu_i + \varepsilon_{it} \quad (5)$$

where SSA is a dummy for SSA countries, RAIN is our rainfall measure, and a proxy of changes in the availability of water which varies over time and country, γ are time specific effects common to all countries, μ are country specific effects that are unobservable to the econometrician, ε is an i.i.d. random term, and the β 's are the coefficients to be estimated.¹⁶ We postulate that the coefficient on the interaction term SSA*RAIN is positive and significant whereas the coefficient on RAIN is either insignificant or of a lower magnitude, implying that rainfall has affected SSA to a lesser extent than NSSA nations. Alternatively, we separate out our SSA and NSSA samples so that the error generating process can differ across these, drop the SSA dummy and its interaction term with RAIN, and then compare the coefficient on RAIN in the two samples.

¹⁵ See also, amongst many others, Block (2001) and Hoeffler (2002).

¹⁶ See Barro (1995)

In estimating (5) and other variants of this specification we generally resorted to estimating the determinants of average GDP per capita growth over five year intervals, so that GR is just $[\log(y_t) - \log(y_{t-5})]/5$. This was done for a number of reasons. Firstly, abstracting from annual movements in GDP per capita is the standard approach in the literature on convergence, as the underlying conditional convergence framework is concerned with longer term growth patterns than with annual short-term fluctuations in GDP per capita.¹⁷ In this regard, researchers of the African growth tragedy have also been mainly interested in long-term divergence from the economic growth patterns of other developing countries.¹⁸ Secondly, in terms of adjustment to shortages of water it is likely that these are to be particularly important when they last for longer periods. For example, droughts are generally defined as rainfall shortages over several years.^{19,20} Nevertheless, we do also experiment with other interval versions of (5) as this will provide additional information regarding the role of rainfall in the African growth tragedy.

Within this five year average economic growth rate empirical framework we define our five year average change in the water stock as the average of normalized rainfall over five year intervals:

$$R_{i,t-j} = [(RAIN_{i,t} + RAIN_{i,t-1} + RAIN_{i,t-2} + RAIN_{i,t-3} + RAIN_{i,t-4})/ARAIN_{i,1901-1959}]/5 \quad (5)$$

where $ARAIN_{1901-1959}$ is average rainfall over the 1901-1959 period and serves as a normalisation factor. One should note that, in addition to the reasons given in Section III, this normalization allows us to take account of the likelihood that even within broad

¹⁷ See Dobson et al (2003) for a review.

¹⁸ One may have even been inclined to use longer than five-year intervals in this regard. However, this would have reduced our sample size considerably, particularly for when we implemented panel methods, and results would have to have been viewed with considerable caution.

¹⁹ See Benson and Clay (1998).

²⁰ Mendelsohn et al (1994) use 30 year averages of precipitation and temperature to examine the effects of global warming on US agriculture. Also, Deschenes and Greenstone (2004) argue that in the short-run agricultural supply is likely to be inelastic due to the lag between planting and harvesting, so that there will be adjustments in price that will mitigate losses in production. Moreover, although they examine short-run effects they note that this “is likely to be biased relative to the preferred long run effect” (p. 7).

regional classifications, such as SSA versus NSSA, countries are likely to be heterogeneous in terms of their very long-term average water availability and will have thus made long-term economic choices, such as the mix of agricultural crops or whether to invest in hydropower, to reflect this. Such choices should be reflected in differences in the country specific steady state growth rates and deviation from these will be driven in this regard by rainfall shortages relative to this. For example, one would expect an average annual rainfall to be of lesser consequence for a country that has for decades been characterized by a dry climate than one that has historically been much wetter. Without any further information in this regard, normalisation of the rainfall proxy in our OLS models thus lets us, to a crude extent, control for such differences. However, one should note that because this normalization is time invariant it is purged from all of our fixed effects specifications and in these only affects the size of the coefficient measured.

In terms of choosing other control variables, X , we took into consideration both what is commonly used in the conditional literature to look at conditional convergence, what has in the past been used to investigate the African growth tragedy, and the channels discussed in Section II. With regard to the latter we included agricultural production, urbanization, hydropower production, size of the population, investment as percentage of GDP, and the average years of schooling as a measure of human capital. Two other common time controls which we used are the degree of openness, measured as the ratio of total exports and imports to GDP, and government expenditure as a percentage of GDP. Moreover, Murdoch and Sandler (2002) have also shown that civil wars within a country and bordering countries can influence differences in growth rates across countries and we thus similarly use proxies of these as part of our set of time varying controls.²¹

²¹ This data was kindly provided by the authors.

For the case where we use simple OLS regression techniques we also experimented with including a number of time invariant controls that have received attention in the literature. These include the degree of ethnic fractionalisation, a dummy for whether the country has a tropical climate, six regional dummies, land size, and a dummy for whether the country is landlocked. The latter are defined at the earliest time at which such definitions are available and are meant to capture the World Bank operational lending categories based, amongst other things, on civil works preferences and IDA eligibility. Moreover, they may serve as rough controls for the potential existence of growth convergence clubs; see, for instance, Quah (1997).

While there have clearly been a sizeable number of other time varying and time invariant variables that have been used in the growth literature 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 just mentioned provided us for the five-year interval growth rate regressions with a sample of 59 countries, of which 20 were sub-Saharan African, covering the period 1960-1990.²² For all five-year growth rate regressions we used only the sample of observations for which there were non-missing values on all time varying and time invariant control variables, so that our sample is the same throughout all the regressions. This gives us 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.²³

²² Our time period was limited to 1990 because a number of our main and auxiliary explanatory variables are limited to this period, namely, urbanization growth, education, civil wars, and hydro-power growth.

²³ The mean number of observations for each country (from a possible 6) is 5.86.

Section V: Econometric Results

A. Main Results

Using standard OLS, we first estimate (5) without any interaction term between RAIN and SSA or other control variables X, as shown in the first column of Table 2.²⁴ Accordingly, the SSA dummy is -0.021 and significant, indicating that SSA countries had on average lower growth rates, thus supporting the idea of an African growth tragedy. More importantly, we find that rainfall has a significant positive effect on economic growth in our full sample with a coefficient of 0.038 . In order to determine whether this differs across SSA and NSSA countries, we, as in (3) included an interaction term of the SSA dummy and rainfall in the second column. This interaction term reveals that rainfall has a positive and significant influence on economic growth only in SSA countries with a coefficient of 0.082 and thus that the positive effect in the overall sample was being driven by the inclusion of SSA observation. Put differently, lower rainfall will negatively affect growth only in SSA countries. As shown in the third and fourth columns, this result, i.e., 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.

To investigate the robustness of our results we included our full set of control variables, including time dummies. Given that our focus here is not on disentangling the effects of the previously mentioned 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 are not discussed, but reported in Appendix. The results on our main variable of interest, rainfall, for the full sample and the sub-samples are provided in the fifth through seventh columns of Table 2. In line with our simple specification, the results similarly indicate that rainfall has only had a

significant impact in SSA countries, with a coefficient of 0.071 on the interaction term in the fifth column and a coefficient of 0.085 for the SSA subsample.

We also re-ran our specifications in Table 3 but using a fixed effects estimator, which allows us to purge not only the effect of our time invariant controls, but all other non-included time invariant factors from the model. Accordingly, purging all 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 a coefficient of 0.101. The results are also similar when 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, producing a coefficient of 0.145. Thus, robust to the control of other determining variables, rainfall only significantly affects the growth path of SSA.

The effect of rainfall on growth in SSA may simply be capturing the effect of temperature changes. In this regard, previous studies have argued and found evidence for some industrialised countries that temperature can have a negative impact on agriculture; see, for instance, Mendelsohn et al (1994). We constructed a similar measure temperature to our rainfall proxy for SSA and NSSA and graph these series in Figure 6.²⁵ 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, from which onwards they have been on a steep ascend. To investigate whether these may have affected growth rates, or whether, feasibly, the effect of rainfall on growth in SSA may simply be capturing the effect of temperature changes, we included temperature in our specification for our two sub-samples in the columns 4 and

²⁴ 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.

²⁵ The data on temperature was also taken from the IPCC database.

5 of Table 3. Accordingly, in neither case is temperature a significant determinant of growth, nor does its inclusion change the coefficient on rainfall.²⁶

B. Further Robustness Checks and Alternative Specifications

Our results thus far suggest that the African continent responds differently to rainfall compared to other developing countries. As our discussion in Section II indicated, there are particular features about the SSA geography that make it relatively more dependent on rainfall than NSSA nations and the lack of the significance of our rainfall variable in NSSA may be simply capturing such differences. To at least roughly try to investigate this we recall that the degree of aridness of SSA geography, its higher temperatures, and its lack of irrigation systems have all made SSA more dependent on rainfall as a direct source of water. To this end we compiled country specific data on the average temperature (prior to 1960), the proportion of land that is dryland, and the percent of arable land irrigated in each country and interacted this separately with our rainfall proxy in Table 4 using fixed effects regression techniques. As can be seen, neither of these interaction terms separately, nor in conjunction with each alter the significance of the SSA*RAIN coefficient.

Some of the studies that have investigated the African Growth Tragedy and many of the conditional convergence papers have included developed countries in their sample. We thus also investigated whether their exclusion may be driving the lack of significant findings between rainfall and growth in our NSSA sample.²⁷ As can be seen from first row of Table 5, the coefficient remains insignificant, although its drop in absolute size may be noteworthy.

²⁶ One may have also liked to investigate whether there was any interaction effect between rainfall and temperature. However, given that much of the variation comes from rainfall the interaction term was highly correlated with the rainfall variable itself (0.90 and 0.91 for NSSA and SSA countries, respectively), so that this proved not feasible.

²⁷ Our list of developed are given in Appendix B.

We also experimented whether our choice of normalisation may be subject to any bias, as discussed in more detail in the Data Appendix. Specifically, one can note from Figure 1 in New et al (2000) that weather station availability, from which the precipitation measurements for our variable was taken, was much higher from the 1940s onwards. Hence we tried using the 1940-59 country means as normalisation factors for both our OLS and our fixed effects specification. But, as shown in the second and third rows of Table 5, this changed little in terms of our estimates qualitatively or quantitatively.²⁸ Additionally, we investigated whether it is indeed important to take account of the possibility that countries with historically less rainfall may have made economic choices so that they are less rainfall dependent by including the level of rainfall using OLS in the fourth row of the table. The results for OLS using the rainfall level indeed supports this view, as for both groups rainfall in levels is not significant.

Our argument for using the average level of rainfall over five periods as a proxy of water availability rested on the assumption that rainfall should be considered an inflow into rather than a proxy of the stock of water. If it arguably were a measure of the stock of water then one should observe a relationship between economic growth rates and the growth rate of rainfall, as a measure of climatic change, over any interval. As the results in the fifth row of Table 5, however show, there is no statistically significant relationship between the growth rate of rainfall and that of economic growth. In the sixth row we report results of including a lagged value of the rainfall to see whether there were effects beyond the five years time span. However, the coefficient reported on this variable shows little indication of such.

We additionally experimented with effects of rainfall over both longer term and annual intervals, where the measure of rainfall and growth were appropriately redefined. As can be seen from the seventh row, over ten year periods, there is still evidence of a

²⁸ The fact that there is no effect on the fixed effects estimation may not be surprising since arguably a

positive relationship for SSA nations. Noteworthy is, however, that the size of the coefficient is about 60 per cent smaller than for our main specification, although the much smaller sample size may have affected the precision of this result. Nevertheless, this difference may suggest that over the very long run African economies have adjusted at least partially to the changes that have taken place, thus dampening their effect on growth. Examining the annual results in the eighth row one finds that the size of the coefficient on rainfall is slightly smaller than for five year growth rates. This may in part be because using annual intervals one is more inclined to measure the impact of variability rather than long term climatic changes. Moreover, there may be some delays in the impact of shortages in rainfall as there can be long lags between the planting and the harvesting seasons. Finally, we also investigated whether rainfall may be a good measure of the stock of water with annual data in the final row, but, as with the five year data, we found no evidence of such.

Section VI – Evidence on Potential Mechanisms

Ideally, if we have really identified all channels through which rainfall affects growth in SSA in Section II and if these can be adequately proxied, then allowing for their changes over any five year period should render the effect of rainfall insignificant in our econometric specification. In part this would first require that one can show that rainfall does indeed affect variations in these channels. To further investigate this we regressed the growth rates of our proxies for identified channels on our rainfall measure, the results of which are shown in Table 6. Accordingly, one only finds evidence for rainfall affecting agricultural production, urbanization and hydropower production in SSA, but not the size of the population, general investment or investment in human capital. The fact that the other channels have little impact, using this simple test, may be

fixed effects estimator already purges such time invariant biases from our specification.

for a number of reasons. Simply, while they may be important, their role from a macroeconomic view point may be minimal and/or there are other channels that we have failed to identify. Having said this, one must keep in mind that perhaps our proxies' measurement of the effect are likely to be substantially less than perfect, so this conclusion must be viewed with some caution.

We can use these results to assess what the contribution of the rainfall via significantly found channels in to the actual growth rate in SSA is in our data. This is done as follows. For agriculture we simply take the estimated coefficient in Table 6 for the agriculture specification and multiply this by the average share of GDP in agriculture in SSA (29.7 %), thus suggesting that its contribution was 10 percentage points. In the case of hydropower we similarly need to identify its share of total GDP per capita in SSA. Figures taken from the International Energy Association suggest that on average in SSA energy production constitutes roughly 6.3 per cent of GDP per capita. Given hydropower's share in total energy production in SSA (37.1%) and the estimated coefficient, our results would suggest then that the effect of rainfall on hydropower is about 0.9 percentage points. Finally, to capture the effect of urbanization rate we postulate that the negative effect of urbanization on growth in SSA may be through the generally higher unemployment rates in urban areas; figures suggest roughly around 4 percentage points (see Todaro, 1997). Additionally figures from the International Labour Organization's KILM database suggest that in SSA labour productivity since the 1980s was about 720 dollars per person and the unemployment rate about 20 per cent, so that, given the average GDP per capita over the same period (1900 dollars), employment's generated share of GDP in SSA would roughly be about 30 per cent (i.e., 720 times 0.8 divided by 1900). Given the difference in unemployment rates we can then assume that one percentage increase in urbanization would reduce the GDP per capita by 1.2 per cent (by reducing employment rates by 4 percentage points). Thus our estimated

coefficient suggests that the effect of rainfall on growth through urbanization would roughly be around 0.2 percentage points. Thus, overall through the various (significant) channels rainfall acts to reduce SSA growth rates over any five year period by 11.1 percentage points.

. If the conjectured channels are truly the aspects through which patterns in rainfall have affected SSA economies one would expect a noticeable reduction in the size of the coefficient on rainfall if their changes were controlled for in our base specification. We thus also proceeded by including the growth rates of our channels variables over any $t-5$ to t period instead of their values at $t-1$ systematically into our empirical equation. In doing so, we again run separate regressions including those variables that are related to the direct effect on agriculture, i.e., agriculture production growth and urbanization growth, jointly and those related to investment decisions, i.e., education attainment growth and overall investment rate growth, jointly. We first report the results without the channel proxies, either as $t-1$ levels or as growth rates, in Table 7. As can be seen, the coefficient is slightly higher than without these. Including agricultural and urbanization growth shows that urbanization has a negative effect on growth, while agricultural production positively influences economic well being, although the latter is insignificant.²⁹ More importantly, however, their inclusion reduces the coefficient on rainfall by over 30 per cent. We subsequently added population growth, but this made essentially no qualitative difference on the estimate on rainfall. In contrast, there is no discernable effect from population growth to the specification. Also, hydropower growth only acts to increase the coefficient, although it must be noted that it appears to be an insignificant determinant of economic growth in SSA countries. Finally, our growth rate variables of human capital and general investment similarly seem to have no great qualitative impact.

Section VII: Simulations

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

In considering how rainfall would affect GDP per capita within our conditional convergence framework, one must realise 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 one can construct the hypothetical GDP per capita series at any time T for a country i by:

$$Y_{i,T}^H = Y_{i,1960} + \sum_{t=1}^{t=T} [GR_{i,t-5 \rightarrow t} - \beta_2 (\log(Y_{i,t-5}) - \log(Y_{i,t-5}^H)) - \beta_5 (R_{i,t-5 \rightarrow t} - R^B)] * Y_{i,t-5}^H \quad (5)$$

where the superscript H indicates simulated hypothetical series and R^B refers to some benchmark Rainfall. We first calculate such a predicted GDP per capita series for SSA holding rainfall at its mean normalised annual level over the period 1955-1960, when rainfall was essentially at its peak of the century, using the coefficient on rainfall from the fifth column and the coefficient on initial GDP per capita from the first column of Table 3.³⁰ The resultant hypothetical GDP per capita series, along with the actual SSA and NSSA series, is depicted in Figure 7. Accordingly, if rainfall had remained at the high level of the late 1950s, the difference in the mean growth rates between SSA and NSSA

²⁹ These variables are, unsurprisingly, highly correlated. Moreover, one may expect that rural-urban migration is ultimately the long-term effect of poor agricultural performance.

nations, which can be gauged from the relative slopes of the series, would have been roughly similar until the late 1970s, from which point onwards 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 23.4 per cent less than what was observed in actuality in 1998. Thus the gap would have been reduced by 787 dollars per capita.

Given the high variability of African rainfall over time, perhaps a more realistic scenario to examine is the one under which rainfall would have remained at its previous long-term mean prior to the 1960s (1901-1959). This is shown relative to the true trends in SSA and NSSA countries, also in Figure 7. 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 and early 1960s was above the previous long-term mean. GDP per capita in SSA nations would 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 9.0 per cent less, reducing the gap by 374 dollars, than what was observed in actuality in 1998.

Section VIII: Concluding Remarks

Using a new cross-country panel climatic data set we provide evidence that changes 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

³⁰ We choose the former so as to allow for an estimate from a less restricted error generating process and

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. As a matter of 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 may have been between 9 and 23.4 per cent (i.e., between 374 and 787 per capita dollars) lower. In investigating the channels through which rainfall has affected the sub-Saharan African continent we find some evidence that they have operated through the agricultural sector by reducing agricultural output directly and by encouraging rural-urban migration.

Our results have important policy implications. Given the conflicting evidence as to whether the general decline in rainfall will continue in Africa (see, for instance, the different predictions by Nicholson (1994), Hulme et al (2001), and IPCC (2001)) it seems important that policy makers take specific steps that are likely to lower African countries' sensitivity to rainfall variations. On a more general level, this would entail creating more diversified African economies that are less reliant on agriculture. More specifically, agricultural techniques should be adopted that optimise water use through increased and improved irrigation systems and crop development.

One aspect that we have not been able to address directly is the role of desertification in the link between rainfall and the African growth tragedy. This is mostly due to the fact that there is little scientific consensus on how exactly climate and desertification are interlinked. However, with further advances in the field this could provide a fruitful area of future research.

the latter to measure convergence relative to all developing countries.

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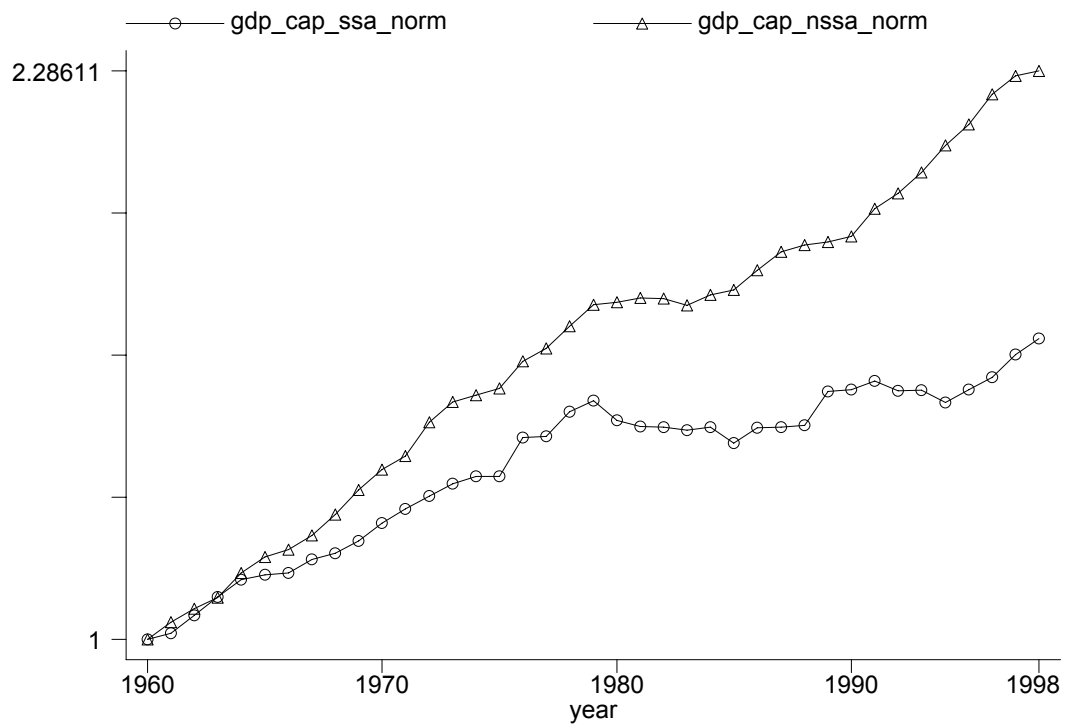
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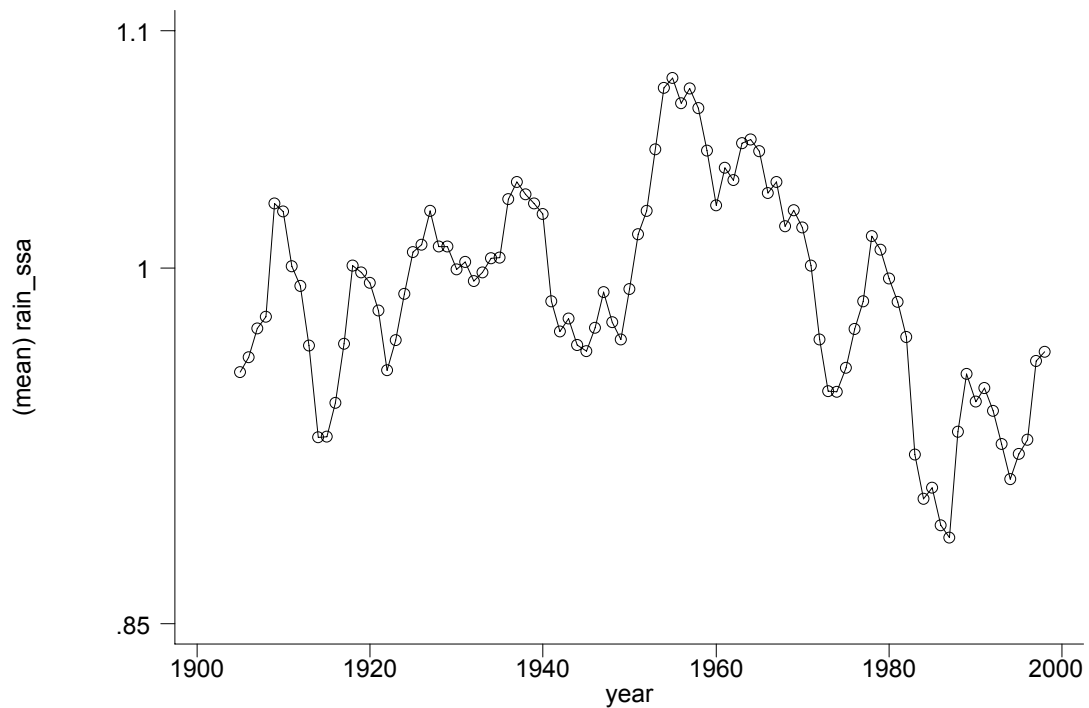
Appendix A: Figures

Figure 1: GDP per Capita Trends



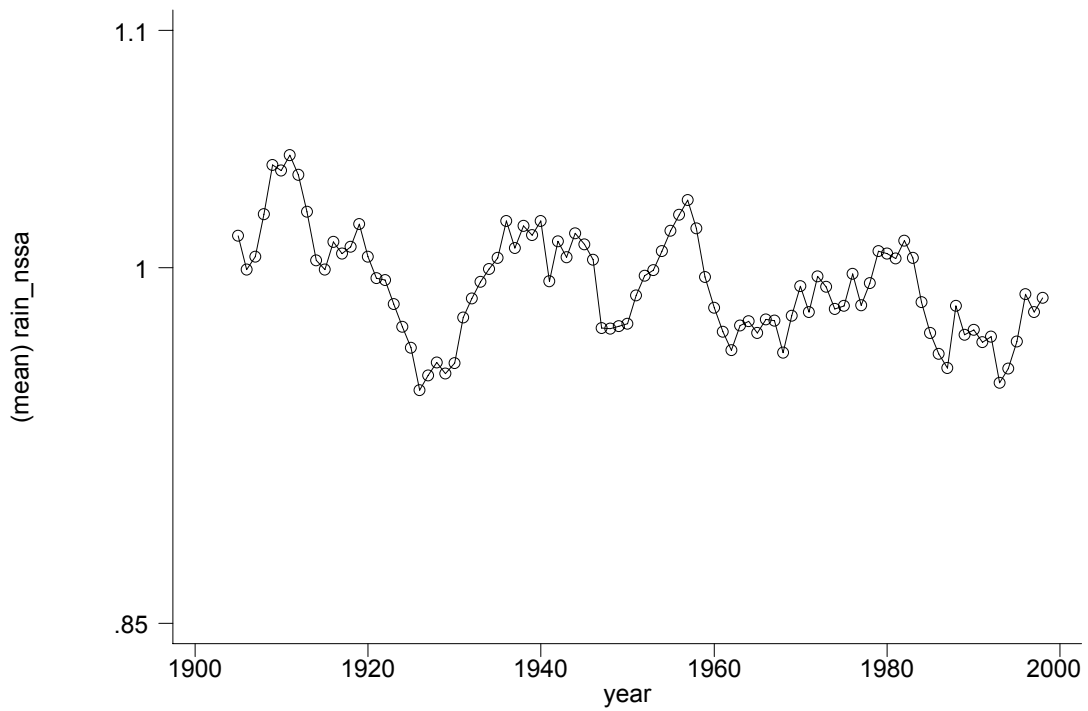
gdp_cap_ssa_norm: mean of normalised GDP per capita levels for SSA; **gdp_cap_nssa_norm:** mean of normalised GDP per capita levels for NSSA;

Figure 2: Rainfall in Sub-Saharan African Countries – Long Term Trends



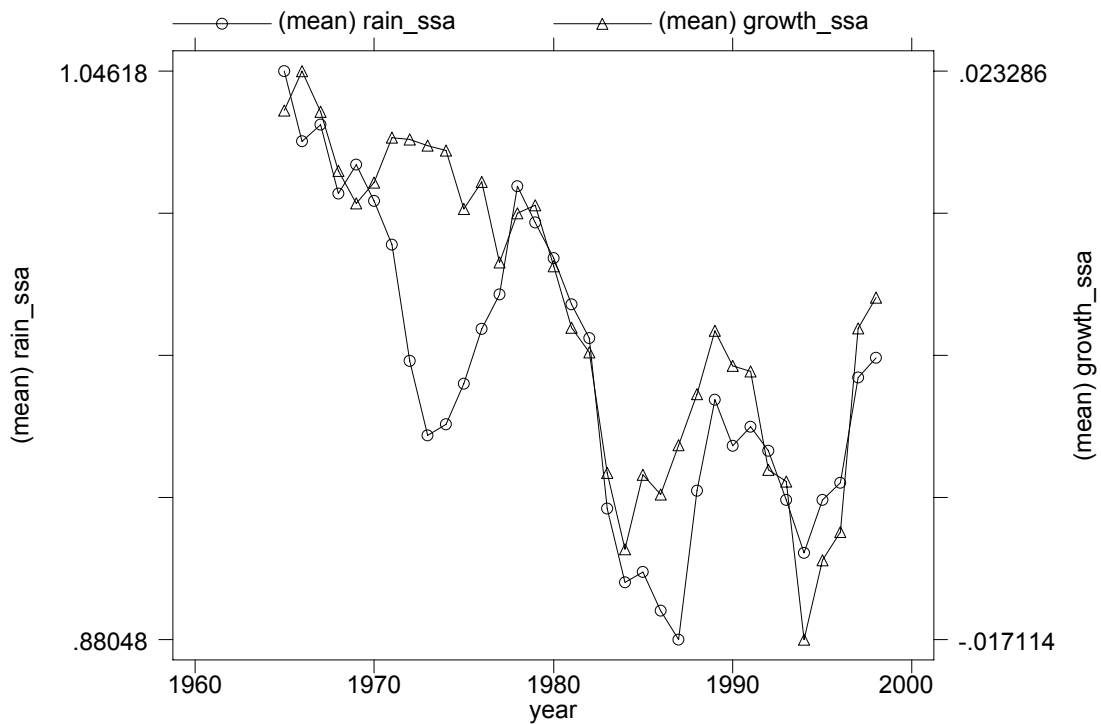
(mean) rain_ssa: mean of normalised rainfall in SSA.

Figure 3: Rainfall in Non Sub-Saharan African Countries – Long Term Trends



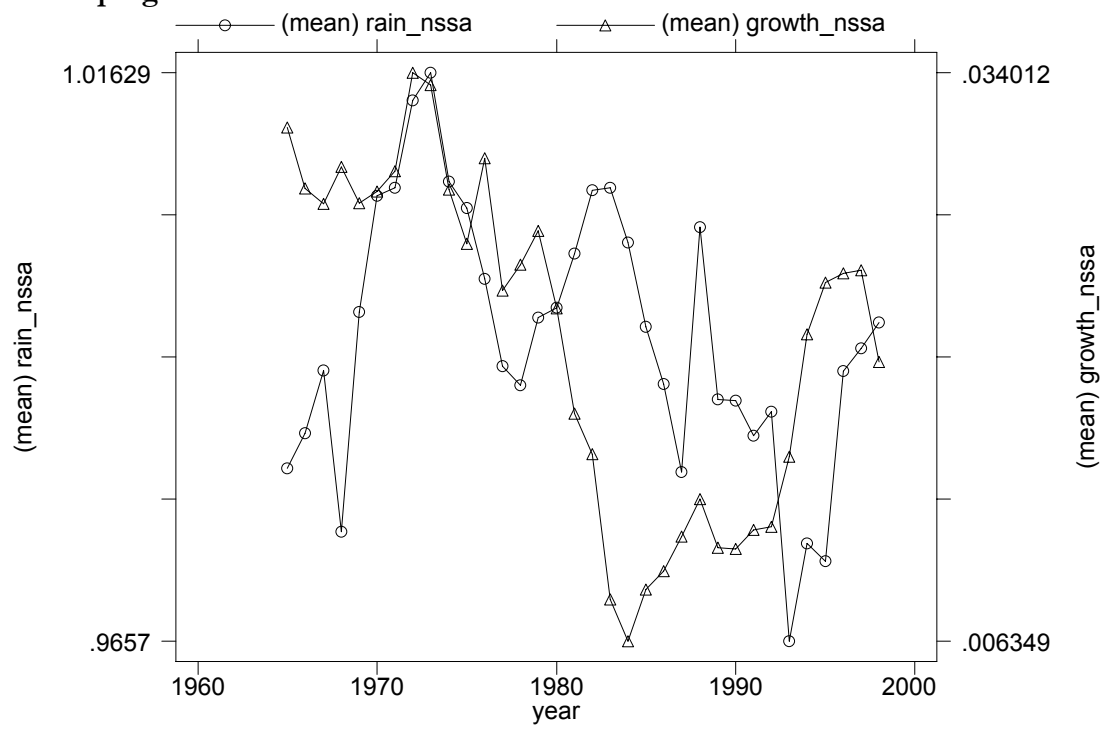
(mean) rain_nssa: mean of normalised rainfall in NSSA.

Figure 4: Trends in real GDP per capita growth rates and Rainfall in Sub-Saharan African Countries



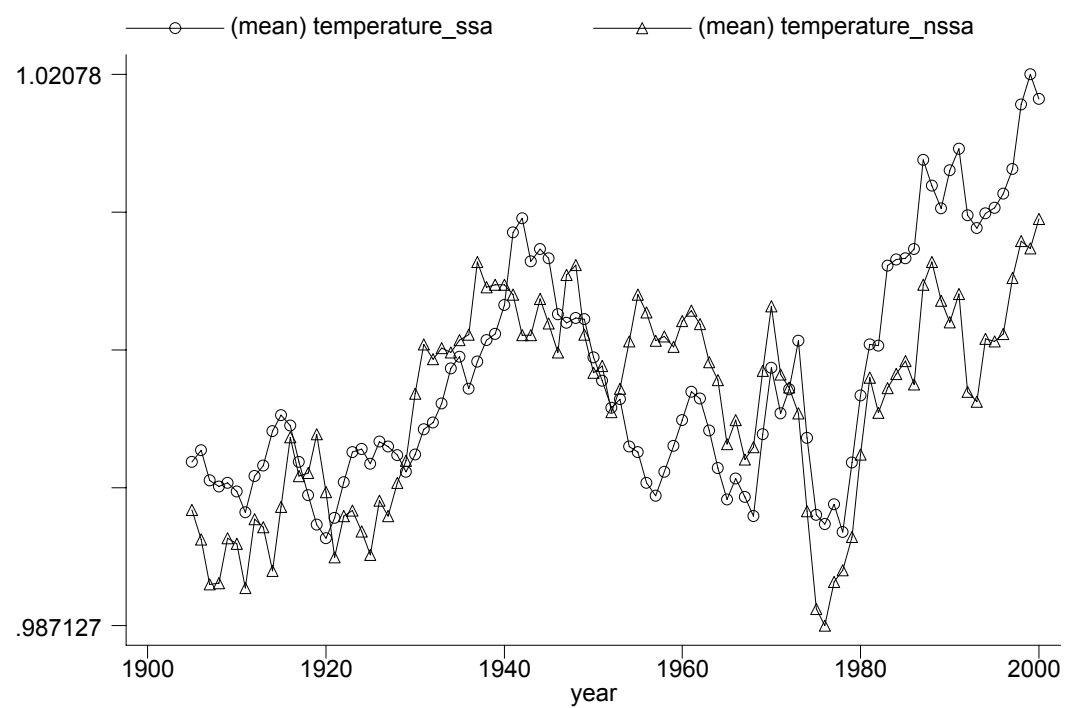
(mean) rain_nssa: mean of normalised rainfall in SSA; (mean) growth_ssa: mean of five year GDP per capita growth rates in SSA.

Figure 5: Trends in Real GDP per Capita Growth Rates and Rainfall in other Developing Countries



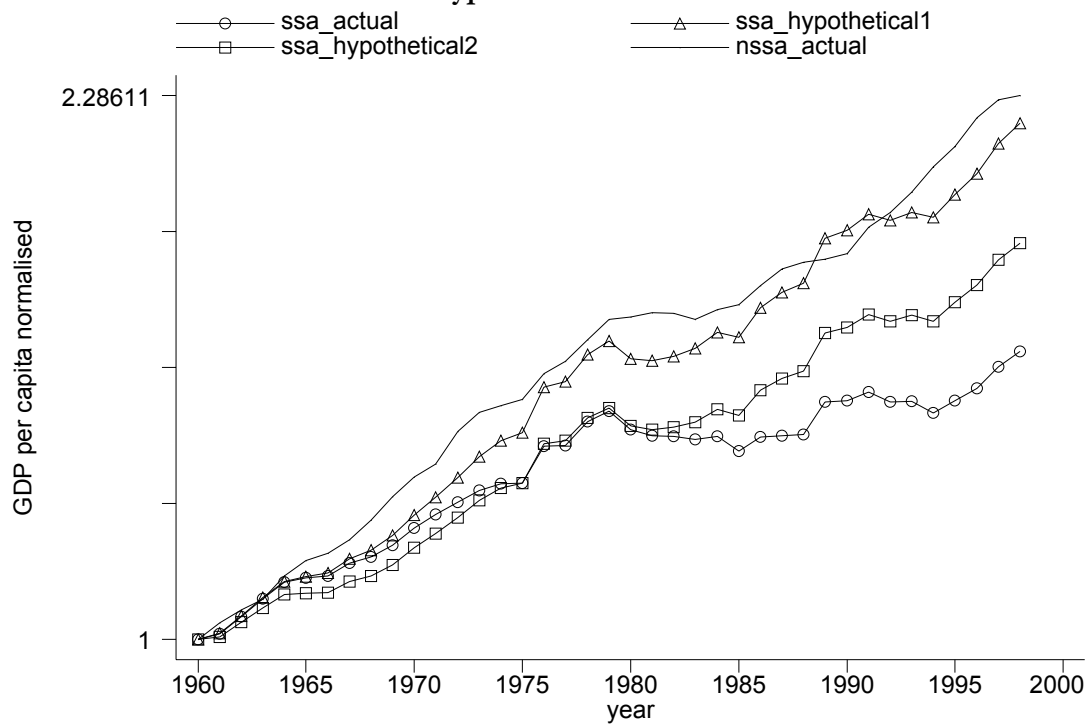
(mean) rain_nssa: mean of normalised rainfall in NSSA; **(mean) growth_nssa:** mean of five year GDP per capita growth rates in NSSA.

Figure 6



(mean) temperature_nssa: mean of normalised temperature in NSSA; **(mean) temperature_ssa:** mean of normalised temperature in SSA

Figure 7: GDP per Capita in Sub-Saharan African Countries – Actual vs. Hypothetical Series



ssa_actual: mean of normalised actual GDP per capita levels in SSA; **nssa_actual:** mean of normalised actual GDP per capita levels in NSSA; **ssa_hypothetical1:** mean of normalised hypothetical GDP per capita levels in SSA holding rainfall at 1950-159 average; **ssa_hypothetical2:** mean of normalised hypothetical GDP per capita levels in SSA holding rainfall at 1900-159 average;

Appendix B: Tables

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 Hydro-power:					
NSSA	35.0	39.4	37.6	39.6	34.1
SSA	27.9	37.3	46.5	42.9	46.6

Notes: (1) Where exact year was not available information from the nearest year was used. (2) The sample of countries may not correspond across the three variables as we only included countries in our sample for which we had observations for all five periods. Sources: World Development Indicators (World Bank), FAO and authors' computations.

Table 2: OLS Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RAIN	0.038*	-0.004	0.002	0.079**	-0.009	-0.018	0.085*
	(0.021)	(0.030)	(0.028)	(0.032)	(0.030)	(0.028)	(0.045)
SSA	-0.014***	-0.093**			0.000		
	(0.005)	(0.041)			(0.000)		
RAIN*SSA		0.082**			0.071*		
		(0.041)			(0.041)		
log(Y)	-0.006*	-0.005*	-0.010***	0.003	-0.008	-0.015**	-0.001
	(0.003)	(0.003)	(0.004)	(0.006)	(0.005)	(0.007)	(0.011)
Constant	0.029	0.066*	0.096***	-0.087*	0.085	0.189***	-0.022
	(0.030)	(0.036)	(0.036)	(0.051)	(0.053)	(0.070)	(0.157)
Sample	All	All	NSSA	SSA	All	NSSA	SSA
Controls	No	No	No	No	Yes	Yes	Yes
Observations	329	329	222	107	329	222	107
Countries	59	59	39	20	59	39	20
F-Test	4.27***	4.20***	3.77***	3.22***	4.53***	3.48***	2.12***
R-squared	0.04	0.05	0.03	0.06	0.25	0.32	0.36

Notes: (1) Robust standard errors in parentheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (3) 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), hydropower production (HYDRO), agricultural production (AGP), landlockedness (LANDLOCK), ethnic diversity (ETHNIC), tropical area dummy (TROP), and geographical size (AREA).

Table 3: Fixed Effects Results

	(1)	(2)	(3)	(4)	(5)
RAIN	-0.021 (0.033)	-0.022 (0.033)	0.145*** (0.045)	-0.026 (0.033)	0.156*** (0.045)
RAIN*SSA	0.101** (0.050)				
TEMP				-0.246 (0.219)	0.641 (0.530)
log(Y)	-0.048*** (0.010)	-0.048*** (0.014)	-0.064*** (0.015)	-0.048*** (0.014)	-0.066*** (0.015)
Sample	All	NSSA	SSA	NSSA	SSA
Controls	Yes	Yes	Yes	Yes	Yes
Obse.	329	222	107	222	107
Countries	59	39	20	39	20
F-Test	6.65***	4.28***	3.57***	4.12***	3.47***
F-U	2.49***	1.68**	3.01***	1.71**	3.03***
R-squared	0.32	0.30	0.46	0.31	0.48

Notes: (1) Standard errors in parantheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (3) 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), hydropower production (HYDRO), and agricultural production (AGP).

Table 4: Interaction Terms Regressions

	(1)	(2)	(3)	(4)	(5)
RAIN	-0.021 (0.033)	-0.022 (0.045)	-0.027 (0.033)	-0.037 (0.034)	-0.052 (0.048)
RAIN*SSA	0.101** (0.050)	0.128** (0.059)	0.101** (0.050)	0.110** (0.051)	0.122* (0.062)
RAIN*IRRIGATE		-0.004 (0.008)			0.000 (0.008)
RAIN*TEMP			-0.003 (0.003)		-0.003 (0.003)
RAIN*DRYLANDS				0.008 (0.006)	0.004 (0.007)
log(Y)	-0.048*** (0.010)	-0.048*** (0.011)	-0.048*** (0.010)	-0.048*** (0.010)	-0.048*** (0.011)
Sample					
Observations	329	329	329	329	329
Number of id	59	55	59	56	52
F-Test	6.65	6.08	6.37	6.32	5.47
F-u	2.49	2.33	2.47	2.61	2.48
R-squared	0.32	0.33	0.33	0.34	0.35

Notes: (1) Standard errors in parantheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (3) 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), hydropower production (HYDRO), and agricultural production (AGP). (4) AGP, URB, HYDRO, POP, INV, ED, and RAIN are centered around their region's mean to reduce correlation.

Table 5: Auxiliary Regression Results

	Sample	Dep. Variable	Rainfall Proxy	Method	Coeff. on Rainfall	Std. E.
(1)	NSSA+ In. C.	5 Avg. GROWTH RATE	Normal: 1901-59	Panel	-0.008	(0.026)
(2)	NSSA	5 Avg. GROWTH RATE	Normal:1940-59	OLS	0.003	(0.024)
	SSA	5 Avg. GROWTH RATE	Normal:1940-59	OLS	0.085***	(0.045)
(3)	NSSA	5 Avg. GROWTH RATE	Normal:1940-59	FE	-0.022	(0.033)
	SSA	5 Avg. GROWTH RATE	Normal:1940-59	FE	0.145***	(0.047)
(4)	NSSA	5 Avg. GROWTH RATE	Level	FE	-0.003	(0.002)
	SSA	5 Avg. GROWTH RATE	Level	FE	0.004	(0.006)
(5)	NSSA	5 Avg. GROWTH RATE	Growth Rate	FE	0.018	(0.021)
	SSA	5 Avg. GROWTH RATE	Growth Rate	FE	0.006	(0.035)
(6)	NSSA	5 Avg. GROWTH RATE	Current and Lagged Normal (1940-59)	FE	-0.017	(0.036)
	SSA	5 Avg. GROWTH RATE	Current and Lagged Normal (1940-59)	FE	0.075	(0.048)
(7)	NSSA	10 Avg. GROWTH RATE	Normal:1901-59	FE	0.000	(0.028)
	SSA	10 Avg. GROWTH RATE	Normal:1901-59	FE	0.064*	(0.034)
(8)	NSSA	Annual GROWTH RATE	Normal:1901-59	FE	-0.006	(0.028)
	SSA	Annual GROWTH RATE	Normal:1901-59	FE	0.077*	(0.042)
(9)	NSSA	Annual GROWTH RATE	Annual GROWTH RATE	FE	-0.020	(0.060)
	SSA	Annual GROWTH RATE	Annual GROWTH RATE	FE	-0.050	(0.073)
(10)	NSSA	Annual GROWTH RATE	Annual GROWTH RATE	OLS	-0.023	(0.048)
	SSA	Annual GROWTH RATE	Annual GROWTH RATE	OLS	-0.075	(0.090)

Notes: (1) FE signifies fixed effects techniques and OLS ordinary least squares econometric techniques. (2) Standard errors in parantheses. (3) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (4) 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), hydropower production (HYDRO), and agricultural production (AGP) in fixed effects regressions, and additionally landlockedness (LANDLOCK), ethnic diversity (ETHNIC), tropical area dummy (TROP), and geographical size (AREA) in OLS regressions. (5) In. C. refers to the sample of developed countries. (6) For estimation #6 reported statistics are for lagged rainfall measure

Table 6: Mechanism Regressions

Sample	Dep. Variable	Rainfall Proxy	Method	Coeff.	Std. E.
NSSA	AGrowth Rateicultural Production 5 Avg. GROWTH RATE	Normal:1901-59	FE	0.117	(0.114)
SSA	<i>AGrowth Rateicultural Production 5 Avg. GROWTH RATE</i>	<i>Normal:1901-59</i>	<i>FE</i>	<i>0.323***</i>	<i>(0.111)</i>
NSSA	Urbanization Avg. GROWTH RATE	Normal:1901-59	FE	0.104	(0.062)
SSA	<i>Urbanization Avg. GROWTH RATE</i>	<i>Normal:1901-59</i>	<i>FE</i>	<i>-0.186**</i>	<i>(0.93)</i>
NSSA	Population 5 Avg. GROWTH RATE	Normal:1901-59	FE	0.021	(0.021)
SSA	<i>Population 5 Avg. GROWTH RATE</i>	<i>Normal:1901-59</i>	<i>FE</i>	<i>0.022</i>	<i>(0.043)</i>
NSSA	Hydropower Production 5 Avg. GROWTH RATE	Normal:1901-59	FE	-0.0620	(0.126)
SSA	<i>Hydropower Proudction 5 Avg. GROWTH RATE</i>	<i>Normal:1901-59</i>	<i>FE</i>	<i>0.389***</i>	<i>(0.187)</i>
NSSA	Education (years) 5 Avg. GROWTH RATE	Normal:1901-59	FE	0.003	(0.331)
SSA	<i>Education (years) 5 Avg. GROWTH RATE</i>	<i>Normal:1901-59</i>	<i>FE</i>	<i>-0.349</i>	<i>(0.324)</i>
NSSA	Investment/GDP 5 Avg. GROWTH RATE	Normal:1901-59	FE	0.054	(0.360)
SSA	<i>Investment/GDP 5 Avg. GROWTH RATE</i>	<i>Normal:1901-59</i>	<i>FE</i>	<i>-0.410</i>	<i>(0.754)</i>

Notes: (1) FE signifies fixed effects regression techniques. (2) Standard errors in parantheses. (e) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (4) Additional controls are time dummies.

Table 7: Fixed Effects Results Including Endogenous Variables

	(1)	(2)	(3)	(4)	(5)	(6)
RAIN	0.135*** (0.043)	0.092** (0.045)	0.092** (0.045)	0.093** (0.045)	0.099** (0.046)	0.106** (0.048)
AGP_GR		0.020 (0.015)	0.020 (0.015)	0.021 (0.016)	0.021 (0.016)	0.021 (0.016)
URB_GR		-0.064** (0.028)	-0.064** (0.028)	-0.065** (0.028)	-0.061** (0.029)	-0.056* (0.032)
POP_GR				-0.046 (0.125)	-0.037 (0.126)	-0.045 (0.128)
HYDRO_GR					-0.000 (0.000)	-0.000 (0.000)
ED_GR						0.013 (0.013)
INV/GDP_GR						-0.002 (0.003)
Log(Y)	-0.057*** (0.014)	-0.063*** (0.014)	-0.063*** (0.014)	-0.063*** (0.014)	-0.061*** (0.014)	-0.062*** (0.015)
Sample	SSA	SSA	SSA	SSA	SSA	SSA
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	107	107	107	107	107	107
Countries	20	20	20	20	20	20
F-Test	4.55***	4.59***	4.59***	4.22***	3.94***	3.51***
F-U	3.59***	3.87***	3.87***	3.82***	3.56***	3.55***
R-squared	0.40	0.45	0.45	0.45	0.45	0.46

Notes: (1) Standard errors in parantheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (3) 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). (4) AG_GR, UR_GR, HP_GR, POP_GR, ED_GR, and IN_GR are agricultural production, urbanization, hydropower production, education, and investment growth rates, respectively.

Appendix A: Selected Full Regression Results of Table 2, Colmns (5)-(7) and of Table 3, Columns (1)-(3)

	(1)	(2)	(3)	(4)	(5)	(6)
METHOD	OLS	OLS	OLS	FE	FE	FE
RAIN	-0.009 (0.030)	-0.018 (0.028)	0.085* (0.045)	-0.021 (0.033)	-0.022 (0.033)	0.145*** (0.045)
RAIN*SSA	0.071* (0.041)			0.101** (0.050)		
SSA	0.000 (0.000)					
log(Y)	-0.008 (0.005)	-0.015** (0.007)	-0.001 (0.011)	-0.048*** (0.010)	-0.048*** (0.014)	-0.064*** (0.015)
URB	-0.010 (0.022)	0.014 (0.028)	0.009 (0.063)	-0.091 (0.076)	-0.135 (0.098)	-0.010 (0.125)
AGP	-0.000*** (0.000)	-0.000*** (0.000)	-0.000 (0.000)	-0.001*** (0.000)	-0.000** (0.000)	-0.000 (0.000)
HYDROP	0.000 (0.000)	0.000 (0.000)	-0.000* (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
POP	-0.004* (0.002)	-0.002 (0.003)	-0.005 (0.007)	0.015 (0.029)	0.001 (0.035)	0.132* (0.073)
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** (0.002)	0.004** (0.002)	0.003 (0.006)	0.003 (0.004)	0.003 (0.005)	0.015 (0.014)
CIVW	-0.009 (0.006)	-0.011* (0.006)	0.005 (0.014)	-0.021*** (0.007)	-0.016** (0.008)	-0.041*** (0.015)
CIVW_S	-0.003 (0.007)	0.005 (0.008)	-0.031 (0.032)	-0.004 (0.009)	0.002 (0.010)	-0.040 (0.031)
INV/GDP	0.001*** (0.000)	0.001** (0.000)	0.001 (0.001)	0.001** (0.000)	0.001* (0.000)	0.001* (0.001)
G/GDP	-0.000** (0.000)	-0.000 (0.000)	-0.001* (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.001)
LANDLOCK	-0.006 (0.006)	-0.007 (0.010)	0.005 (0.013)			
ETHNIC	-0.000* (0.000)	-0.000 (0.000)	-0.000 (0.000)			
TROPICAL	-0.005 (0.008)	-0.002 (0.008)	0.010 (0.050)			
AREA	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)			
Constant	0.085 (0.053)	0.189*** (0.070)	-0.022 (0.157)			
Sample	ALL	NSSA	SSA	ALL	NSSA	SSA
Obs.	329	222	107	329	222	107
F-Test	4.53***	3.48***	2.12***	6.65***	4.28***	3.57***
F-u				2.49***	1.68**	3.01***
R-squar.	0.25	0.32	0.36	0.32	0.30	0.46

Notes: (1) Standard errors in parantheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. See appendix B for a definition of the variables.

Appendix B

1. 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 1987.³¹ These cut-off points were based on the Bank's operational lending categories (civil works preferences, IDA eligibility, etc.). 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 was available.³² 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 Rep., Ecuador, Egypt, Fiji, Grenada, Guatemala, Guyana, Honduras, Haiti, Hungary, Indonesia, India, Iran, Is, Israel, Jamaica, Jordan, Cambodia, St. Kitts, Korea, S, Lebanon, St. Lucia, Sri Lank, Morocco, Mexico, Malta, Malaysia, Nicaragua, Nepal, Pakistan, Panama, Peru, Philippi, Papua New Guinea, Poland, Puerto R, Portugal, Paraguay, Romania, Singapore, El Salvador, Syrian A, Thailand, Trinidad, Tunisia, Turkey, Uruguay, St. Vincent, Venezuela, Vietnam, Yemen.

Developed:

Austria, Australia, Belgium, Canada, Denmark, Finland, France, Great Britain, Germany, Greece, Hong Kong, Ireland, Israel, Island, Italy, Japan, Luxembourg, Macao, Malta, Netherlands, Portugal, Spain, Switzerland, Sweden, USA.

2. Rainfall Data

Our main variable of interest, the measure of rainfall, is taken from the Inter-Governmental Panel on Climate Change (IPCC) data set, which provides, amongst other things, times series data on the average annual rainfall for 289 'countries' (comprised of 188 states and 101 islands and territories) from 1901 to 1998; see Mitchell et al (2002) for

³¹ <http://www.worldbank.org/data/countryclass/countryclass.html>

³² The only countries covered in the World Penn Tables that changed from 'developing' to developed status were Singapore, Cyprus, and Puerto Rico.

a complete description of the data set. The underlying methodology used to derive these measurements of rainfall by country is what New et al (1999) have called an ‘anomaly’ approach. This approach consisted essentially of three steps. 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 a time series of *gridded time series of rainfall* over the desired period. Finally, the individual gridded values then were assigned to individual countries to arrive at *country-wide times series*.

Gridded Climatology

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.³³ 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. The authors then used a thin-plate spline-fitting technique to interpolate the climate surfaces into the 0.5 by 0.5 degree high-resolution climatology grid. One should 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.

Gridded Times Series of Rainfall

For deriving the time series for each grid, first each station rainfall series from the beginning of the 20th 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.³⁴ 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 zero if they were beyond the correlation decay distance, thus ‘relaxing’ their value towards the monthly 1961-1990 mean of that station measurement.³⁵ 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.

Country-Wide Series of Rainfall

In order to arrive at country-wide measures each grid-box from the gridded climatology was then assigned to the appropriate country by visual inspection.³⁶ Since spatial areas by a 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.

³³ See New et al (1999) for details

³⁴ The ADW essentially “..employs a distance weighting function so that stations closest to the grid point of interest carry greater weight” (New et al 2000, p. 2221).

³⁵ The correlation decay distance is the distance at which zonally averaged interstation correlation is no longer significant at the 95 per cent level.

³⁶ Where a grid box was located across more than one country, the grid box was assigned to the country with the largest stake, except where a country would otherwise have been left without any grid box. Weighting was essential since the spatial areas represented by each grid box differ in latitude. For further details see Mitchell et al (2002).

Our Proxy of Climatic Changes in Rainfall

In order to obtain a proxy of cross-country movements in rainfall we chose to normalise the country-wide rainfall measure provided in the IPCC data set by the long-term mean annual rainfall in each country prior to 1960. Apart from being similar to a measure already used by the FAO, see Gommaes and Pettrassi (1996), our choice of this normalization factor was due to two reasons.³⁷ Firstly, we wanted a normalization factor that was outside the sample period of our econometric analysis, which uses data after 1959. Secondly, our measure should capture changes in rainfall relative to long-term trends in rainfall. Typically, as shown by Nicholson (2001) for Africa, long-term trends in rainfall seem to move in very long cycles lasting several decades.

Nevertheless our choice of this normalization factor could conceivably introduce another type of bias into our estimation. In particular, as noted earlier in the description of the construction of the gridded data series, when there was insufficient information on any of the necessary eight stations to calculate each monthly gridded value, values were 'relaxed' towards the 1961-1990 mean monthly measure, where the extent of 'relaxation' depended on the number of stations outside the decay distance. This 'relaxation' is, unsurprisingly, most likely to have happened for grids located in developing countries in the early part of the data set where station frequency was relatively scarce. As a matter of fact, examining Figure 1 in New et al (2000) suggests this may have been a problem for some parts of South America and Africa in the very early part of the 20th century. Nevertheless, rather than disregarding potentially important information on changes with regard to long-term trends from the earlier data, we in the text experiment with alternative normalization factors and use appropriate econometric techniques for robustness checks for our normalized proxy.

3. Temperature Data

The country-wide data for temperature are also taken from the IPCC data set, where they were constructed in a similar fashion to the series on precipitation. We also used a similar normalization factor to construct a proxy of rainfall.

4. Other Variables

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

Variable	Definition	Nature	Source
RAIN	Annual Rainfall normalised by 1901-1959 mean value	Time varying (annual); 1901-1998	IPCC
SSA	1-0 Dummy	Time invariant	
Log(GDP/Cap)	Log of initial year GDP per capita	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-	Murdoch and Sandler (2002)

³⁷ One should note that meteorological droughts, which refer to shortfalls of rainfall are, typically defined in a similar manner, see Benson and Clay (1998).

		1990	
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
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 Fractionalisation	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
DRY	Percentage of Land Dryland	Time Invariant	WRI (World Resource Institute)
6 Regional Dummies	Dummies indicating whether country is in Asia, Latin America, Middle East, SSA, South Asia, and East Asia	Time invariant	