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Dry Times in Africa

by

Salvador Barrios, Luisito Bertinelli and Eric Srobl

Centre for Research in Economic Development and International Trade, University of Nottingham

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Abstract
While there have been some references in the literature to the potential role of the general decline in rainfall in sub-Saharan African nations on their poor growth performance relative to other developing countries, this avenue remains empirically unexplored. In this paper we use a new cross-country panel climatic data set in an economic growth framework to explore the issue. 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 13 and 36 per cent of today's gap in African GDP per capita relative to rest of the developing world.

Outline

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) 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 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

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, and to non-sub-Saharan countries for the other developing countries.

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 in Africa's poor performance, is the distinct climatic change 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).[2] Given the importance of agriculture for African countries and the dependence of this sector on rainfall, this decline in rainfall may, as suggested by Nicholson (1994), Collier and Gunning (1999), O'Connell and Ndulu (2000), and Bloom and Sachs (1998), have had potentially severe consequences for economic growth. Moreover, Africa is much more reliant than other countries on hydro-power for electricity generation.

In this paper we explicitly investigate for the first time the role that changes in rainfall have had on Africa's relative economic performance.[3] 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, rainfall has been on a general decline in Africa since 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.[4] Using these

2 One should note that there was also a general rise in the temperature in Africa over the period, but that this also occurred elsewhere around the world (see Hulme et al, 2001), and is thus unlikely to have played a role in the relative economic performances, except by enhancing the effects of rainfall.

3 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 a 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. Secondly, given the rainfall dependence of agriculture in Africa, grouping years into dry and non-dry years is likely to be too restrictive to capture the full effect of rainfall variations. Related to this it should be noted that the years 1941-1960 were, as we show in Section III, years of unusually high rainfall and thus are unlikely to serve as a good benchmark with which to define years as dry.

4 The role of rainfall on economic cycles in general has had a long, although sparse, history in the economics literature, starting with the well known study by Moore (1914). Most of these have focused on the impact on agricultural cycles, in particular in developed countries; see, for instance, O'Hagan (2001) for recent examples.

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 13 and 36 per cent lower, depending on what level of rainfall is considered as the benchmark.

The paper proceeds as follows. In the next Section we discuss the importance of rainfall for Africa. Section III discusses our main data sources and provides a discussion on summary statistics. The results of our econometric analysis is given in Section IV. Using these results hypothetical growth scenarios under more benevolent rainfall conditions are explored in Section V. The last section provides concluding remarks.

II. RAINFALL AND ECONOMIC GROWTH: WHAT IS DIFFERENT ABOUT AFRICA?

Changes in rainfall can potentially have a wide array of economic implications anywhere in the developing world, ranging from influencing water levels and quality, to determining agricultural and energy production. Historically, however, shortages in rainfall in Africa seem to have been associated with particularly damaging consequences, in the most extreme cases causing food and water shortages and the death and displacement of substantial shares of population.[5] This particular sensitivity to rainfall variations seems at least in part to rest on features specific to Africa, see, for instance, IPCC(2001). We group these below into those related to agriculture and all other aspects.

A. Agriculture

The most direct impact of rainfall in Africa is certainly on agriculture, and a large part of this is due to the importance 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 any other developing regions – nearly 40 per cent in 1960. Although this share has since been steadily decreasing, it still represent almost a third of total GDP in the 1997, compared to the average 15 per cent in the rest of the developing world. However, even apart from the importance of agriculture per se,

5 One of the worst episode of the African tragedy occurred during the droughts between 1968 and 1973 in the Sahel causing 250,000 deaths (IPCC, 2001).

there are other aspects of the African agricultural sector that are likely to make shortages in rainfall more damaging for Africa compared to other developing countries.

First, Africa's agriculture growth potential is more likely to be undermined by rainfall variation because of the geography and climatic conditions specific to the African continent. Broadly speaking, agriculture in the African tropical area is seriously hampered by high temperature, fragile soils, and low yield potential. It also suffers from chronic diseases affecting both animal and non-animal production. Outside its equatorial area, a large share of Africa's arable land suffers from aridity, tending to increase the risk of drought as drier soil absorbs more rainfall, see Bloom and Sachs (1998).[6] Today, around 60 per cent Arican countries are considered to be vulnerable to drought and 30 per cent extremely so, see Benson and Clay (1998). The vulnerability to rainfall in the arid and semiarid areas of the continent translates into a poor capacity of most African soils to retain moisture. In addition, areas without surface water rely essentially on evapotranspiration as the sole input to the hydrological cycle. Evapotranspiration is in turn relatively high in Africa, as a consequence of high temperature throughout the year, thus leaving low quantities of water for soil moisture. [7]

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. The consequence of this process can also spread beyond the most immediately affected areas. For example, there is increasing evidence showing that African countries located in the South of the Sahel suffered from reduced rainfall in the Sahel, see Shinoda (2001) for a review of the evidence.

Second, African agriculture relies heavily on rainfall for irrigation of crops. Indeed, compared to other developing areas in the world, a much smaller proportion of crop land

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6 Over the last decades, climate variability has been largely influenced by the El Niño-Southern Oscillation (ENSO) which is the most important factor explaining rainfall changes in Eastern and Southern Africa, see Nicholson and Entekhapi (1986), and Richard et al. (2000).

7 Evapotranspiration is the combination of water that is evaporated and transpired by plants as a part of their metabolic process.

is irrigated. For example, figures in Table 1 show that still less than 10 per cent of arable land in Africa is irrigated, compared to nearly a fifth in other developing countries. Given the relatively higher degrees of evapotranspiration in Africa due to its all year round high temperature climate, the severity of the problem is probably underestimated by these figures.

Third, agricultural practices often add to the water shortage problem in Africa more than anywhere else due to differences in property rights. More precisely, because farmers are often not owners of the land they work on, the preservation of natural resources is often 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 Gommes and Petrassi (1996). This causes greater exposure to desertification with the shortages in rainfall directly influencing agricultural productivity.

Related to desertification, one should note that range-fed livestock are usually concentrated in the arid and semi-arid areas because the tropical areas provide potentially more exposure to animal diseases. Since livestock are directly dependent on grass quantity, rainfall variations have, in turn, direct consequences on livestock. Here also, human activity can add to the desertification risks through overgrazing, which is represented by higher density and/or shorter rotations of livestock beyond the limit of the ecosystem, see IPCC(2001).

Finally, changes in rainfall are also likely to have greater consequences for investment in agriculture in Africa as the insurance capacity of households is extremely limited; see Christiansen et al (2002). More specifically, 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.[8]

8 Examples include Dercon and Krishnan (2000) for Ethopia and Molua (2002) for Cameroon.

B. Other Aspects

Variation in rainfall may also have more direct consequences on the economy other than through agriculture. In particular, shortages in rainfall can significantly affect the energy sector as energy supply in African countries now relies heavily on water as both a direct and an indirect source of energy production. Over the last 50 years, African countries have invested heavily in hydroelectric power. This has translated into increased vulnerability of energy production to climatic changes affecting in turn the industry and urban areas, see Magadza (1996).

For example, figures provided in Table 1 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. Inadequate supply of water, as its primary input, can thus have drastic consequences. River flows in Africa regions are very sensitive to changes in precipitations, that is, a change in rainfall has a larger impact in runoff than in temperate regions. One of the reason for this is that, apart from the Zambezi and Congo Rivers, major African rivers like the Nile, Niger, Senegal, Senqu/Orange, and Rufiji are in arid or semi-arid regions. Evidence shows that the African major rivers' performance is indeed significantly lower to that of other areas in the world.[9] In addition, these rivers originate in tropical areas where high temperatures increase evaporation losses. Lakes and reservoir are also largely exposed to the rise in temperature and decrease in rainfall with increased evaporation, see IPCC (2001). For example, declines in precipitation led to a significant loss of as much as 30% of total hydropower energy from the Kariba dam supplying power for Zambia and Zimbabwe, see Watson et al (1998), and similar evidence has been found for many other regions in African countries. Moreover, water also serves as an important secondary input for thermal power generation as it serves as a cooling device and it is needed in huge quantities for this purpose. As a consequence, the effect of a fall in rain intensity not only reduces generation capacity, but may also retard the construction of new and more productive plants. Climatic change 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, 2002).

9 For example, the total runoff as 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).

Finally, the availability of fresh water for direct human consumption constitutes one of the most emerging issues concerning Africa's development problem, see World Bank (2003) and shortages in rainfall can affect both its quantity and quality. For example, some devastating diseases such as typhoid, cholera and schistosomiasis are directly linked to water abundance and quality, and policy measures to palliate the consequences of these are often costly; see for example, the study of Spalding-Fecher and Moodley (2002) for the economic consequences of malaria in South Africa and its relationship to rainfall variations.

III. DATA SET AND DESCRIPTIVE STATISTICS

A. Rainfall Data

The primary data used for the purpose of the paper is derived from a number of sources.[10] Our main variable of interest, the measure of rainfall, is taken from the Inter-Govermental 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 a complete description of the data set.[11] These rainfall series were constructed by assimilating measurements of rainfall from meteorological stations across the world into 0.5 degree latitude by 0.5 degree longitude grids covering the land surface of the earth. Each grid-box was then assigned to the appropriate country[12] in order to calculate a measure of rainfall for each by using the weighted mean of the values of all grid boxes within a country.[13] This procedure resulted in comparable mean measures, given in millimetres, of annual rainfall for each country.[14] For the purposes of this paper we use observations on developing countries, where 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 2001 definition. All countries used in any part of our empirical analysis are listed in Appendix E.

10 See the Data Appendix for a summary of variable definitions and sources.

11 We are not the first to apply this data in an economic context. See Masters and McMillan (2001) for an analysis of the number frost days on economic growth.

12 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.

13 Weighting was essential since the spatial areas represented by each grid box differ in latitude.

There are a number of issues to be noted in terms of constructing and using the cross-country measure of annual rainfall in our empirical analysis. First, we chose to normalise the rainfall measure provided in the data set by the long-term mean annual rainfall in each country. This was primarily done because we are interested in climatic changes, rather than permanent cross-country climatic differences in levels. In order to avoid any concerns regarding the exogeneity of this normalisation factor we used the mean of the annual rainfall for the period prior to 1960, although using the long-term mean over the entire available period produced very similar results.[15] One should note that a similar measure is also used by the FAO; see Gommes and Petrassi (1996). Since most of our econometric analysis focuses on the effect of rainfall on long-term, five year, cross-country growth rates, we calculated the simple arithmetic mean of the annual normalised rainfall measure over the appropriate five year intervals.

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 climatic change. While one could in theory also hypothesize that perhaps economic growth (or lack thereof) could, through economic decision-making, affect such aspects as environmental degradation and desertification, and thereby possibly rainfall, Nicholson (1994) finds no evidence suggesting such. As a matter of fact, earlier historical data suggests that rainfall naturally moves through long cycles of relative troughs and peaks, and that a similar cycle to the present one seems to have occurred in the 19th century, see Nicholson (2001).

B. Other Data

The main source of our economic variables are the World Penn Tables (WPT) Version 6.1. This data set provides us with information to calculate the real GDP per capita growth rate for a large number of developing countries. Additionally, the WPT can be used to calculate a number of time varying control variables that may determine cross-country differences in growth rates and that have been used in the growth literature. Specifically, the ones we use are investment as a percentage of GDP, the population

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14 For further details see New et al (1999, 2000)

15 Details are available from the authors.

growth rate, openness, government expenditure as a percentage of GDP, and the population growth rate. All our regressions with time varying controls also included a measure of the log initial GDP per capita to account for possible dynamic effects, see for instance Temple (1999). Recently, 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.[16] Finally, we additionally included the average years of schooling as a measure of human capital, as constructed by Barro and Lee (1993), in our set of time varying controls.

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, a dummy for whether the country is landlocked, and three dummies for individual income categories within the 'developing' status.[17]

We also, as supplementary evidence, utilise data on agricultural production and energy production. For the former, we extracted data from the FAO database on an index of agricultural production. Data on energy production by source type was taken from the UN Energy Statistics database.

While there have been clearly a sizeable number of other 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 61 countries, of which 22 where sub-Saharan African, covering the period 1960-1990. 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

16 This data was kindly provided by the authors.

17 These latter dummies are intended as rough controls for the potential existence of growth convergence clubs; see, for instance, Quah (1997).

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.[18]

For all graphical depictions and all other tabulations we also included developing countries for which there may have not been a full set of controls, so as to be more representative. 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. Basic summary statistics, the precise definition and the source of all variables, as well as the list of countries, used in our analysis are provided in the Data Appendix.

C. Summary Statistics and Trends

We first graphed trends in average real GDP per capita, by normalising and taking 1960 as the base year, for sub-Saharan African (SSA) and other non-sub-Saharan developing countries (NSSA) in Figure 1.[19] 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. As can be seen, while variable, the mean rainfall in SSA remained roughly constant during the first part of the 20th century until the 1950s, peaking in the late 1950s. 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 most of the first 60 years of the century. These trends suggest that there has been an important climatic change 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 climatic 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 onwards simultaneously in Figure 4. This reveals that the two series seem to move very

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

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

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.

IV. ECONOMETRIC ANALYSIS

The graphical trends just depicted seem to suggest that SSA's relatively poor growth performance has gone hand in hand with climatic changes in terms of a decline in mean rainfall. In contrast no such trends are apparent for other developing countries. We now investigate this possibility econometrically using our assembled cross-country growth data set.

Using standard OLS, we first regress mean annual real GDP per capita growth rates on rainfall over five year intervals including a SSA dummy, as shown in the first column of Table 2. Accordingly, while the SSA dummy is significantly negative, indicating that SSA countries had on average lower growth rates, rainfall has no discernable effect on economic growth in our full sample. In order to determine whether this differs across SSA and NSSA countries, we 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 – in other words, lower rainfall will negatively affect growth in these. As shown in the following two columns, this result, i.e., a significant positive relationship 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 D. 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. Moreover, the size of the coefficient remains relatively stable to including the set of control variables.

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 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. 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. In general, however, all our findings seem to unequivocally indicate that rainfall positively affects economic growth only in SSA countries.

Our discussion in Section II indicated a number of reasons of why SSA nations would be more susceptible to changes in rainfall than other developing countries. In particular, with regard to its impact on agriculture, it has been argued to be more rainfall dependent. To investigate this further we first graphed the mean of agricultural production indices relative to trends in rainfall for SSA and NSSA nations in Figures 6 and 7, respectively. As can be seen, in general movements in agricultural production follow changes in rainfall fairly closely. In contrast, there is little visual evidence of such a relationship for the NSSA sample. We subsequently used average annual cross-country time series data on agricultural production indices over five year intervals obtained from the FAO database and regressed these on the (normalised) rainfall and a set of time dummies using fixed effects in Table 4. One should note that given that we only use time dummies as control here we use a larger sample of countries, but reducing these to the same sample as for the growth rate regressions gave us similar results.[20] As can be seen from the first column, mean annual rainfall positively affects agricultural production in our sample on average. However, interacting rainfall with the SSA dummy reveals that this effect only occurs for SSA countries, which is further confirmed by separating our total sample into the SSA and Non-SSA sub-samples. Thus we also find empirical support for the contention that the SSA agricultural sector is relatively more reliant on rainfall.

In Section II we have argued that not only the share of hydro-power, as a source of energy, is higher in SSA than in NSSA, but also that this hydro-power generation is

20 Details available from the authors.

likely to be more rainfall dependent in SSA. We similarly graph the trends in rainfall and total hydro-power energy production for our two sub-samples in Figures 8 and 9, respectively. Accordingly, the link between these and rainfall for SSA and the lack thereof for NSSA is not quite as apparent as for agricultural production, although there seems to be some co-movement in SSA countries during some of the period.[21] In, as for agricultural production, estimating a simple fixed effects specification of a regression of mean annual hydro-power generation on rainfall over five year intervals one can see in Table 5 that energy production by hydro-power plants is only significantly affected in SSA, although this only holds if one examines the sub-samples separately.[22] Nevertheless, this provides some evidence that rainfall affects hydro-power production in SSA, but is less relevant for other developing countries.

V. ALTERNATIVE SCENARIOS

Our results for both the short and long-term clearly indicate that rainfall variability has had a significant direct marginal 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 taken if rainfall had remained at some previous level using our estimated coefficient on rainfall. One should note that in doing so we can only be confident in measuring the direct impact of rainfall. Arguably, shortages in rainfall may also adversely impact other determinants of economic growth. For example, in very severe shortages, it may affect mortality rates and political stability. However, even small changes may influence such aspects as schooling or investment decisions. Thus, one should keep in mind that any predictive estimates are likely to be lower bounds.

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 last column of Table

21 Part of the reason for the lack of apparent trends in either sample may be due to the construction of new hydro-power plants influencing general shifts in overall energy production through hydro-power. Unfortunately we have not auxiliary data to control for this aspect.

22 As with agricultural production we used a larger sample for these, but reducing the sample to that used in the growth regressions produced similar results.

2. The resultant hypothetical GDP per capita series, along with the actual SSA and NSSA series, is depicted in Figure 10. 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 as late as the late 1980s, 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 36 per cent less than what was observed in actuality in 1998.

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. This is shown relative to the true trends in SSA and NSSA countries in Figure 11. 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 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 would have been about 13 per cent less than what was observed in actuality in 1998.

VI. 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 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 13 and 36 per cent lower.

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 and thus dependant on rainfall. More specifically, agricultural techniques should be adopted that optimise water use through increased and improved irrigation systems and crop development. Also, the use of hydro-power should be weighed against its susceptibility to water shortages in Africa.

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Appendix A: Figures

Figure 1: GDP per Capita Trends

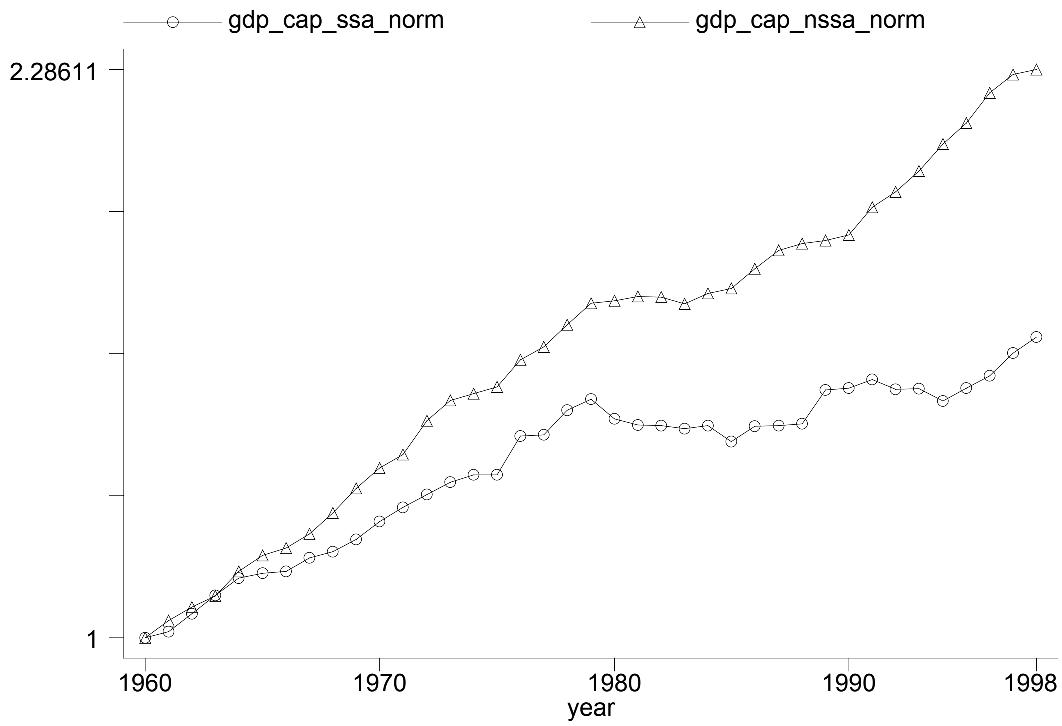


Figure 2: Rainfall in Sub-Saharan African Countries – Long Term Trends

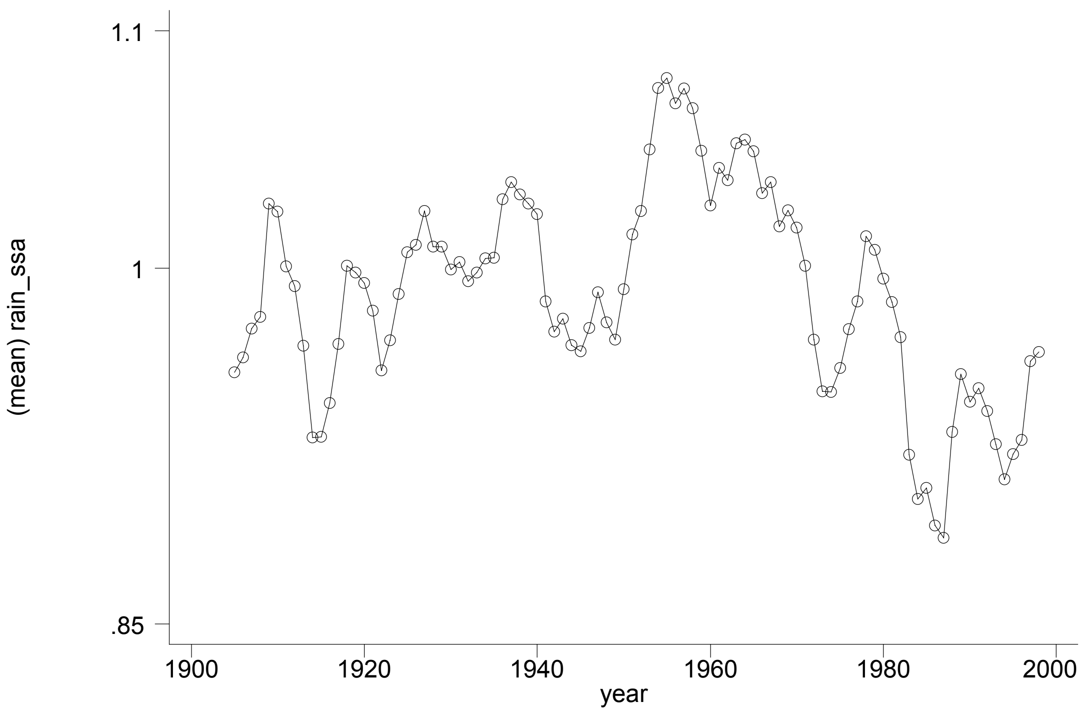

(mean) rain_ssa
1.1
1
.85
1900
1920
1940
1960
1980
2000
year

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

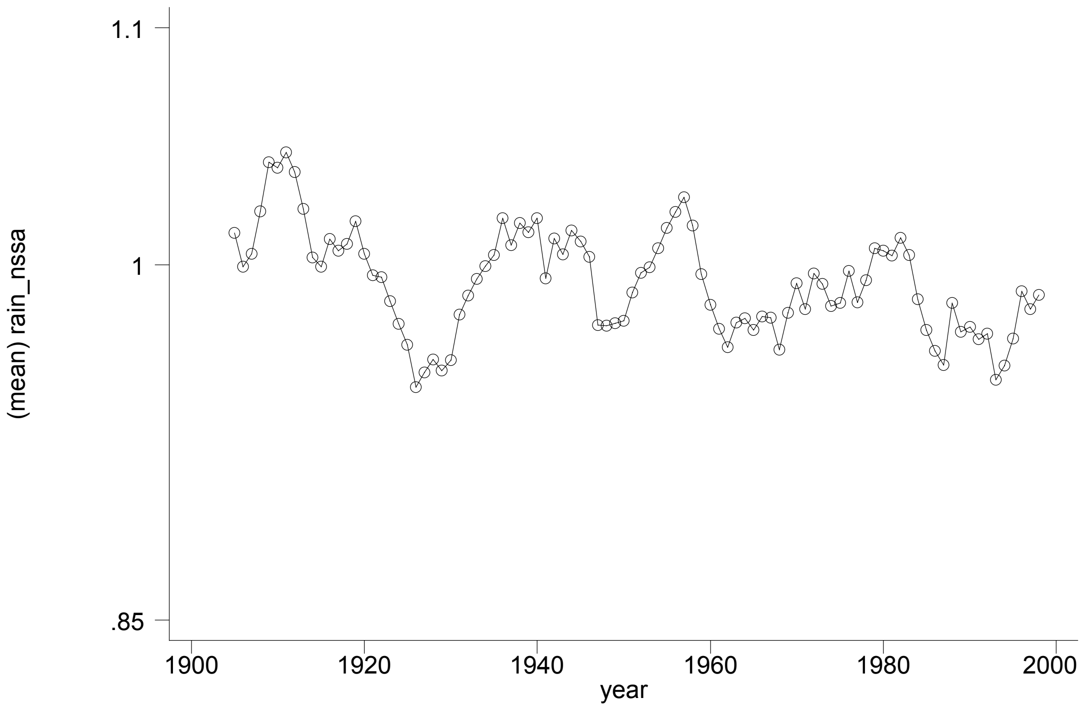


Figure 4: Trends in real GDP per capita growth rates and Rainfall in Sub-Saharan African Countries

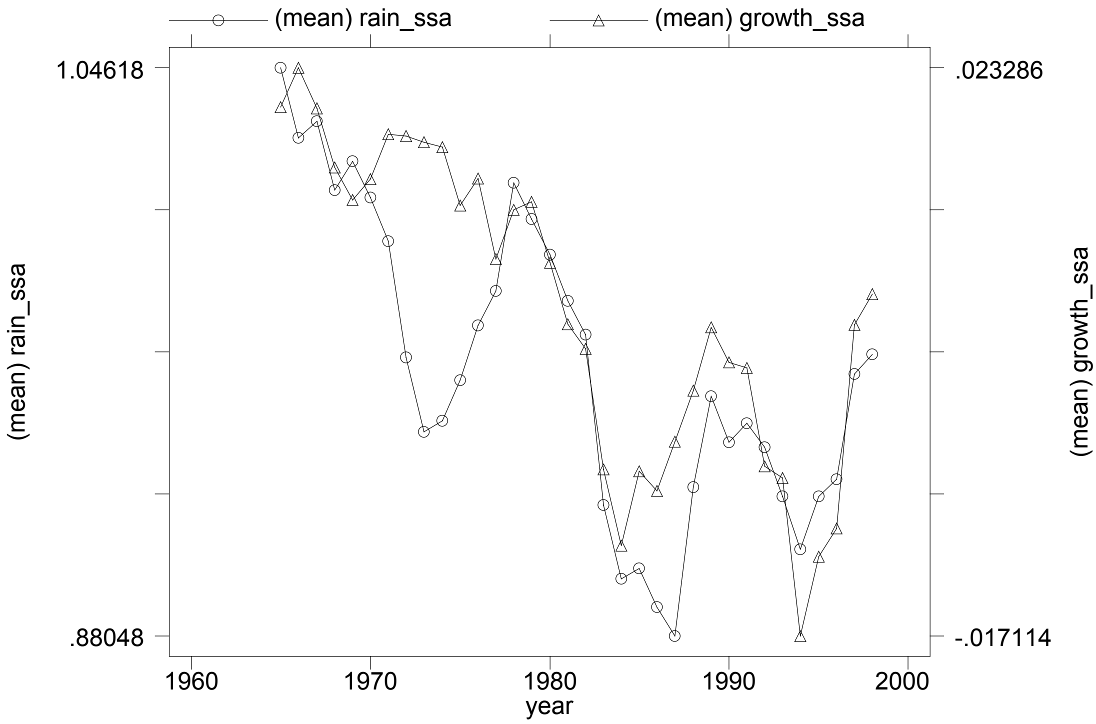

(mean) rain_ssa
(mean) growth_ssa
1.04618
.88048
.023286
-.017114
1960
1970
1980
1990
2000
year
(mean) rain_ssa
(mean) growth_ssa

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

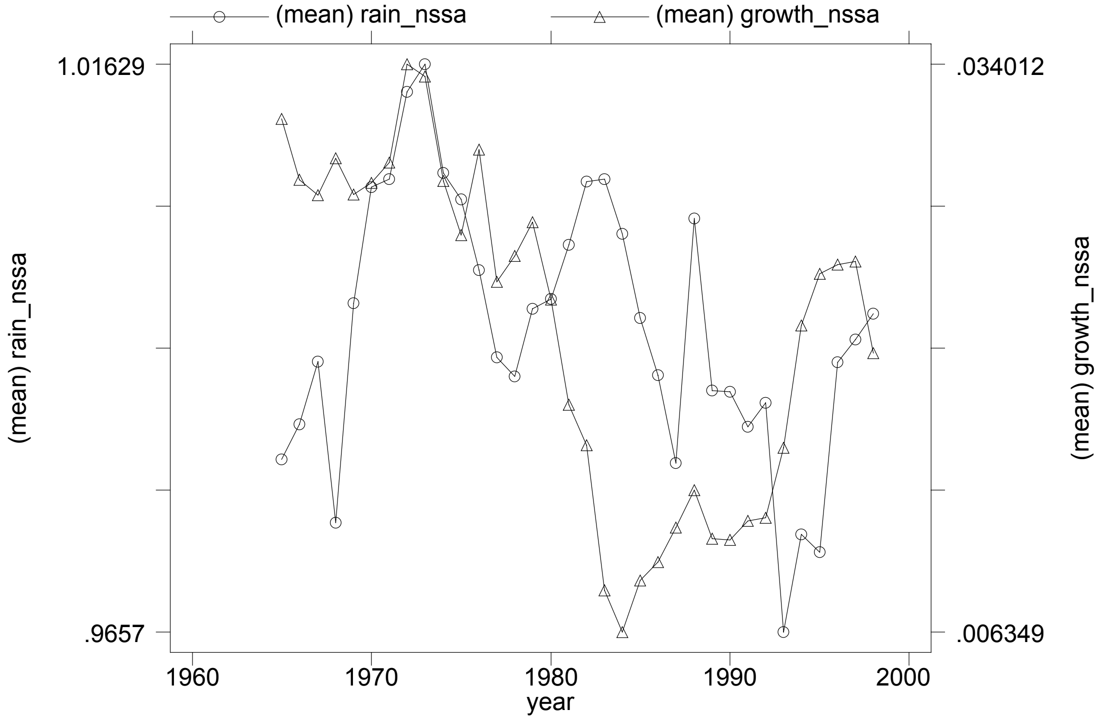


Figure 6: Trends in Agricultural Production and Rainfall in SSA

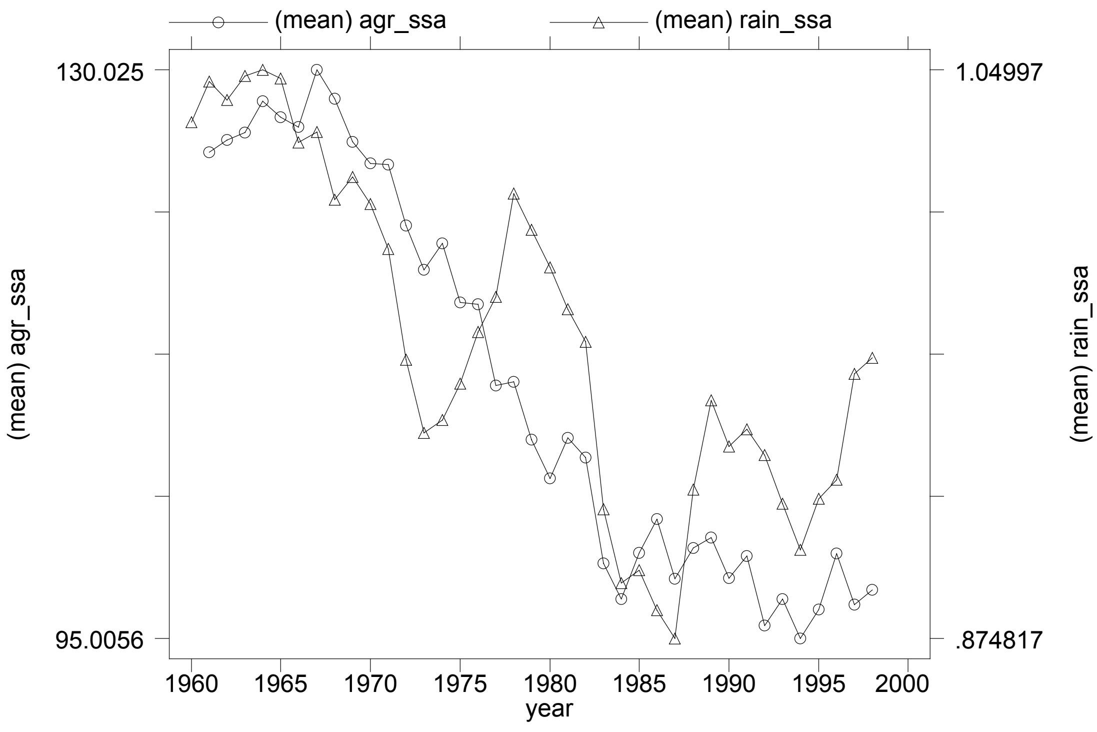

(mean) agr_ssa
(mean) rain_ssa
130.025
95.0056
1.04997
.874817
(mean) agr_ssa
(mean) rain_ssa
1960
1965
1970
1975
1980
1985
1990
1995
2000
year

Figure 7: Trends in Agricultural Production and Rainfall in NSSA

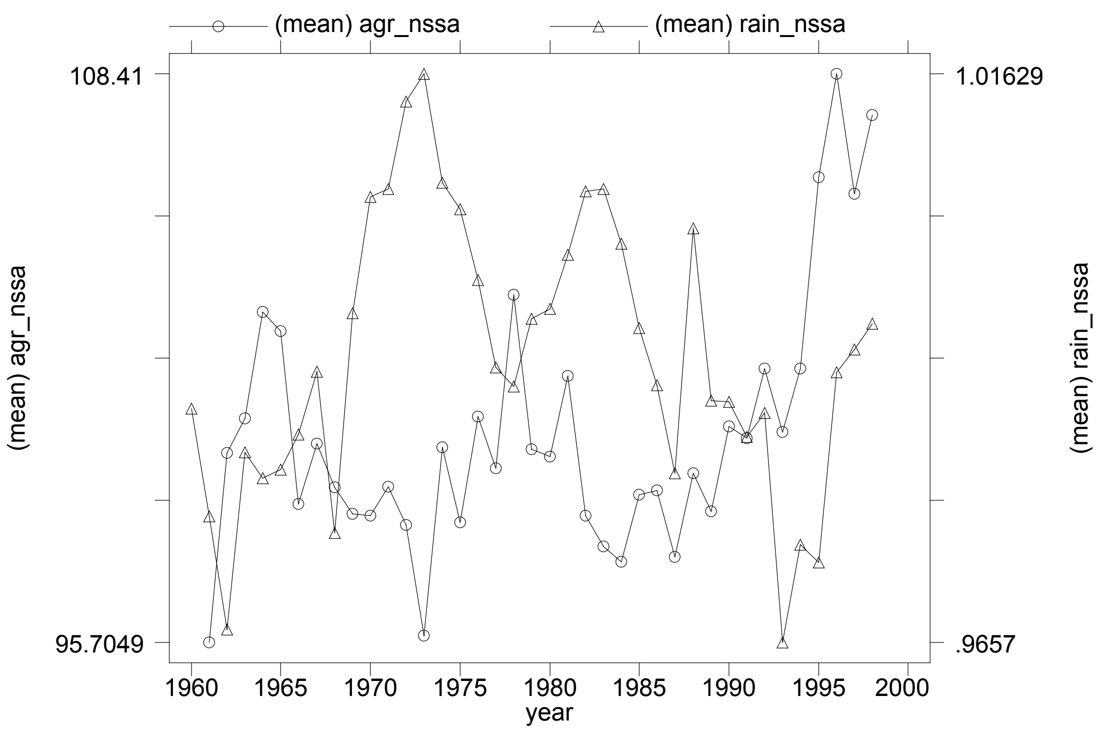


Figure 8: Trends in Hydro-Power Energy Production and Rainfall in SSA

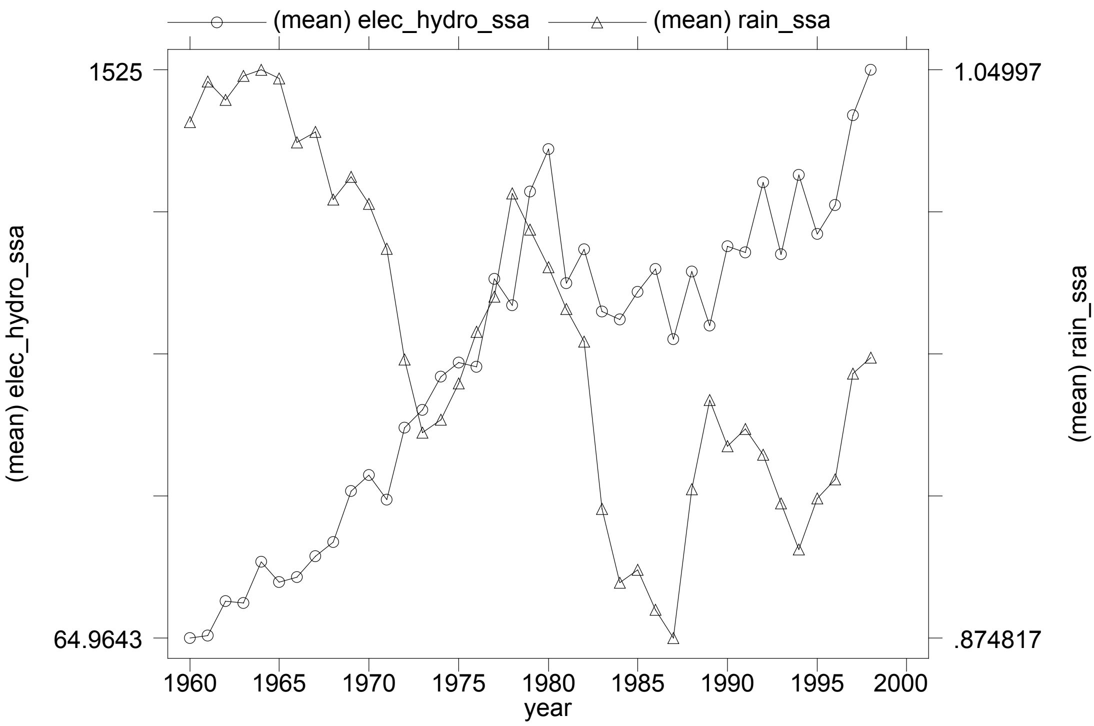

(mean) elec_hydro_ssa
(mean) rain_ssa
1525
64.9643
1.04997
.874817
1960
1965
1970
1975
1980
1985
1990
1995
2000
year
(mean) elec_hydro_ssa
(mean) rain_ssa

Figure 9: Trends in Hydro-Power Energy Production and Rainfall in NSSA

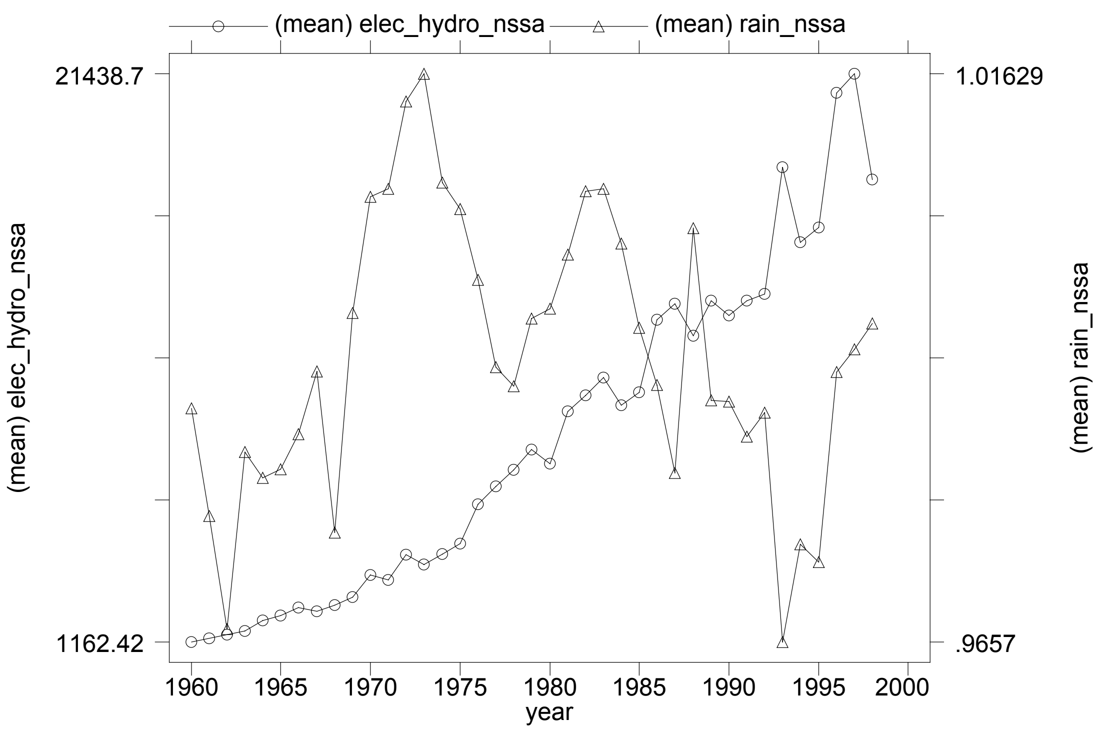


Figure 10: GDP per Capita in Sub-Saharan African Countries – Actual vs. Estimated with 1955-1960 Mean Rainfall

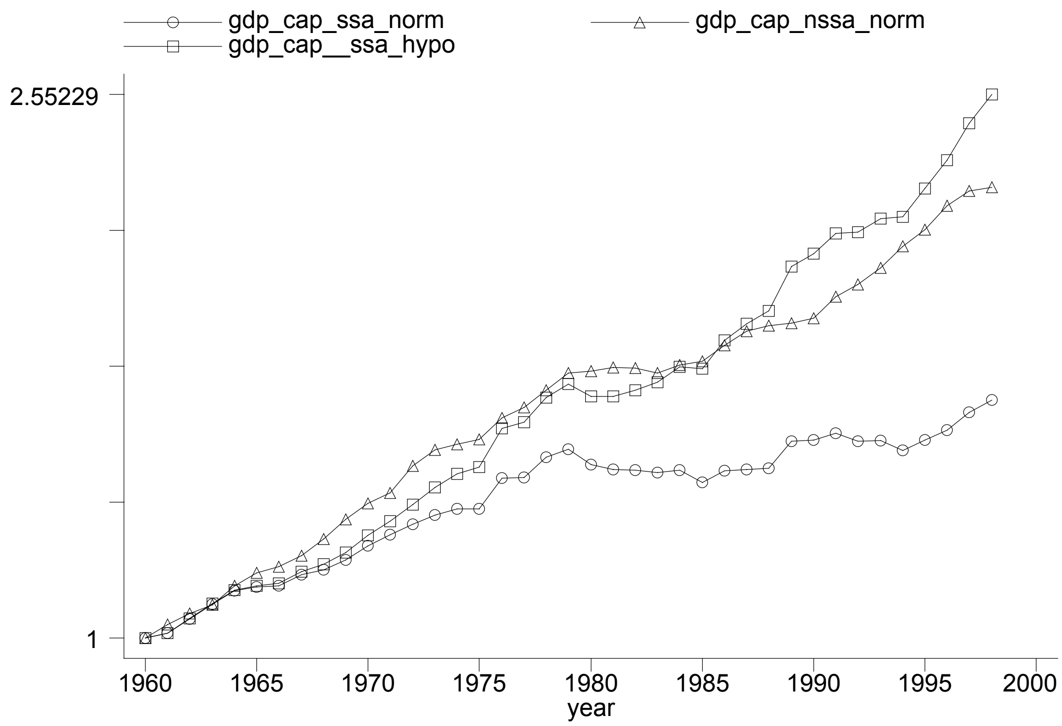
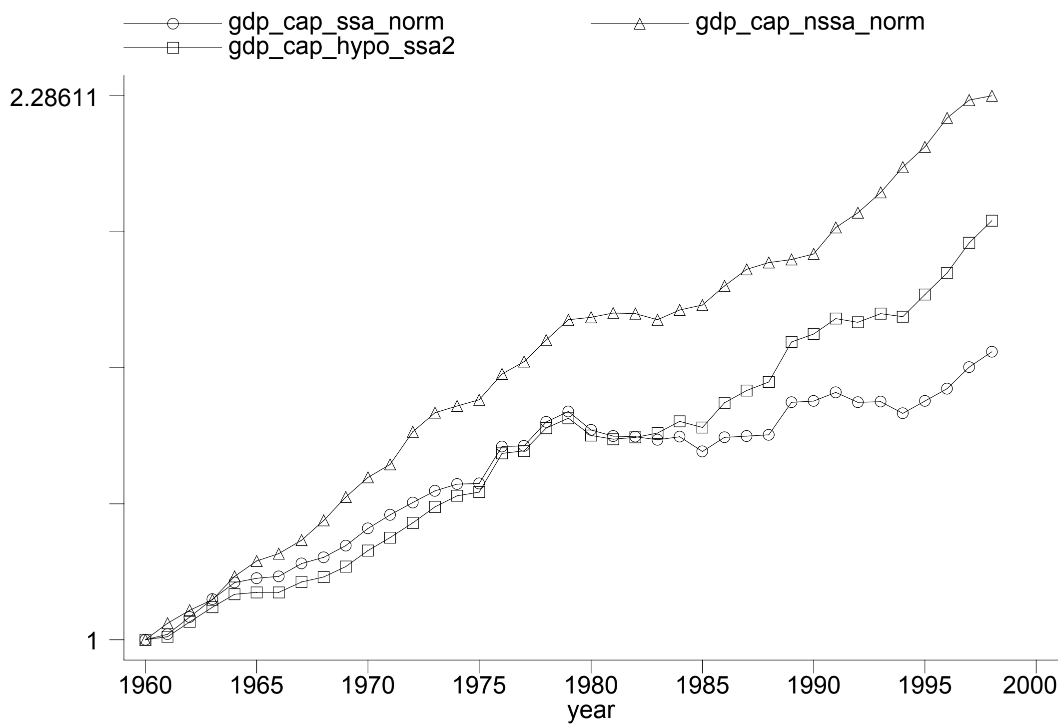

gdp_cap_ssa_norm
gdp_cap_nssa_norm
gdp_cap__ssa_hypo
2.55229
1
1960
1965
1970
1975
1980
1985
1990
1995
2000
year

Figure 11: GDP per Capita in Sub-Saharan African Countries – Actual vs. Estimated with Long-Term Mean Rainfall



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 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.

Table 2: OLS Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RAIN	0.030	-0.014	-0.014	0.071**	-0.022	-0.017	0.079**
	(0.020)	(0.029)	(0.028)	(0.031)	(0.027)	(0.027)	(0.037)
SSA	-0.009**	-0.093**			-0.057		
	(0.004)	(0.040)			(0.040)		
RAIN*SSA		0.085**			0.069*		
		(0.041)			(0.039)		
Constant	-0.009	0.035	0.035	-0.059*	0.188***	0.235***	0.147*
	(0.020)	(0.029)	(0.027)	(0.030)	(0.045)	(0.056)	(0.088)
Sample	All	All	NSSA	SSA	All	NSSA	SSA
Controls	No	No	No	No	Yes	Yes	Yes
Observations	352	352	230	122	352	230	122
Countries	61	61	39	22	61	39	22
F-Test	4.33***	4.39***	0.26	5.39***	5.55***	3.65***	3.47***
R-squared	0.02	0.04	0.00	0.04	0.31	0.30	0.41

Notes: (1) Standard errors in parantheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (3) Controls the time invariant and variant controls as set forth in Table of the Data Appendix and described in the text.

Table 3: Fixed Effects Results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RAIN	0.023	-0.033	-0.033	0.078**	-0.025	-0.022	0.134***
	(0.026)	(0.036)	(0.035)	(0.038)	(0.033)	(0.032)	(0.045)
RAIN*SSA		0.111**			0.098**		
		(0.051)			(0.049)		
Constant	-0.005	0.012	0.054	-0.065*	0.389***	0.478***	0.234**
	(0.026)	(0.027)	(0.035)	(0.037)	(0.073)	(0.112)	(0.103)
Sample	All	All	NSSA	SSA	All	NSSA	SSA
Controls	No	No	No	No	Yes	Yes	Yes
Observations	352	352	230	122	352	230	122
Number of id	61	61	39	22	61	39	22
F-Test	0.77	2.71***	0.87	4.20***	6.43***	5.01***	2.80***
F-u	1.86***	1.86***	1.43***	2.34***	2.34***	1.86***	2.46***
R-squared	0.00	0.02	0.00	0.04	0.26	0.28	0.31

Notes: (1) Standard errors in parantheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (3) Controls the time variant controls as set forth in Table of the Data Appendix and described in the text.

Table 4: Effect of Rainfall on Agricultural Production

	(1)	(2)	(3)	(4)
RAIN	46.601***	-23.369	-17.380	67.442***
	(11.280)	(17.014)	(16.348)	(15.783)
RAIN*SSA		119.354***		
		(22.164)		
Constant	65.745***	82.924***	121.147***	58.359***
	(11.204)	(11.367)	(16.264)	(15.290)
Sample	All	All	NSSA	SSA
Controls	Time Dummies	Time Dummies	Time Dummies	Time Dummies
Observations	616	616	339	277
Number of id	96	96	56	40
F-Test	11.06***	13.83***	0.36	21.59***
F-u	6.66***	6.61***	5.88***	7.87***
R-squared	0.13	0.18	0.01	0.40

Notes: (1) Standard errors in parantheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (3) Time dummies included. (4)

Table 5: Effect of Rainfall on Hydro-Power Production

	(1)	(2)	(3)	(4)
RAIN	7,586.452	939.292	2,734.459	1,385.333*
	(5,438.591)	(7,100.853)	(8,870.221)	(800.046)
RAIN*SSA		15,791.304		
		(10,860.190)		
Constant	-10,854.558*	-10,098.868*	-5,018.002	-1,991.676**
	(5,700.476)	(5,718.889)	(9,160.917)	(864.442)
Sample	All	All	NSSA	SSA
Controls	Time Dummies	Time Dummies	Time Dummies	Time Dummies
Observations	4018	4018	2531	1487
Number of id	116	116	75	41
F-Test	11.06***	13.83***	0.36***	21.59***
F-u	6.66***	6.61***	5.88***	7.87***
R-squared	0.13	0.18	0.01	0.40

Notes: (1) Standard errors in parantheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (3) Time dummies included. (4)

Appendix C: Variable Description

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
POPGR	Growth rate of population	Time varying (annual) 1950-2000	World Penn Tables 6.1
SCHOOL	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 eal 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
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
INC_LOW	1-0 Dummy for low income country	Time invariant	World Bank Global Network Development Growth Database
INC_LOWM	1-0 Dummy for lower middle income country	Time invariant	World Bank Global Network Development Growth Database
INC_UPPM	1-0 Dummy for upper middle income country	Time invariant	World Bank Global Network Development Growth Database
AREA	Land Area	Time invariant	World Bank Global Network Development Growth Database

Appendix D: Selected Full Regression Results For Five Year Growth Rate Samples

	(1)	(2)	(3)	(4)	(5)	(6)
RAIN	-0.022	-0.017	0.079**	-0.025	-0.022	0.134***
	(0.027)	(0.027)	(0.037)	(0.033)	(0.032)	(0.045)
RAIN*SSA	0.069*			0.098**		
	(0.039)			(0.049)		
SSA	-0.057					
	(0.040)					
Log(GDP/Cap)	-0.022***	-0.026***	-0.018**	-0.050***	-0.056***	-0.045***
	(0.005)	(0.007)	(0.008)	(0.009)	(0.013)	(0.014)
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)
POPGR	0.012	-0.002	-0.015	-0.062	-0.052	-0.126
	(0.044)	(0.054)	(0.096)	(0.070)	(0.092)	(0.130)
SCHOOL	0.000	0.002	-0.005	-0.001	0.002	-0.010
	(0.002)	(0.002)	(0.005)	(0.004)	(0.005)	(0.013)
CIVWAR	-0.008	-0.007	-0.009	-0.018***	-0.016**	-0.029**
	(0.005)	(0.006)	(0.011)	(0.006)	(0.007)	(0.015)
CIVWAR_S	-0.003	0.003	-0.038*	-0.008	0.001	-0.054**
	(0.007)	(0.008)	(0.022)	(0.009)	(0.010)	(0.026)
INV/GDP	0.001***	0.001**	0.001**	0.001**	0.001**	0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
G/GDP	-0.000	-0.000	0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
LANDLOCK	-0.006	-0.003	-0.007			
	(0.005)	(0.009)	(0.009)			
ETHNIC	-0.000*	-0.000	-0.000			
	(0.000)	(0.000)	(0.000)			
TROP	-0.005	0.000	-0.021			
	(0.006)	(0.008)	(0.017)			
INC_LOW	0.000	0.000	-0.062***			
	(0.000)	(0.000)	(0.015)			
INC_LOWM	0.024***	0.014*	-0.042			
	(0.006)	(0.008)	(0.030)			
INC_UPPM	0.043***	0.032***	0.000			
	(0.008)	(0.012)	(0.000)			
AREA	-0.000**	-0.000	-0.000			
	(0.000)	(0.000)	(0.000)			
Constant	0.188***	0.235***	0.147*	0.389***	0.478***	0.234**
	(0.045)	(0.056)	(0.088)	(0.073)	(0.112)	(0.103)
Method	OLS	OLS	OLS	FE	FE	FE
Observations	352	230	122	352	230	122
Countries	61	39	22	61	39	22
F-Test	5.55***	3.65***	3.47***	6.43***	5.01***	2.80***
F-u	---	---	---	2.34***	1.86***	2.46***
R-squared	0.31	0.30	0.41	0.26	0.28	0.31

Notes: (1) Standard errors in parantheses. (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels. (3) Time dummies included.

Appendix E: Country list

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.

Non Sub-Saharan Africa

Algeria, Albania, Argentina, Antigua, Bangladesh, Bulgaria, Belize, Bolivia, Brazil, Barbados, Chile, China, Colombia, Costa Rica, 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.

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