Do weather events affect income inequality in Africa?

Mark Edem Kunawotor*

Department of Banking and Finance,
University of Professional Studies,
P.O. Box LG 149, Legon, Accra, Ghana
and
Department of Finance,
University of Ghana Business School,
P.O. Box LG 78, Legon, Accra, Ghana
Email: mark.kunawotor@upsamail.edu.gh
*Corresponding author

Godfred Alufar Bokpin and
Patrick O. Asuming

Department of Finance,
University of Ghana Business School,
P.O. Box LG 78, Legon, Accra, Ghana
Email: gabokpin@ug.edu.gh
Email: poasuming@ug.edu.gh

Kofi A. Amoateng

School of Business,
North Carolina Central University,
Durham, North Carolina, 27713, USA
Email: amoateng@nccu.edu

Abstract: This paper investigates the effects of weather events on income inequality in Africa over the period 1990–2017. Our novel findings using GMM reveal a non-monotonic U-shape effect of the incidence of weather events on income inequality. The result of the simultaneous quantile regression shows that weather events increase income inequality at the 10th, 25th, 50th and 75th percent quantiles. In terms of weather events type, we also find a non-monotonic U-shape effect of the incidence of flood on income inequality. Furthermore, some institutional quality indicators such as the control of corruption, political stability and rule of law tend to moderate the impacts weather events have on income inequality. We however find no statistically significant mediating effect of weather events on income inequality through agricultural productivity in our sample. Again, there is no significant moderating effect of adaptive capacity on income inequality. We suggest that income inequality concerns should not be ignored in global climate change discussions. Furthermore, African countries should strengthen their institutions and adaptive capacities as they remain very weak in the continent.

Keywords: weather events; flood; income inequality; institutions; Africa.

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Biographical notes: Mark Edem Kunawotor is a Lecturer in Economics and Finance at the University of Professional Studies, Accra. His previous research work has focused on retirement, pensions, productivity and financial access. His current research interest centres on climate change, weather events, income inequality, fiscal and monetary policies aimed at addressing the sustainable development goals (SDGs) in Africa.

Godfred Alufar Bokpin is an Economist and Professor of Finance at the University of Ghana Business School. He has extensive experience consulting for industry, civil society and government institutions. He has over 50 articles in high impact journals. He has been interested in theoretical and empirical analysis of market microstructure in Africa as well as corporate disclosure, transparency, information disclosure and more recently in environment and climate change impact studies.

Patrick O. Asuming is an Economist and Senior Lecturer at the University of Ghana Business School. His research interest lies in health economics and development economics. His recent research uses randomised field interventions to evaluate the effects of Ghana's National Health Insurance Scheme on utilisation of healthcare services and health outcomes. He has expertise in the design of field experiments, analyses of large datasets and impact evaluation.

Kofi A. Amoateng joined N.C. Central University in 1990. He earned his PhD in Economics minor in Finance, from the University of Texas at Austin, MA from Eastern Illinois University, and BA in Economics from the University of Ghana. His research papers are published in journals such as *Applied Economics*, *Applied Economics Letters*, *Journal of Emerging Markets*, *Managerial Finance*, *OPEC Review*, *Review of Accounting and Finance*, and *International Journal of Economics and Finance*. He has 36 lifetime peered-reviewed publications. He and Professor Ben Amoako-Adu published a Google Scholar article in applied economics in 1996 with 138 citations.

1 Introduction and motivation

Climate change continues to be a pivotal focus of discussion amongst many world leaders and governments worldwide as it is considered a major threat in this century (World Economic Forum, 2019). The importance of climate change is reflected in the United Nations Millennium Development Goals (MDGs) of ensuring environmental sustainability and now more visibly in goal 13 of the Sustainable Development Goals (SDGs) which discusses actions to reduce climate change impacts. Besides governmental efforts, the academic literature continues to churn lots of empirical evidence to buttress the dangers of climate change impacts for both the current and future generations. One key global evidence of climate change is the change in average temperature patterns and the frequent occurrence of extreme weather events in the form of floods, droughts, earthquakes, hurricanes, tremors, tornadoes, wildfires, etc. Available scientific evidence (see Kireyev, 2018; CRED, 2017; Lis and Nickel, 2010) supports the assertion that the severity and frequency of extreme weather events are due to climate variabilities.

Weather events as captured by the Emergency Events Database (EM-DAT) are a special type of natural disasters that are climatological, meteorological or hydrological and may require the happenings of at least one of the following; 10 or more people killed, 100 or more people affected or injured, a declaration of a state of emergency by the affected country and/or a call for international assistance. According to the Global Climate Risk Index Report (2017), more than half a million people died due to 11 thousand extreme weather events between 1996 and 2015. FAO (2017) also reports that between 2008 and 2015, about 27 million people have been displaced annually by natural hazards and climate-related disasters and this trend keeps rising. In Africa, about 51,569 people were killed and 412 million people adversely affected due to 1,381 different forms of weather events over the period 1990–2019 as recorded in the emergency events database maintained by the Center for Research on the Epidemiology of Disasters (CRED). Weather events have destroyed properties, thrown a lot of people in poverty and continue to widen the income disparities between the rich and the poor. Climate change and various forms of weather events also have detrimental impacts on economic growth (Rana and Sharma, 2019; IMF, 2017; Cashin et al., 2017; Hallegatte et al., 2016) and agricultural productivity (Calvin et al., 2020; FAO, 2018; Mendelsohn and Massetti, 2017; Auffhammer and Schlenker, 2014; Dell et al., 2012). Particularly, FAO (2017) estimates suggest that 25% of the hazards caused by natural disasters affect agriculture and 80% of the damages caused by droughts affect the agricultural sector.

However, although the consequences of climate change are severe, inequality also seems to be a key concern on the global landscape and hence considered as one of the SDGs. Income inequality and climate change are a defining challenge of our time as the two are considered to be the two most important challenges currently facing the international community (UNDESA, 2016). These two reinforcing phenomena also simultaneously appear on the SDGs agenda and addressing them according to Markkanen and Anger-Kraavi (2019) is imperative to achieving most of the other SDGs. Not only do most African countries endure and continue to be the most affected by climate change impacts, but also, income inequality appears very high and persistent in Africa. The African continent ranks almost least in the regional distributions of income inequality performing just a little better than Latin America and the Caribbean (UNDESA, 2019; World Bank, 2016). Shimeles and Nabassaga (2018); Odusola (2017) and Anyanwu (2016) also lend support to this assertion.

African countries have also had high levels of initial income inequality with ten out of the world's 19 most unequal countries found in Africa (UNDP, 2017). High levels of economic inequality have numerous implications for economic growth, macroeconomic stability, poverty reduction and human sustainability (OECD, 2015; Cojocaru and Diagne, 2014; Ostry et al., 2014; IMF, 2014). UNDESA (2020) for instance argues that high inequality does not only harm the poor and disadvantaged groups but also affects the general well-being of society at large and also, highly unequal societies grow more slowly and find it very difficult in reducing poverty. Similarly, the available evidence (see Shimeles and Nabassaga, 2018; Fosu, 2015) show that no amount of growth in GDP per capita income amongst some African countries would be sufficient enough to reduce extreme poverty unless income inequality declines considerably. However, recent studies albeit very few show that concerns of reducing economic inequality could further be hindered by changing climate and its adverse cascading effects in the form of weather events. For example, studies by UNDESA (2020), Dasgupta et al. (2020), Otrachshenko and Popova (2019) and Diffenbaugh and Burke (2019) show that climate change and weather events worsen inequality. Attention is also being directed towards the risk climate change poses to exacerbating income inequality and achieving the sustainable development goals (see Winsemius et al., 2018; Hallegatte and Rozenberg, 2017). Few others looked at the consequences climate mitigation policies have on inequality (Klinsky and Winkler, 2018; Brugnach et al., 2017). Yet still, UNDESA (2016) shows that climate change and income inequality are locked in a vicious cycle. While most of these studies focus on temperature change or extreme weather (heat waves or cold waves) as proxies for climate change and mainly between-country income inequality except for Dasgupta et al. (2020) who focused on South Africa, no study was identified to comprehensively study the impact of weather events and its types on within-country income inequality in Africa. Accordingly, our study attempts to investigate the effects of weather events and the various types, on income inequality in Africa. Also, it investigates the impacts that institutions and adaptive capacity play in moderating the impact of weather events on income inequality. Furthermore, we investigate if agricultural productivity mediates the impacts that weather events has on income inequality in Africa as climate-sensitive agriculture is noted to be the predominant form of livelihood for most Africans.

The remaining sections of this study contain a literature review, data and methods, results and conclusions as well as some recommendations.

2 Literature review

2.1 Climate change, weather events and poverty

Ludwig et al. (2007) narrate why the poor tend to be more affected by climate change impacts. First, many poor people live in semi-arid regions in Africa and Asia that are more likely to be affected by climate change impacts because these regions have an erratic climate with unpredictable rainfall patterns causing floods and droughts. Therefore, increased climate variability further pushes these people into poverty due to the loss of income and properties. Even, those in the urban centres settle in slums which are mostly flood-prone, and official developments not permitted. Secondly, the poor predominantly depend on vulnerable economic sectors such as agriculture which is susceptible to changes in rainfall and temperature in these regions. Since future rainfall patterns are unpredictable, their livelihood on agriculture is unsustainable. The amount of water available for irrigation is reduced especially for small-scale farmers. The health concern of the poor is also jeopardised as they mostly have a low resistance to diseases caused by climate variabilities such as malaria, diarrhoea, cholera, and other infectious diseases. Also, the poor lack the needed resources for healthcare. Finally, there are generally low adaptive capacities to cope with climate change. No insurance, no access to credit markets and unavailable institutional framework to help the poor cope with climate impacts. Very related to the above, the World Economic and Social Survey (2016) reports that in countries where there is widespread poverty, the poor suffer disproportionately more from climate hazards not only because of their poverty status but also because of their unequal standing in society. Brugnach et al. (2017) argue that the poor and the marginalised are the most vulnerable to extreme weather events and rising temperatures mainly because they lack the necessary resources to adapt to it. Evidence

(FAO, 2017) indicates that the heavy rains that flooded Mumbai, India in 2005 affected poor households twice as much as it affected others. Similarly, poor people lost thrice as much as others when hurricane Mitch occurred in Honduras in 1998. They also alluded to the fact that the poor reside in risk exposed areas and have fewer resources to adapt, buffer and recover quickly from shocks. More recently, UNDESA (2020) affirms that climate change affects the prevalence and depth of poverty, and if left unchecked will contribute to income inequality both within and between countries. Climate change also affects the resources and assets that aid the poor to generate income. The wealth of the poor is more affected by climate change because their wealth is concentrated in houses and livestock which are more fragile. Bikorimana and Sun (2020) found a bi-directional causal relationship between poverty and deforestation in Rwanda.

2.2 Empirical literature on climate change, weather events and inequality

Literature is generally in high dearth when it comes to climate change and income inequality. The very few available and accessible ones are discussed in this section. A study by Burgess et al. (2014) on the unequal effects of weather and climate change with evidence from mortality in India used district-level panel data to test whether hot weather shocks have unequal effects on mortality in both rural and urban populations. They mentioned that this effect to a large extent depends on the degree to which incomes are affected by weather shocks. Their findings revealed that a rise in high-temperature days by one standard deviation within a year causes a decrease in agricultural productivity and real wages among the rural population but has no effect among the urban population. Otrachshenko and Popova (2019) used regional panel data from Russia and showed the effect that extreme weather (hot temperature and cold temperature) has on income inequality. Their findings reveal that extremely hot temperatures affect income distribution and worsen income inequality in poorer regions while having minimal impact in rich regions. The study explains that extremely hot temperatures reduce employment in private sector industries while increasing employment in the low-paid public sector. More recently, Diffenbaugh and Burke (2019) find that there is a high likelihood of an anthropogenic climate to exacerbate income inequality among countries. They mentioned that the increase in inequality between countries is a result of global warming induced-penalties in poor nations along with warming-induced benefits in rich countries. They estimate the parabolic relationship between temperature change and economic growth and find long term global warming to increase growth in cold countries (such as Norway) but decrease growth in warm countries (such as India). Quite related to our study is the paper by Dasgupta et al. (2020) who investigates the impact of climate change on income distribution and income inequality in South Africa using global, regional and household-level panel data. Their findings show that inequality and poverty have a U-shaped relationship with temperature while that between temperature and GDP or income per capita shows an inverted U-shaped relationship. They argue that these relationships hold for global macro aggregates and micro household inequality data. Their findings imply that substantial increases in inequality are projected at higher temperatures.

2.3 Climate change and agricultural production

Barrios et al. (2008) examine the impact of climate change on agricultural production in sub-Saharan Africa and other non-African developing countries. Measuring climate change as changes in country-wide rainfall and temperature, the study finds that decreases in rainfall and temperature change reduce agricultural output in sub-Saharan Africa while having a minimal impact in non-sub-Saharan developing countries. Dell et al. (2012) find that one degree Celsius higher temperature is associated with a 2.66 percentage points reduction in the growth of agricultural output in poor countries but find an insignificant result for rich countries. Auffhammer and Schlenker (2014) argue that agricultural productivity heavily depends on weather outcomes since the weather is considered a direct input in the agricultural production function and hence climate change has a great potential to cause a major upset in the agricultural sector. This finding is based on both reduced form studies as well as integrated assessment models. Similar thoughts are shared by Calvin et al. (2020) using the global integrated assessment model (GCAM). Also, Burgess et al. (2014) find that agricultural yield reduces, and the wage of agricultural labourers also reduces in the presence of hot weather especially during planting seasons. FAO (2018) asserts that climate variabilities have both direct and indirect effects on agricultural yields, aquaculture, livestock, and fisheries production. Statistically, FAO (2017) also estimates that 25% of the hazards caused by natural disasters affect agriculture and the agricultural sector also absorbs 80% of the damages and loss caused by droughts. Finally, UNDESA (2020) argues that indigenous people and small landholders are more exposed to climate change because most of these people depend on agriculture, fishing and other ecosystem income-generating activities while Owusu et al. (2016) acknowledged that farmer's location is a principal determinant of flood vulnerability in Ghana.

2.4 Empirical determinants of income inequality

Literature is not in dearth when it comes to the empirical determinants of inequality. Few of the sampled but relevant studies that focused on inequality drivers are discussed in this section. Dabla-Norris et al. (2015) came out with a study on the global causes and consequences of income inequality in 100 advanced and emerging markets and developing countries and find that a number of inter-related factors can affect inequality and these factors may have differential effects depending on the country and income group. The following factors are identified to affect inequality; skill premium, financial globalisation, labour market regulations, government spending, technology, financial deepening and female mortality rate. The paper by Anyanwu (2016) on the main drivers of inequality in Southern Africa finds gross capital formation, GDP per capita, the squared term of political globalisation, population growth and the first lag of income inequality to positively and significantly influence inequality. On the other hand, he finds the squared term of GDP per capita, political globalisation, secondary school enrolment, total resource rent and the second lag of inequality to negatively affect income inequality. Similarly, Anyanwu et al. (2016) find the following as the main drivers of income inequality in West Africa; the first two period lags of inequality, GDP per capita, squared term of GDP per capita, FDI inflows, resource rent, population density, secondary school enrolment, gross capital formation, trade openness, government expenditure, remittances received, democracy, civil war, unemployment rate, political and social globalisation. A working paper by Cevik and Correa-Caro (2015) conducted a study on the proximate determinants of inequality with a particular focus on the distributional impacts of fiscal policy. The paper concentrated on Brazil, Russia, India, China (BRIC) and other 30 emerging market economies. They find only the previous year's inequality, per capita GDP and its square to be significant. Government expenditure and tax which are used as proxies for fiscal policy remain insignificant in addition to trade openness, financial development, index of human capital and the share of the urban population. The fiscal policy variables of taxation and government spending were found to be statistically significant in China with taxation serving as a redistributive tool while government spending increases inequality. Lastly, Jaumotte et al. (2013) examine the relationship between technology, trade, or financial globalisation on income inequality in 51 advanced and developing countries and find a greater impact for technological progress than for globalisation. They include controls such as access to education, shares of employment in agriculture and industry and domestic financial development.

3 Methodology

3.1 Model specification, measurement of variables and a priori expectations

The model specification of this study follows recent income inequality studies (see Kunawotor et al., 2020; Adeleye et al., 2017; Anyanwu et al., 2016) where income inequality is predicted by inequality in previous year, explanatory variables and some control variables. The lag of income inequality is introduced because income inequality is said to be persistent and hence changes at a slow pace. That is, the previous year (s) income inequality affects the current level. The past income inequality is an unbiased predictor of the current income inequality. Our models, therefore, take the form:

Model 1 The effects of weather events & flood on income inequality.

$$Inequality_{it} = \alpha_1 Inequality_{it-1} + \alpha_2 WeatherEvents_{it} + \beta' X_{it} + \mu_i + \mu_t + \varepsilon_{it} \quad (1)$$

Model 2 The moderating effects of institutions and adaptive capacity on income inequality.

$$\begin{aligned} Inequality_{it} &= \theta_1 Inequality_{it-1} + \theta_2 \left(WeatherEvents_{it} * Institutions_{it} \right) \\ &\quad + \beta' X_{it} + \mu_i + \mu_t + \varepsilon_{it} \end{aligned} \quad (2a)$$

$$\begin{aligned} Inequality_{it} &= \sigma_1 Inequality_{it-1} + \sigma_2 \left(WeatherEvents_{it} * AdaptiveCapacity_{it} \right) \\ &\quad + \beta' X_{it} + \mu_i + \mu_t + \varepsilon_{it} \end{aligned} \quad (2b)$$

Model 3 The indirect effects of weather events on income inequality through agricultural productivity

$$\begin{aligned} Inequality_{it} &= \alpha_1 Inequality_{it-1} + \alpha_2 WeatherEvents_{it} + \alpha_3 AgricProductivity_{it} \\ &\quad + \beta' X_{it} + \mu_i + \mu_t + \varepsilon_{it} \end{aligned} \quad (3)$$

Income inequality ($Inequality_{it}$) is the dependent variable in all the models and it is measured using the market Gini index in equations (1) and (3) but the disposable/net Gini index is used in equation (2). The market Gini index estimates inequality using equivalised household market (pre-tax, pre-transfer) income while the disposable or net Gini measures inequality using post-tax and post-transfers. The index ranges from 0 to 100 with 0 indicating perfect equality while 100 indicates perfect inequality. The within-country Gini coefficient measures the income distribution or consumption among households in a country. The letter i and t represent a given country and year respectively. $Inequalityi_{t-1}$ represents income inequality in a given country in the previous year. It is expected that past levels of inequality will drag current levels of inequality and hence exhibiting a great degree of inertia.

Our main independent variable is weather event ($WeatherEvents_{it}$). Weather event is measured as a count variable based on certain set criteria and decision rule. An event is counted if at least a weather event occurs within a year and 0 otherwise. Multiple counts are considered within a year depending on how many times weather events occur. For an event to be considered and entered in the Emergency Events Database (EM-DAT), at least one of the following criteria need to be fulfilled; ten (10) or more people reported killed, a hundred (100) or more people reported affected, a declaration of a state of emergency, a call for international assistance. Our classification of weather events follows exactly this criterion which is used by EM-DAT under disaster sub-group climatological, hydrological or meteorological. Generally, we expect weather events to widen income inequality as poor households tend to be more affected by these occurrences.

The main types and sub-types of weather events in Africa over our sample period are flood, drought, storm, landslide, wildfire, extreme temperature, heatwave, cold wave, land fire, forest fire, tropical cyclone and mudslide. We, therefore, attempt to find out which of these occurrence (s) is likely to directly or indirectly affect income inequality. Flood ($Flood_{it}$) and drought are the most frequent and hence their effects on inequality were considered under equation (1). Flood and drought are also measured as count variables just like weather events so long as they are considered and entered by EM-DAT. It is also expected that either flood or drought will increase income inequality.

In model 2, equations (2a) and (2b), we attempt to find how adaptive capacity (*AdaptiveCapacity*) and institutions ($Institutions_{it}$) moderate the linkage between weather events and income inequality. Institution is measured using the index developed by Kaufmann et al. (2011). Institution in extant literature is generally computed as an average of these six indicators; control of corruption, government effectiveness, political stability, regulatory quality, rule of law and voice and accountability. Institution ranges from –2.5 to 2.5 with higher values indicating stronger institutions. However, we created a dummy variable from the institution index with values above the average considered as ‘1’ while those equal to or below the average considered as ‘0’. We expect strong institutions to reduce the impact of weather events on inequality and weak institutions to depict a converse effect. Also, adaptive capacity measured by the Notre Dame Global Adaptation Index (ND-GAIN) basically assesses a country’s level of vulnerability to climate change impacts as well as readiness and preparedness to make use of adaptation investment. ND-GAIN ranges from 0–100 with higher values indicating strong adaptive capacity. It is expected that countries with strong adaptive capacities will absorb most of the effects of weather events on inequality.

Agricultural productivity ($AgriculturalProductivity_{it}$) is computed as an index using data of crop yield and livestock yield with the aid of principal component analysis. An alternative measure is the net agricultural production value computed by the Food and Agricultural Organisation (FAO). We expect agricultural productivity to serve as a mediator through which weather events and the types may impact inequality. Thus, weather events such as floods and droughts could cause crop failure and affect the already marginalised.

A vector is introduced in all the models to represent our controls (X_{it}) that affects inequality. These include real GDP per capita and its square term, democracy, trade openness, resource rent, foreign direct investment, age dependency ratio, population growth rate, school enrolment rate and gross capital formation.

Real gross domestic product (GDP) per capita is measured by taking the natural log of constant GDP per capita. Also, we introduce the square of real GDP per capita. It is expected that real GDP per capita will increase inequality in the short term and decrease it in the long term.

School enrolment is measured by the gross secondary school enrolment rate. As a measure of human capital development, we expect a higher enrolment rate to decrease income inequality in Africa all things being equal. We also expect a positive relationship between population growth rate and inequality.

Trade openness is measured as the sum of total export and total imports scaled by GDP. We expect a negative relationship with inequality as trade liberalisation opens more opportunities for employment of low skilled and low-income earners. Similarly, foreign direct investment (FDI) is measured as the net inflow of foreign direct investments as a ratio of GDP. We also expect a negative relationship with inequality.

Natural resource rents depict the extent to which a country relies on natural resources for development and we proxy natural resource rents as a percentage of GDP. It is our expectation that these resources will reduce income inequality when applied well, all things being equal. Similarly, capital formation as a percentage of GDP proxies the usage of physical capital in production. This is expected to generate more jobs and higher earnings and hence the potential to reduce income inequality.

Age dependency ratio is measured as the sum of the proportion of the young age population (0–15 years) and the old age population (65 years and above) to the working-age population (16–64 years). We expect a higher dependency ratio to translate to a low income per capita and hence a higher income inequality.

Finally, democracy is proxied by the polity2 index and it ranges from –10 to 10 with higher values indicating a high level of democracy in a country while lower values indicate autocracy. We expect democracy to reduce inequality as there is a guaranteed fair share of the national cake.

Finally, U_i, U_t and ε_{it} represent the country fixed effects, time fixed effects and the idiosyncratic error term respectively.

3.2 Sources of data and scope of the study

The data used in this study is panel data and it includes 52 countries in Africa over the period 1990–2017. The income inequality data is gleaned from the Standardized World Income Inequality Database (SWIID) developed by Solt (2018) at the United Nations University World Institute for Development Economics Research (UNU-WIDER). Data from SWIID is more preferable as it collates data with comparable figures across various countries over a relatively long period of time. Data on weather event is sourced from the Emergency Events Database (EM-DAT) maintained by the Center for Research on the Epidemiology of Disasters (CRED) at the School of Public Health at the University of Louvain, Brussels, Belgium. This data is sourced mainly from the United Nations, non-governmental organisations and governmental agencies, research institutes, insurance companies and press agencies. Data on institution is from Kaufmann et al. (2011) while that of adaptation index is from Notre Dame Global Adaptation Index. The components of agricultural productivity and net agricultural production index are sourced from the Food and Agricultural Organisation (FAO). Data on democracy (polity 2) is taken from Marshall's Polity IV Project. The other variables including per capita GDP, FDI, age dependency ratio, gross capita formation, resource rent, trade openness, school enrollment and population growth are all taken from the World Bank World Development Indicators (WDI).

3.3 Estimation technique

In this study, we opt for the two-step difference generalised method of moments (GMM) estimation approach, the fixed effects and the quantile regression technique. The use of GMM is justified by four main motives following recent GMM-centred literature (Kunawotor et al., 2020; Asongu et al., 2019; Tchamyou et al., 2019; Fosu and Abass, 2019):

1. The number of cross sections (N) outweighs the time series (T). While the countries are 52, the time is 28 years
2. A panel dataset is used and GMM as the estimation strategy accounts for differences across countries in the estimation process.
3. GMM also addresses endogeneity issues in two main ways; first, it accounts for unobserved heterogeneity using time-invariant omitted variables. Secondly, it produces internal instruments to account for reverse causality. Reverse causality exist as environmental degradation activities that lead to weather events can be caused by low income groups who usually depend on the environment for survival. This means that income inequality can cause weather events and vice versa.
4. Some empirical studies have identified inequality as persistent and hence it depends on its previous years' level (see Asongu et al., 2020; Shimeles and Nabassaga, 2018; Anyanwu et al., 2016; Cevik and Correa-Caro, 2015).

Our estimation technique is robust to several checks including the Hansen test and the Arellano–Bond test for autocorrelation. All these tests proved satisfactorily. The bootstrap simultaneous quantile regression estimation technique is also used to determine if the impacts of weather events on income inequality vary at different distributions of income inequality. The quantile regression detects and controls for outliers. It also ensures the consistency and reliability of the results. Its usage is consistent with recent development literature (see Altunbas and Thornton, 2019; Asongu and Nwachukwu, 2016; Asongu, 2014). Also, the fixed effects model is used to test for robustness and also to control for country fixed effects.

4 Results

4.1 Descriptive statistics, frequency distributions and correlation matrix

The summary statistics in Table 1 shows the various distributions of the variables used in the study. Income inequality measured by market Gini has a mean score of 48.254. Income inequality generally appears quite high in the African continent relative to other continents. In terms of the regional distributions in Africa, inequality is much higher in Southern Africa (59.0659), than West Africa (46.03594), East Africa (45.38987) and the least being Northern Africa (42.49917). Weather events have a 93% probability of occurring within a year in an African country. We further tabulate the frequency of occurrence of weather events in Africa in order to get a detailed and perhaps a more meaningful interpretation of the results as shown in Table 2. Out of a total of 1,456 outcomes, weather events have occurred 53 percent of the time for at least once in a year. Out of these occurrences, weather events have occurred 82% of the time for at least once or twice in a year and the remaining 18% have occurred between three to nine times.

In terms of weather events types, flood and drought have 58% and 21% probability of occurring in a year in Africa. Since floods have been more frequent than the other types of weather events, its distribution just like weather events is shown in Table 2. The mean of institutions (–.628) shows that institutions are generally weak in Africa. The same applies to adaptive capacity which has a paltry mean of 37 out of 100. Most African countries are also at the budding stage of democracy as shown by the mean of 0.616. There is generally no concern for multicollinearity in the models as shown by the matrix of correlations in Table 3 and also evident in the variance inflation factor (VIF) presented in Appendix 1 as none of the VIFs exceeds 10.

Table 1 Descriptive statistics

Variable	*Obs*	*Mean*	*Std. dev.*	*Min*	*Max*
Inequality – Market Gini	986	48.254	7.921	33.7	70.7
Weather Events	1,456	.931	1.229	0	9
Flood	1,456	.581	.913	0	7
Drought	1,456	.205	.419	0	2
Agricultural Productivity	1,122	.026	1.778	–2.072	9.341
Trade openness	1,251	.693	.35	.191	3.762
Resource rent	1,423	12.263	12.336	0	84.24
Polity2	1,345	.616	5.658	–10	10
Adaptive capacity	1,173	37.237	6.358	25.238	55.918
Institutions	988	–.628	.588	–2.1	.88
Dependency ratio	1,450	84.509	15.633	41.293	112.849
FDI	1,388	4.036	9.132	–8.589	161.824
Per capita GDP	1,390	2,211.006	2,926.692	164.337	20,512.941
Gross capital formation	1,293	21.575	9.888	–2.424	85.101
Population growth rate	1,450	2.379	1.085	–6.766	8.118
Secondary school enrolment	862	41.225	25.644	5.221	115.957

Table 2 Weather events tabulation from 1990–2017

Weather events			*Flood*		
Variable count	*Frequency*	*Percent*	*Variable count*	*Frequency*	*Percent*
0	689	47.32	0	889	61.10
1	435	29.88	1	378	25.98
2	191	13.12	2	131	9.00
3	76	5.22	3	37	2.47
4	36	2.47	4	14	0.96
5	18	1.24	5	1	0.07
6	5	0.34	6	5	0.34
7	2	0.14	7	1	0.07
8	3	0.21	8	--	--
9	1	0.07	9	--	--
Total	1,456	100	Total	1,456	100

Source: Authors construct (2020) from EM-DAT data

4.2 Empirical results of the effects of weather events and flood on income inequality

The results of the GMM estimates in Table 4 show that there is a non-monotonic U-shape relationship between weather events and income inequality. Thus, lower counts of weather events cause a reduction in income inequality while further occurrence within the same fiscal year causes an increase in income inequality. This is shown in models 1 and 2. In model 1, the linear form of weather events is negative and statistically significant. However, with the introduction of the square of weather events in model 2 along with its linear term, the linear term maintains the negative sign and also remains statistically significant while the squared term produces a positive and statistically significant nexus with income inequality. This presupposes that weather events have a non-monotonic U-shaped effect on income inequality. Thus, a higher frequency of weather events beyond a certain threshold actually causes income inequality to increase. The findings also reveal that the turning point for this U-shape effect occurs at the sixth count of the occurrence of weather events within a fiscal year in Africa. The turning point is computed as $5.911 = -(-0.0344)/2 \times (0.00291)$. This U-shape effect corroborates the recent finding of temperature change effects on inequality in South Africa by Dasgupta et al. (2020). In furtherance of the above and more intriguingly, the result of the bootstrap quantile regression technique in Table 5 clearly shows that the occurrence of weather events actually increases income inequality. The income inequality-increasing effect of weather events occurs at all levels of the income inequality distribution including the lower and mid-quantiles (i.e., 10th, 25th, 50th, and 75th percent quantiles) except for the upper tail of the distribution (90th percent quantile). It should be noted, however, that only the 25th percent quantile and 50th percent quantile appear statistically significant and these are shown in models 6 and 7, respectively. The 10th quantile and 75th quantile although have positive signs appear statistically insignificant in models 5 and 8. Thus, weather events affect the poor more disproportionately at lower and mid-levels of the income distribution. Also, the result using both GMM and the fixed effects model and controlling for country fixed effects is presented in Appendix 2 in models 18 and 19, respectively.

The probable intuition and implication of weather events causing an increase in income inequality is that a greater reliance on weather-dependent forms of production will cause households to experience larger income shocks upon happenings of weather events as alluded to by Burgess et al. (2014) and UNDESA (2020). Thus, weather events may widen income inequality because the economically poor and the marginalised are more disproportionately affected by weather events making them poorer and this tends to widen the income inequality gap. This may be because they depend more on climate-sensitive activities such as agriculture for their source of livelihoods and as such a little disturbance may tend to be a destabiliser. Another plausible explanation according to Ludwig et al. (2007) is that richer households can afford to buy insurance which minimises or mitigates the impact of weather events on their incomes through compensation packages, poorer households may not be able to afford such insurance packages further widening the income inequality gap. Also, the poor are mostly found in semi-arid regions which are more prone to weather events such as floods and droughts due to the erratic climate nature of such environments which makes weather events almost unpredictable.

Interestingly, when we attempt to find which of these weather event types have a statistically significant impact on income inequality, we found the occurrence of floods to follow the same pattern as weather events. The findings reveal that the incidence of flood also has a non-monotonic effect on income inequality and this is shown in model 4. The form also takes a U-shape and the turning point occurs at the third occurrence of flood within a fiscal year. This is computed as $3.155 = -(-0.0424)/2 \times (0.00672)$. Intuitively, poor households and those who live in flood-prone areas and occupy houses made of flimsy materials with poor drainage systems are more susceptible than those who live in sturdy houses and this may further widen the income inequality gap. We did not find the other disaster types such as drought, to have any significant effect on income inequality (results not shown here). This may probably be so because floods have occurred more frequently in Africa than the other types of weather events types as shown in the summary statistics.

Consistent with our usage of the GMM model, the past level of income inequality is positive and statistically significant in all the models (models 1–4). This justifies the persistent nature of income inequality and hence higher income inequality levels in the past may drag current levels from falling.

School enrolment as a measure of skill premium and human capital development has a negative and statistically significant effect on inequality in models 1–3. This means that the diffusion of human capital among the populace in Africa may empower households economically and this may help reduce the income inequality gap. That is, as more people become enlightened through our educational systems, their skill set is enhanced and a greater propensity to acquire a job or reduce the earnings gap between the highly-skilled and unskilled. This finding is in line with the findings of Anyanwu (2016) for Southern African countries, Anyanwu et al. (2016) for West Africa, Dincer and Gunalp (2012) for the USA.

Table 3 Matrix of correlations

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*
(1) Inequality_Gini	1.000										
(2) Weather events	0.008	1.000									
(3) Real GDP	0.186	–0.160	1.000								
(4) Democracy-polity2	0.313	0.180	–0.009	1.000							
(5) Trade openness	0.076	–0.141	0.357	0.101	1.000						
(6) FDI	–0.046	–0.060	0.040	0.019	0.300	1.000					
(7) Age dependency	–0.086	0.102	–0.627	–0.148	–0.356	–0.033	1.000				
(8) Population growth	–0.168	0.103	–0.172	–0.032	–0.202	0.094	0.450	1.000			
(9) School enrol7lment	0.205	–0.094	0.687	0.245	0.291	0.024	–0.812	–0.501	1.000		
(10) Gross capital	–0.002	–0.009	0.273	0.084	0.343	0.292	–0.276	–0.006	0.176	1.000	
(11) Resource rents	–0.288	0.004	0.169	–0.216	0.168	0.219	0.098	0.269	–0.208	0.076	1.000

Table 4 The effects of weather events and flood on income inequality – GMM

Variables	*Model 1*	*Model 2*	*Model 3*	*Model 4*
Lag of income inequality	0.859***	0.893***	0.856***	0.898***
	(0.039)	(0.034)	(0.044)	(0.037)
Weather events	*–0.025***	*–0.034***	--	--
	(0.010)	(0.014)		
Weather events – squared	--	*0.003**	--	--
		(0.002)		
Flood	--	--	*–0.026***	*–0.042****
			(0.013)	(0.014)
Flood – squared	--	--	--	*0.007***
				(0.002)
GDP per capita	0.063	–0.357	0.035	–0.510
	(1.335)	(1.137)	(1.371)	(1.193)
GDP per capita^2	0.022	0.048	0.026	0.059
	(0.087)	(0.075)	(0.088)	(0.079)
Democracy – polity2	–0.019*	–0.012	–0.020*	–0.011
	(0.009)	(0.007)	(0.011)	(0.007)
Trade openness	–0.115	–0.074	–0.109	–0.055
	(0.218)	(0.173)	(0.227)	(0.174)
FDI	0.007	0.006	0.007	0.006
	(0.006)	(0.003)	(0.006)	(0.004)
Dependency ratio	–0.016**	–0.009*	–0.016**	–0.008
	(0.007)	(0.005)	(0.008)	(0.006)
Population	0.037	0.025	0.039	0.024
	(0.038)	(0.025)	(0.039)	(0.024)
Gross school enrolment	–0.015**	–0.009*	–0.015**	–0.009
	(0.005)	(0.005)	(0.006)	(0.005)
Capital formation	–0.008**	–0.009***	–0.008**	–0.009***
	(0.003)	(0.002)	(0.003)	(0.002)
Resource rent	–0.016***	–0.014***	–0.017***	–0.014***
	(0.005)	(0.005)	(0.006)	(0.005)
Observations	472	472	472	472
Number of countries	40	40	40	40
Number of instruments	14	25	14	25
Wald test of joint sign (P-value)	0.000	0.000	0.000	0.000
AR(1): (Pr > z)	(0.001)	(0.003)	(0.005)	(0.005)
AR(2): (Pr > z)	(0.978)	(0.928)	(0.925)	(0.874)
Sargan test of overid: (Prob > chi2)	(0.546)	(0.746)	(0.516)	(0.668)
Hansen test of overid: (Prob > chi2)	(0.517)	(0.729)	(0.485)	(0.721)

Notes: Standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

Table 5 The effects of weather events on income inequality – quantile regression

Variables	*Model 5*	*Model 6*	*Model 7*	*Model 8*	*Model 9*
Quantiles	*0.10*	*0.25*	*0.50*	*0.75*	*0.90*
Weather event	*0.114*	*0.409***	*0.293**	*0.083*	*–0.013*
	(0.161)	(0.196)	(0.154)	(0.185)	(0.144)
Real GDP per capita	14.35***	14.51***	7.228	–54.27***	–49.83***
	(3.941)	(3.857)	(10.52)	(7.008)	(11.74)
Real GDP per capita – squared	–1.021***	–1.077***	–0.472	4.143***	3.700***
	(0.267)	(0.256)	(0.822)	(0.466)	(0.847)
Democracy – polity2	–0.072*	–0.085**	0.079	0.232***	0.310***
	(0.037)	(0.037)	(0.091)	(0.070)	(0.074)
Trade openness	0.934	3.538***	2.149	–2.031*	0.901
	(1.085)	(1.184)	(1.844)	(1.097)	(1.976)
FDI	–0.006	–0.011	0.072	0.088**	–0.038
	(0.054)	(0.063)	(0.052)	(0.045)	(0.054)
Dependency ratio	0.036	0.116*	0.285***	0.280***	–0.020
	(0.046)	(0.063)	(0.043)	(0.054)	(0.081)
Population growth	–0.098	–0.112	–1.661*	–1.628*	–0.726**
	(0.383)	(0.557)	(1.006)	(0.860)	(0.328)
Secondary school enrolment	0.006	0.055*	0.119***	0.043	–0.065**
	(0.022)	(0.033)	(0.024)	(0.031)	(0.026)
Capital formation	–0.101***	–0.043	–0.026	–0.046	–0.012
	(0.035)	(0.047)	(0.044)	(0.041)	(0.038)
Resource rent	–0.163***	–0.175***	–0.185***	–0.158***	–0.207***
	(0.038)	(0.041)	(0.051)	(0.033)	(0.032)
Observations	501	501	501	501	501
Pseudo R^2	0.225	0.169	0.145	0.297	0.467

Notes: Standard errors in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

The study also finds natural resource rent to be highly significant with a negative effect on income inequality in all the models (models 1–4). African countries can leverage on the abundance and dependence on natural resources to help poor households catch up on the income and wealth ladder lending support to the findings of Anyanwu (2016) but contradicts that of Anyanwu et al. (2016).

Similarly, we find gross capital formation which proxies for domestic capital investment to have a negative and significant effect on inequality in Africa which confirms the findings of Kunawotor et al. (2020) in Africa and Lee et al. (2013) in Korea but contradicts that of Anyanwu (2016) and Anyanwu et al. (2016) in South and West Africa respectively. This finding is in line with our a priori expectations and the implication is that, as more domestic investments are made, it creates more employment and earnings opportunities for the less privileged hence reducing the income inequality gap. The Age dependency ratio contrary to our expectation rather appears to reduce inequality. Finally, among the set of controls, we find democracy to have a negative and statistically significant effect on income inequality. Countries that tend to practice democracy may see their inequality gap narrowing than those that lean towards autocracy probably because of equity and fair distribution. All the other variables including per capita GDP, FDI, population and trade openness remain statistically insignificant.

4.3 Results of the moderating role of institutions and its sub-components on income inequality

The findings show that the interactive effect of weather events with institutions is statistically insignificant as shown in model 10 in Table 6. However, a closer look at the sub-components that make up the institution index reveals that control of corruption, political stability and rule of law independently help significantly moderate the relationship between weather events and income inequality. This is so as we find the interactive terms to be negative in all three of these instances as shown in Models 11, 12 and 13, respectively. The implication is that countries with relatively stronger institutions in the form of the ability to control corruption, stable political climate and strict adherence to the rule of law endure less severe impacts of the occurrence of weather events. However, there appears to be no significant effect for the other three components of institutions including government effectiveness, voice and accountability, and regulatory quality (results not shown here). Also, there is no statistically significant moderating effect of adaptive capacity on income inequality at the occurrence of weather events even though we expect countries that have put in place strong adaptive mechanisms against climate events to experience less of these impacts (results not shown here).

Table 6 The moderating role of institutions on inequality – net/disposable Gini

Variables	*Model 10*	*Model 11*	*Model 12*	*Model 13*
Lag of inequality	0.855***	0.859***	0.853***	0.849***
	(0.033)	(0.042)	(0.035)	(0.042)
Weather event	–0.000	–0.000	–0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Institutions	0.000	--	--	--
	(0.002)			
Weather event – institutions	*–0.000*	--	--	--
	(0.000)			
Control of corruption	--	0.000	--	--
		(0.001)		
Weather Event – control of corruption	--	*–0.000**	--	--
		(0.000)		
Political stability	--	--	0.000	--
			(0.001)	

Notes: Standard errors in parentheses.
***p < 0.01, **p < 0.05, *p <0.1.

Table 6 The moderating role of institutions on inequality – net/disposable Gini (continued)

Variables	*Model 10*	*Model 11*	*Model 12*	*Model 13*
Weather event – political stability	--	--	*–0.000***	--
			(0.000)	
Rule of law	--	--	--	0.001
				(0.001)
Weather event – rule of law	--	--	--	*–0.001***
				(0.000)
Population growth	0.000	0.001	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.001)
School enrolment	–0.000*	–0.000	–0.000*	–0.000*
	(0.000)	(0.000)	(0.000)	(0.000)
Gross capital formation	–0.000***	–0.000***	–0.000***	–0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Natural resource rent	–0.000***	–0.000***	–0.000***	–0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Observations	472	472	472	472
Number of countries	40	40	40	40
Number of instruments	18	18	18	18
Wald test of joint sign (P-value)	0.000	0.000	0.000	0.000
AR(1): (Pr > z)	0.101	0.056	0.058	0.036
AR(2): (Pr > z)	0.301	0.350	0.318	0.303
Sargan test of overid: (Prob > chi2)	0.473	0.395	0.623	0.682
Hansen test of overid: (Prob > chi2)	0.565	0.404	0.669	0.683

Notes: Standard errors in parentheses.
***p < 0.01, **p < 0.05, *p <0.1.

4.4 Empirical result of the mediating role of agricultural productivity

Weather events may not only affect income inequality directly but may also do so through its effects on agricultural productivity. In this regard, we attempt to find if agricultural productivity may serve as a conduit for weather events to impact income inequality. We did this by estimating the effect of weather events on income inequality without agricultural productivity and then afterwards we introduce agricultural productivity in the same model with weather events. Weather events appears statistically significant as shown in model 14 in Table 7 but we did not find any significant mediating role of agricultural productivity as it appears statistically insignificant in model 15 when introduced in addition to weather events. We did the same for flood and drought (result for drought not presented here) in model 17 and find a similar insignificant outcome for agricultural productivity even though flood by itself has a significant impact on income inequality in model 16. These outcomes are also not significant when we estimate for Sub-Saharan Africa, West Africa, East Africa and Southern Africa countries independently. These findings imply that weather events and its types such as flood and drought may have a negative impact on agricultural productivity by reducing agricultural yield as experienced in some parts of Africa and this may affect income inequality but these impacts do not appear statistically significant in our study.

Table 7 The indirect effects of weather events and flood on inequality through agricultural productivity

Variables	*Model 14*	*Model 15*	*Model 16*	*Model 17*
Lag of income inequality	0.859***	0.864***	0.856***	0.858***
	(0.039)	(0.056)	(0.044)	(0.064)
Weather event	–0.025**	–0.021*	--	--
	(0.010)	(0.012)		
Agricultural productivity	--	0.007	--	0.008
		(0.048)		(0.050)
Flood	--	--	–0.026**	–0.023
			(0.012)	(0.014)
GDP per capita	0.063	0.069	0.035	0.082
	(1.335)	(1.795)	(1.371)	(1.875)
GDP per capita^2	0.022	0.020	0.026	0.022
	(0.087)	(0.124)	(0.088)	(0.128)
Polity2	–0.019*	–0.017	–0.020*	–0.018
	(0.009)	(0.011)	(0.011)	(0.012)
Trade openness	–0.115	–0.067	–0.109	–0.060
	(0.218)	(0.227)	(0.227)	(0.238)
FDI	0.007	0.008	0.007	0.008
	(0.006)	(0.006)	(0.006)	(0.007)
Dependency ratio	–0.016**	–0.017	–0.016**	–0.017
	(0.007)	(0.010)	(0.008)	(0.011)
Population growth	0.037	0.037	0.039	0.039
	(0.038)	(0.038)	(0.039)	(0.041)
School enrolment	–0.015**	–0.016**	–0.015**	–0.017**
	(0.006)	(0.006)	(0.006)	(0.007)
Capital formation	–0.008**	–0.009**	–0.008**	–0.009**
	(0.003)	(0.003)	(0.003)	(0.004)
Resources rent	–0.016***	–0.016**	–0.017***	–0.017**
	(0.005)	(0.006)	(0.006)	(0.007)
Observations	472	436	472	436
Number of countries	40	38	40	38
Number of instruments	14	15	14	15

Notes: Standard errors in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 7 The indirect effects of weather events and flood on inequality through agricultural productivity (continued)

Variables	*Model 14*	*Model 15*	*Model 16*	*Model 17*
Wald test of joint sign (P-value)	0.000	0.000	0.000	0.000
Arellano-Bond test for AR(1): (Pr > z)	(0.001)	(0.004)	(0.005)	(0.012)
Arellano-Bond test for AR(2): (Pr > z)	(0.978)	(0.877)	(0.925)	(0.821)
Sargan test of overid: (Prob > chi2)	(0.546)	(0.475)	(0.516)	(0.477)
Hansen test of overid: (Prob > chi2)	(0.517)	(0.413)	(0.485)	(0.415)

Notes: Standard errors in parentheses.
***p < 0.01, **p < 0.05, *p < 0.1.

5 Conclusions and recommendations

Climate change and inequality remain a critical focus of world leaders as they are enshrined in the sustainable development goals. Weather events are the trickle-down effects of climate change as they appear much patterned in Africa due to their frequent occurrences and the damning consequences they come with, especially by affecting the marginalised poor and disproportionately widening the economic inequality gap. Our study empirically examined the effects of weather events on income inequality and found a non-monotonic U-shape effect using GMM while the results of the quantile regression clearly show that weather events increase income inequality at lower and mid quantiles. We also found a very similar effect for weather events type, flood. In addition, we found institutional quality components such as political stability and absence of violence, control of corruption and rule of law to significantly moderate the relationship between weather events and income inequality. Finally, we do not find a moderating effect of adaptive capacity, neither did we find any mediating effect of agricultural productivity on income inequality.

The study recommends that critical attention should be paid to climate change mitigation as the impending future impacts of climate change in the form of weather events appear gloomy for major economic and social indicators such as income inequality. African countries should also build stronger institutions and put in place systems for adaptation against climate change impacts as institutions and adaptive capacities remain very weak.

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Appendix 1

Table A1 Variance inflation factor (VIF)

	VIF	*1/VIF*
School enrolment	4.882	.205
Age dependency ratio	4.617	.217
Real GDP per capita	2.702	.37
Population growth	1.98	.505
Trade openness	1.577	.634
FDI	1.459	.685
Gross capital formation	1.382	.724
Total natural resource rent	1.242	.805
Democracy	1.212	.825
Weather events	1.118	.894
Mean VIF	2.217	.

Appendix 2

Table A2 Weather events and inequality with country fixed effects

Variables	*Model 18*	*Model 19*
	Fixed effect	*GMM*
Lag of inequality		0.861***
		(0.0406)
Weather events	–0.141	–0.0339*
	(0.0913)	(0.0168)
Weather events – squared	0.00465	0.00180
	(0.0160)	(0.00229)
Real GDP per capita	3.778	0.0734
	(10.16)	(1.421)
Real GDP per capita^2	–0.0918	0.0212
	(0.679)	(0.0931)
Democracy – polity2	–0.115**	–0.0193*
	(0.0428)	(0.0103)
Trade openness	–0.0333	–0.116
	(1.233)	(0.228)
FDI	0.0103	0.00660
	(0.0245)	(0.00602)
Age dependency ratio	–0.116**	–0.0158*
	(0.0476)	(0.00782)
Population growth	0.408	0.0365
	(0.252)	(0.0400)
School enrolment	–0.0799***	–0.0150**
	(0.0249)	(0.00623)
Gross capital formation	–0.0243*	–0.00798**
	(0.0132)	(0.00340)
Natural resource rent	–0.0945***	–0.0160***
	(0.0283)	(0.00547)
Country effect	Yes	Yes
Observations	501	472
R-squared	0.289	
Number of countries	41	40

Notes: Robust standard errors in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.