Climate Variability and Urbanization in sub-Saharan Africa: Mitigating the Effects on Economic Growth

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Abstract

This study sought to analyze the interactions between climate variability, urbanization, and economic growth in Sub-Saharan Africa. Specifically, it analyzed the extent to which climate variability could maintain the interaction between economic growth and urbanization a virtuous one. An empirical strategy combining a literature review, a descriptive analysis, and a PSTR model, was designed to achieve the specified objectives. More specifically, the PSTR model was estimated using a panel data of 32 Sub-Saharan African countries over the period 1990-2018 to obtain some interesting findings. The literature review pointed to several research avenues, of which: i) multivariate analyses of economic growth, urbanization, and climate variability; (ii) measurement challenges with urbanization and climate change; and (iii) modelling approaches. Quantitative results indicated that in Sub-Saharan Africa, urbanization only has a positive effect on economic growth if the temperature variability is below the threshold of - 0.4501, while the average temperature variability is around 0.5470.

Keywords: *Climate variability, Urbanization, Economic growth, PSTR model, Threshold.*

JEL classification: *C33, J43, O47, O55, P25, Q54, R23.*

1. Introduction

The displacement of populations from rural to urban areas (rural exodus) has always been considered as a windfall for various economies that benefit from the implied factors of production, in this case labour, in significant quantities and inexpensively. Labour increases the overall productivity of the economy, resulting from the process of structural change. That is especially the case in the reallocation of resources between regions and sectors, of which one of the main dimensions is the transfer of the workforce from agriculture to the industrial sector (Lewis, 1954). The structure of the economy due to rural exodus, for a long time, has had a positive effect on the rate of urban growth, which represents a factor of wealth creation for the economy (Todaro and Haris, 1970).

The strong correlation between urbanization and economic growth is fostered by a good deal of statistics that are observed in both developed and developing countries, and in economic zones (World Bank, 2016). Examples are the United States, China, and some Latin American countries. For instance, the urbanization rate in the United States increased from 28% in 1880 to 81% in 2006, a change of 53% in 126 years. Over that period, GDP per capita increased from 3,380 to 37,832 current US dollars, an increase of 34,452 current US dollars over the same period. Similarly, China saw its urban growth rate increase from 16% in 1960 to 39% in 2004, say an average increase of 51% in 44 years. Over that period, China's GDP per capita rose from 448 to 7,593.5 current US dollars. In Latin American countries, with an urbanization rate ranging from 20% to 40%, the GDP per capita was between 10,000 and 20,000 current US dollars. These observations also hold in Europe and Central Asia. Corresponding to an average urban growth rate of 50%, GDP per capita in Central Europe and Asia is 20,000 current US dollars, having been estimated to average 42,500 current US dollars when its urbanization rate ranges between 60% and 95%.

Following Mayaki et al. (2017), Africa is urbanizing at a historically rapid pace coupled with an unprecedented demographic boom. The population living in cities has doubled since 1995 to reach 472 million in 2015. By 2050, about 56% of Africans are expected to live in cities. These decision makers, quoting the African Economic Outlook 2016, further indicated that Africa's urbanization holds immense potential for accelerating structural transformation that drives economic growth. This is the case as the sustained and growing demand in African cities translate into tremendous investment in urban infrastructure to be met by 2050. Indeed, higher agricultural productivity, industrialization, services stimulated by a growing middle class, and foreign direct investment in urban corridors, all create real ways to generate economic growth.

Unfortunately, while urban concentration has been beneficial for the economic growth of high-income countries, such effects do not hold for developing countries according to Bala (2009). This view contrasts with authors such as Bertinelli and Strobl (2007), Henderson (2003), particularly those who reported a particularly important effect on the low levels of economic development. Following Frick and Pose (2018), urban concentration reveals totally disconnected from the economic performance of the considered country, in cases of low levels of economic development, especially in Sub-Saharan Africa. It seems that with a record urbanization rate of 40% achieved in 2016, the GDP per capita of Sub-Saharan Africa stagnates at around 3,750 current US dollars. Thus, it appears, without extending to all African cities, that the "drive mechanism" linking urbanization and economic development has, until now, worked less well in Africa than in the other major regions of the world.

African cities might be growing due to the massive departure from rural areas, coupled with the growing devastating effect of climate change. In effect, agricultural and pastoral activities that are mainly dependent on rainwater resources are growing, vulnerable to changes in rainfall patterns. Unable to adapt to the risks of climate change and to manage climate variability or develop a good capacity of adaptation, farmers in rural areas will adopt new behaviours to ensure their development (survival). A common response is the migration from rural areas (mainly agricultural) to urban areas (mainly industrial) in search of well-being.

Regrettably, however, cities in developing countries, mainly in Sub-Saharan Africa, have grown to become drivers of climate change, while being confronted by urbanization challenges, natural hazards, and their interactions. Indeed, according to the AfDB et al. (2016), IPCC (2014), Amraoui et al. (2011), Africa is the most vulnerable continent to climate variability and change, a condition that is exacerbated by the interaction between "multiple constraints" including widespread poverty and a weak capacity of adaptation. In effect, over half of Africa's natural disasters are related to hydrological hazards, such as droughts, floods, and landslides (CRED, 2015). The temperature variability between 1970 and 2004 was estimated between 0.2°C and 2°C for the African continent (Amraoui et al., 2011). Compared with the period 1980-1999, the excess of warming could reach values between 0.5°C and 1.5°C for the decade 2020, between 1.5°C and 6°C for the decade 2090 (GIEC, 2007).

Chapman et al. (2017) contend that urbanization reduces green space, and increases impervious surfaces, which in turn reduce the amount of evapotranspiration, hence entertain a good deal of Urban Heat Island (UHI). Urban Heats (UHs) are also nurtured by heat released from human activities, building climate control and weather conditions. Still Chapman et al. (2017), citing authors such as Pielke (2011), indicate that the UHI is the clearest example of how land use and land cover change affects the local and regional climate. Therefore, examining climate change without considering urban land use patterns excludes the interaction between climate change and the

UHI, and could result in under-estimating future increases in urban temperatures, both mean and extreme values.

Nevertheless, migratory movements are increasing the urban populations, hence creating additional needs to which the urban milieu was not prepared for. Thus, migration can have negative impacts on the environment, highlighting the existence of a vicious circle. In short, environmental deterioration encourages migration, which in turn contributes to impairing the environment in (urban) destinations. Furthermore, the rampant urbanization in Africa poses enormous challenges to the public authorities: sanitation, water and electricity supply, basic equipment (school, hospitals, police, etc), unemployment, insecurity, slums development, etc.

In short, climate variability, among others, is threatening the economies of the predominantly agricultural economies in Sub-Saharan Africa, hence having raised the question to know how the interactions between climate variability and urbanization can contribute to mitigate the combined effects on economic growth in Sub-Saharan Africa. The general objective was to analyze the effects of urbanization on economic growth in a context of climate variability. The specific objectives were to: (i) evaluate existing research on the relation between climate variability, urbanization, and economic growth; (ii) examine research avenues along with possible empirical strategies; and (iii) determine, in an innovative framework, the effects of urbanization on economic growth in a context of climate change in Sub-Saharan Africa.

The second section presents the status quo on the interactions between climate variability, urbanization, and economic growth, whereas section 3 discusses some research directions on the prevailing interactions. Section 4 presents some stylized facts on the interactions between the variables based on a panel of 32 Sub-Saharan African countries over the period 1999-2018. In section 5, the evaluation of a PSTR model contributes to the determination of the climate variability thresholds that secure a virtuous relationship between economic growth and urbanization in Sub-Saharan Africa. Section 6 concludes the study with some recommendations both on research and policy.

2. Interactions between climate variability, urbanization, and economic growth: A status quo

Examining the nexus between climate change, urbanization and economic growth requires a review of literature on key references, from the conceptual,theoretical and analytical frameworks.

A theoretical appraisal

Historical lessons have shown that urbanization, considered as a key element in a country's development process, has numerous causes (Bairoch, 1988). The term "urbanization", as defined by the United Nations, refers to a complex dynamism, which can result either from a change at a certain time; for example a movement of the rural population to urban areas, or from an increase in the urban population, faster than the increase in the rural population (Nassori, 2017).

In its development process, urbanization affects both economic growth and changes in the environmental quality. To this end, several theoretical and sometimes contradictory approaches have been presented to analyze the interaction between these three variables. The analysis of the relationship between economic growth and urbanization derives mainly from the works of Lewis (1954), Todaro and Harris (1970) and later from those of Cahuc and Célimène (1993).

Although developed to describe the process of economic development in developing countries, the model of the dual economy proposed by Lewis (1954) and formalized by Fei and Ranis (1961) has long dominated the literature on urbanization. Indeed, Lewis (1954) formulated a theory stating that development of the industrial sector is a means for developing countries to reduce unemployment resulting from the excess labour in the rural sector. Based on the dual nature of the economies of developing countries, the author contends that labour remains plentiful in the agricultural sector, mainly due to the relative scarcity of land. A rural exodus (an increasing factor of urbanization) can then occur without affecting the agricultural production capacity of the rural sector.

Also, Lewis' development builds on productivity gains in the agricultural sector, which leaves unused a good deal of labour to be made available to the urban industrial sector to contribute to industrial growth. The Lewis's model specifically predicts that urbanization has a positive effect on the primary sector, thus helping to reduce the disguised unemployment that prevails there, and to equalize the salary differences between sectors. In short, the individual motive for populations' moving to urban areas is the salary differential between the traditional and the modern sectors.

Todoro (1969) rather assumes that individuals move to urban centres because they hope to earn more than rural people and that the likelihood of finding employment is directly related to the urban employment rate. In other words, a differential increase in urban-rural income can lead to an increase in the urban population even in the case of high urban unemployment.

Following Lewis (1954), and Todaro and Harris (1970), Cahuc and Célimène (1993) conclude that the antagonism between Lewis and Todaro's theories is mainly due to the structural specificities of the different economies, and that their conclusions depend on the returns in the agricultural and industrial sectors. Thus, Cahuc and Célimène (1993) umpired Todaro's theory by postulating that job creation would not only lead to an increase in the rate of urbanization, but also give rise to a spatial expansion of the urban labour market. More specifically, the expansion of the urban labour market, by reducing the marginal costs of transport for labour, would strengthen migration and thus increase unemployment.

For the neoclassical theorists (Kuznets, 1955; Henderson, 2003), economic growth is positively linked to urbanization, both in rich and poor countries. Thus, at the beginning of the development process, one witnesses a polarization of the population. A diffusion is then triggered when development spreads to the rest of the national territory. It should also be noted that the strong wealth creation or the high rate of industrialization has a negative effect on the environment in terms of its degradation.

Beyond these different theoretical approaches that have been developed over time, factors that promote population mobility are not only multiple, but also interdependent. For instance climate change can also lead to health problems or food insecurity, which in turn encourages the displacement of populations from vulnerable areas to secured areas (Piguet, 2010). In such cases, it is probably impossible to identify the "primary" cause of urban increase, given that all the causes do reinforce each other. On those grounds, other theoretical approaches explain the relationship between climate change, urban settlement, and its impact on wealth creation in urban areas.

Although relatively recent, models of the urban space organization are in numerous and varied (Bailly, 1973). According to this author, the term displacement of populations must be understood in its broadest geographical meaning to include, in addition to migrations in the strict sense, the phenomena of movement that cover a wide variety of displacements without a permanent or lasting change of residence. Thus, for demographers, the foundations of urbanization can be expressed quite conveniently by means of a quasi-theoretical representation related to another one, that of the demographic transition, which is known to have strongly influenced the demographic thinking and research (Allen and Sanglier, 1981).

But beyond these contradicting theoretical views highlighting environmental degradation, urbanization and economic growth, what could the empirical work tell us about the interaction between the three phenomena?

Some empirical views

A first group of studies looked at the relationship between urbanization and economic growth, with a good deal of conflicting results. Authors such as Hossain (2011), Zhao and Wang (2015) found a positive relationship between economic growth and urbanization. Indeed, Hossain (2011) looked at the dynamic effect between economic growth, trade opening and urbanization in newly industrialized countries, using panel data for the period 1971-2007. The causality test did not reveal any long-term relationship, whereas a short-term unidirectional link was found between economic growth and trade opening and between urbanization and economic growth. Zhao and Wang (2015), using a VEC model over the period 1980-2012, found that economic growth and urbanization are positively linked. But unlike Hossain (2011), the results of the two authors point to a unidirectional relationship from economic growth to urbanization. According to Zhao and Wang (2015), urbanization is the result of economic growth. Wealth creation is accompanied by the development of the industrial sector, which mobilizes a large mass of labour from the rural world to the urban world. Authors such as Arouri et al. (2014), Nguyen (2018) rather pointed to a non-linear relationship. For Nguyen (2018), specifically, urbanization reaches a threshold beyond which it can hinder economic growth. Such a threshold is estimated to be 67.94%, indicating that when urbanization in Asian countries exceeds the rate of 67.94%, production factors become harmful by creating less wealth.

For many others, such a relationship does not exist (Fay and Opal, 2000; Turok and McGranahan, 2013; Nassori, 2017). More specifically, Fay and Opal (2000) report that most African countries are going through a process of urbanization without economic growth. For these authors, the factors of urbanization in Africa are not those predicted by the theory: that is, those resulting from the development of the industrial sector. Africa’s urbanization style is generally explained by growth in income; ethnic tensions; civil unrest and democracy, income gap, etc. In urban areas, most of these populations are moving to the informal sector that does not contribute to economic growth. As a result, there is a strong "sterile" urban growth in wealth creation at the national level.

The second group of studies looked at the interaction between economic growth and the environment. As in the previous cases, the authors also obtained some conflicting results. While some are testing and confirming the inverted U-shaped relationship highlighted by Grossman and Krueger (1995), others found a U-shaped relationship (Wang et al., 2017). For other authors who have been interested in a causality relationship, they have identified a two-way causality between these two variables (Jebli and Youssef, 2015). For instance, Wang et al. (2017) verified that economic growth and population agglomeration play an important role in environmental degradation. These authors used panel data on 290 cities in China between 2003 and 2012, applied to the IPAT (Human Impact, Population, Affluence and Technology) model. For these cities, GDP per capita shows a significant and negative effect, so is its square. Thus, economic growth and environmental pollution too have a U-shaped relationship.

A third group of studies investigated the relationship between urbanization and the environment. Again, the results were quite diverging. Authors such as Shahbaz et al. (2014) and Barido and Marshall (2014) show a one-way causality ranging from urbanization to environmental degradation. Others, however, found that environmental damage promotes urbanization. Naudé (2008), specifically, indicates that the environment would be the largest and oldest determinant of displacement of people through three channels: 1) the scarcity of water and arable land; 2) conflicts over natural resources; and 3) natural disasters. However, it should be noted that climate change is exacerbating these three factors, pushing populations into urban areas. Some others,Ali et al. (2016) for instance, found no effects. These last authors analyzed the dynamic impact of urbanization, economic growth, energy consumption and trade opening on Nigeria's CO2 emissions. Based on the autoregressive approach to distributed lags (ARDL) over the period 1971-2011, the estimated coefficients show that economic growth has a positive and significant impact on CO2 emissions. Contrary to the conclusion of Shahbaz et al. (2014), whreas the long-term coefficients revealed that urbanization has no significant impact on CO2 emissions in Nigeria.

3. Climate variability, urbanization, and economic growth: Some research directions

The literature review points to the fact that a lot remains to be done on a theoretical ground and on an empirical perspective, in understanding the relationships between urbanization, economic growth, and climate variability in Sub-Saharan Africa. More specifically, based on the observed lack of consensus, it appears interesting to give more research scope to the relationship between climate change, urbanization, and economic growth in Sub-Saharan Africa. Future research could explore: (i) multivariate analyses of economic growth, urbanization, and climate change; (ii) measurement challenges with urbanization and climate change; and (iii) modelling approaches.

Urbanization and economic growth in a context of climate variability

Contrary to theoretical predictions, some authors in the empirical literature show that urbanization does not always lead to economic growth (Fay and Opal, 2000; Turok and McGranahan, 2013; Nassori, 2017), or rather dampens economic growth (Nguyen, 2018). Moreover, the same literature identifies climate change as a cause of urbanization. Under these conditions, a multivariate analysis, simultaneously considering the three variables, would allow a sound understanding of the relationship between economic growth and urbanization.

Future research should go in this direction. In addition, topics related to the implications of this relationship will also need to be explored. In this sub-section, the global framework in which future analyses are to be done, and some underlying topics, are successively presented.

Urbanization and economic growth

Although the relationship between urbanization and economic growth has been widely discussed in the literature, these studies do not explicitly consider the climate context. This could justify the conflicting results of those studies conducted for some of them in a framework that linked only these two variables (Hossain, 2011; Zhao and Wang, 2015; Nguyen, 2018).

According to the Lewis model (1954), and following Todaro and Harris (1970), differences in productivity between the two sectors are at the root of urbanization;

what in turn positively affects economic growth, based on the pull factors' hypothesis. In Sub-Saharan Africa where economies heavily rely on agriculture, this difference in productivity is the result of several factors, including climate change. Thus, the pace of urbanization would no longer be linked exclusively to the search for industrial development. Interrelated factors, including climate change, play a key role in the analysis of the relationship between urbanization and economic growth. Further studies could deepen existing work, especially in avenues opened by authors such as Singh et al. (2014), Arouri et al. (2014), and more recently by Murshed and Saadat (2018).

The current work sought to add to the existing literature by providing, in a macroeconomic framework, another look at the relationship between urbanization and economic growth in a context of climate variability, using a smooth-transition threshold-effect model.

Urbanization and industrial productivity in a context of climate variability

Since Lewis (1954), urbanization has been considered as a factor of industrial growth (Henderson, 2010; Duranton, 2013; Glaeser, 2013; Jedwab and Vollrath, 2015). Indeed, agglomeration economies, induced by urban concentration, should theoretically lead to an increased industrial production. However, in Sub-Saharan Africa, there is a relative disconnection between the rate of urbanization and the rate of industrial (economic) growth. Authors have even highlighted, on a large scale, the negative effect of urbanization on industrial productivity (Cainelli et al., 2014; Sudarshan et al., 2015). Worst in recent years, a tendency to deindustrialization was observed in the presence of a high rate of urbanization (Rodrik, 2015). Urbanization is no longer synonymous with industrialization in some countries (Gollin et al., 2016).

Understanding the disconnection between urbanization and economic growth, to inform policy, should require an analysis of the determinants of urbanization, including climate change, which is a definite driving force. Depending on the nature of the factors (pull factors or attractive factors), one could get divergent results and policy measures. Recall that the virtuous relationship defended by Lewis (1954), and Todaro and Harris (1970) is based on the differences in sector productivity, based on an implicit climate neutrality. Therefore, explicitly accounting for climate change in the relationship between urbanization and industrial productivity could lead to relevant outcomes for Sub-Saharan Africa, whose economies heavily depend on rainy type of agriculture.

Another research avenue, which is in line with the previous one, is an analysis of the total factor productivity. Indeed, external effects induced by urban concentration are determinants of economic growth. However, these external effects can be positive and negative depending on the nature of the factors that are causing urban concentration. Thus, urbanization, caused by climate change, where the city is a refuge rather than an industrial attraction, will not produce the positive external effects expected in the form of a growth push agglomeration economy (Gollin et al., 2016).

Urbanization and economic sectoral convergence

The convergence of labour productivity between sectors, as postulated by the Lewis model (1954) and thus the equalization of the standards of living between rural and urban milieus, is another research avenue in understanding the link between urbanization and economic growth.

This research route derives from the implications of the two-sector, rural-urban model (Lewis, 1954; Todaro and Harris, 1970; Cahuc and Célimène, 1993). In those studies, urbanization will continue despite an increased unemployment rate. Such a dynamic process could affect the labour market, which in turn will affect the convergence process. In short, in the neoclassical assumption of a flexible urban labour market, an increase in unemployment rate would lead to a decrease in the urban wage rate, which would eventually lead to a low equilibrium that would equalize incomes in both sectors. Such an evolution should depend on the nature of the factors that cause urbanization, including climate change.

Unfortunately, such a trend towards income equalization between sectors is barely the case in Sub-Saharan Africa given high inequalities between the rural and the urban sectors. Therefore, identification of factors that can sustain the expected equalizing process cannot be done rigorously without considering the climate context. In Sub-Saharan Africa, where the economies are mainly based on agriculture, the productivity gap between the two sectors is not independent of other factors (Jedwab et al., 2014), especially of climate change. Determining the conditions under which a stabilization of populations in their respective environments could be achieved in the context of climate change could be an important guide in the design of local development policies.

Measurement challenges in economic growth, urbanization and climate change relationship

The literature review revealed conflicting results in the empirical analyses of the relationship between urbanization and economic growth. These conflicting results can be justified by lack of consensus on the indicators used to capture urbanization and climate change.

Urbanization indicators

As concerns urbanization, the authors generally use the urban predominance indicator and the urban population ratio. While the first indicator focuses on urban concentration (density) by focusing on the largest metropolitan areas or capital cities, the second indicator considers all the cities. Both approaches appear unsatisfactory for two main reasons. The first is related to the criteria for the upgrading an agglomeration into a city. These criteria are based mainly on the size of the population and vary from country to country. While agglomerations with a population of 2,500/5,000 to 20,000 are considered urban in some countries, other countries classify them as cities only beyond a population threshold of 20,000 (De Bercegol, 2012). This makes international comparisons rather difficult.

The second reason is the failure to account for the diversity and specificity of urban features, especially in developing countries. For example, by focusing primarily on urban hierarchy, the approach to urban primacy obscures the role played by small towns in regulating the urban pressure of larger agglomerations (Rondinelli, 1983; Hardoy and Sattethwhaite, 2019; Choguill, 1989). Moreover, in a functioning system of cities, each type of city (primary and secondary) plays special and complementary roles.

As for the ratio of urban population, although it is the most widely used indicator in the literature (Henderson, 2010; Hoffman and Wan, 2013; Singh et al., 2014; Cainelli et al., 2014; Murshed and Saadat, 2018; World Bank, 2020), it does not account for all the dimensions of a country's urbanization. Urbanization is multidimensional because it is not only a measure related to human displacement, while it could also indicate population increase or reclassification (Jedwab and Vollrath, 2015). In that perspective, Gross and Ouyang (2020) proposed new measures of urbanization, centred on natural urban growth and residual urban growth. The latter accounts for both internal migration (the movement of the population of a country from the countryside to the city) and reclassification (the process by which a municipal area is reclassified from a countryside to a city).

Thus, it appears necessary to adopt a holistic measure of urbanization that accounts for the diversity of the social and economic structures, while relating the level of infrastructure to the concerned populations (quality of urbanization).

Indicators of climate change

Climate change is defined as a variation in the state of the climate that can be detected by changes in the average and/or variability of its properties and persists for a long period (IPCC, 2007). It thus refers to the climate change of the earth, characterized by a variation in the average temperature of the oceans and of the atmosphere over several years. This change is generally attributed directly or indirectly to human activity (UNFCCC, 1992[4]). It differs from climate variability, which refers to fluctuations, in the short- or in medium-term, around the average state of the climate.

Climatic concerns are at the heart of the great debates of the 21st century. Indeed, climate shocks have important effects on both economic activity and on the reconfiguration of the society (migration, rural exodus, etc). However, there remains controversies over the measurement of the climate variable. Most studies use the volume of precipitation, or the level of temperature, humidity or even the speed of the wind, as a measure of climate change.

These isolated pieces of information are rather insufficient to seize such a complex phenomenon as climate change. Indeed, climate corresponds to the set of atmospheric and meteorological conditions (humidity, pressures, temperature, etc) that are specific to a given geographical area. This composite nature of the climate variable requires the use of a composite index capable of considering climate in all its dimensions (Miguel and Satyanath, 2011; Couttenier and Soubeyran, 2013). On that basis, Harari and La Ferrara (2012) exploit intra-annual and intra-country variations using the standardized precipitation and evapotranspiration index (SPEI). The SPEI has the advantage of being simple and available at a disaggregated level (Vicente-Serrano et al., 2010). Although the SPEI index is simplistic, it does not sufficiently reflect the actual level of evapotranspiration that affects water balance (Dai, 2011).

Therefore, Couttenier and Soubeyran (2013) propose the Drought Meteorological Index (DMI), that is the Palmer Drought Severity Index (PDSI), based on the theoretical model developed on hydrology by Palmer (1965). This index captures weather conditions on the ground by capturing the significant effects that were absent in previous indices. These are non-linearities and the effects of interaction between precipitation and contemporaneous and past temperatures. Clearly, it is based on a soil moisture supply and a demand model, and is calculated using data on precipitation and temperature, and the available local water content of the soil. In other words, the PDSI measures the difference between humidity levels and climatological averages.

Several authors recognized the superiority of the PDSI index in measuring climate change and presented it as the most important meteorological drought index (Couttenier and Soubeyran, 2013; Dai, 2011). For future research involving climate issues, it would be interesting to use such a multidimensional index.

Modelling approaches

General discussion

To better understand the relationship between climate variables and other economic variables, several models have been developed. The objectives of these models are to assess the impact of human behaviour on the climate and the effect of climate on the rest of the economy. Analyzing economic variables in a bivariate manner (economic growth and urbanization; economic growth and climate change; urbanization and climate change), research, as a whole, used, among other things, Cobb-Douglas production models (Singh et al., 2014; Andersson and Lef, 2009; Lall et al., 2004), error-correcting vector models (Zhao and Wang, 2015), Granger's causal models (Hoffman and Wan, 2013; Murshed and Saadat, 2018). Also, threshold models were used by some researchers in studies of the relationship between urbanization and economic growth, or the relationship between urbanization and climate variability (Dash and Mallick, 2017; Chapman et al., 2017). But these simplistic models are criticized for their inability to grasp the complexity of the economic environment, and/or in incorporating the multidimensional variable of climate. The integration of the climate variable, in a more holistic way in the analyses, led to the development of new models, of which the technical-economic models (bottom-up models) and the macroeconomic models (top-down models).

Botton-up models are most often in partial equilibrium types and incorporate only a global and exogenous representation of the rest of the economy in the form of a trajectory of large macroeconomic aggregates chosen by the researcher. To rely on a partially balanced model is to consider the externalities to be negligible; what seems to be at odds with the reality of the economy (Goulder, 1995; Otto, 2006). However, top-down models are characterized by an overall representation of the economy and a more aggregated representation of the energy system. These empirical strategies are dominated by computable general equilibrium models (MEGC) and DSGE models (Golosov et al., 2014). The underlying models provide an assessment of the macroeconomic cost of reduction policies in the form of changes in GDP or welfare costs, from where all systemic effects in the economy are considered.

Some examples

Dell et al. (2009) provide a framework for reconciling new cross-sectional and panel estimates in their analysis of the interaction between temperature and income. Quoting Nordhaus (2006), these authors indicate that temperature alone can explain 23% of the variation in cross-country income today. Unfortunately, they think that substantial debate continues over whether climatic factors can explain contemporary economic activity. They even wonder if other correlated variables such as a country's institutions or trade policy drive prosperity in contemporary times, leaving no important role for geography. For details on those two concerns, Dell et al. (2009) refer readers to authors such as Sachs (2003); Acemoglu, Johnson and Robinson (2001);. Therefore, Dell et al. (2009) provided, first, a cross-sectional evidence by considering the temperature-income relationship using not only cross-country data but also subnational data at the municipal level for 12 countries in the Americas. In a second stand, the authors developed a theoretical framework to reconcile their cross-sectional effects, which they tested on panel data. Finally, they reconciled the cross-sectional effects and those of the panel data with a theory that emphasizes adaptation and convergence.

Abidoye and Odusola (2015) also looked at the interaction between climate change and economic growth in Africa, because the economic landscape of most African countries depends essentially on the dynamics of climate change. In a panel data framework, they found a negative impact of climate change on economic growth. They departed from a thorough review of the literature on the interaction between growth and climate change, arriving at the conclusion that climate change has negative impact in most tropical regions' economies, both directly and indirectly. Their empirical strategy was derived from cross-country growth models, with the specificity of reducing the impact of omitted variable bias on parameters of interest. Overall, the authors confirmed the negative relationship, with some country specificities.

Most used models in current research, however, are the DICE and RICE models (Nordhaus, 2019; Nordhaus et al., 2015; Couttenier and Soubeyran, 2013). These models link the factors that influence economic growth, carbon dioxide emissions, climate change, climate damage and climate policies. In other words, these integrated assessment models should help to understand the interactions between the environment and the economy in the context of climate change.

Unfortunately, due to data and time constraint, the current paper evaluated a partial equilibrium model, in its innovative form, a PSTR model, in its determining climate variability threshold that assures a virtuous relationship between economic growth and urbanization in Sub-Saharan Africa.

4. Interactions between climate variability, urbanization, and economic growth: Some stylized facts

Three interactions were deemed interesting to graph in the search for a priori relationship between the considered variables. These were: interactions between economic growth and urbanization, between temperature variability and urbanization, and between economic growth and temperature variability, in the considered countries.

Interactions between economic growth and urbanization

Figures 1, 2 and 3 present the interactions between economic growth and urbanization in sub-periods over 1990-2018.

In recent years, Africa has developed much faster than other countries in the world due to several factors beyond initial endowments and favourable geographical conditions. At the domestic level, some of the driving forces include the improvement of governance, the strengthening of policies, the emergence of a middle class and favourable conditions for agricultural activity. At the external level, soaring prices and capital inflows are seen as the main factors of economic growth. Likewise, the United Nations' projections indicate that Sub-Saharan Africa will become increasingly urban between 2025 and 2035, with 1.2 billion people expected to live in cities in 2050.

The interaction between the two variables remained positive over the period for most of the considered countries, as shown in Figures 1, 2 and 3. It was negative for Sierra Leone, and Burundiin the 1990s; for Zimbabwe in the 2000s and for Mauritius, in the 2010s. Rwanda, Uganda, Ghana, Tanzania, Niger, Kenya, Senegal, and Benin maintained a strong positive relationship throughout.

Figure 1: Relationship between urbanization and GDP over the period 1990-1999

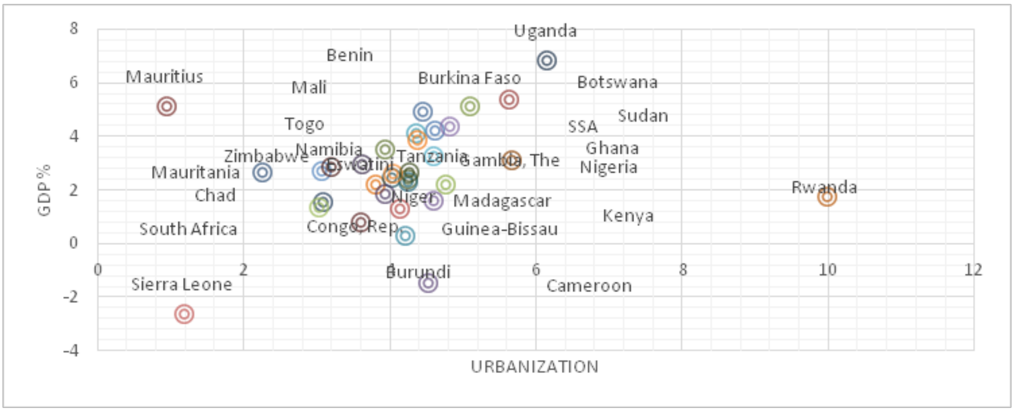


Figure 2: Relationship between urbanization and GDP over the period 2000-2009

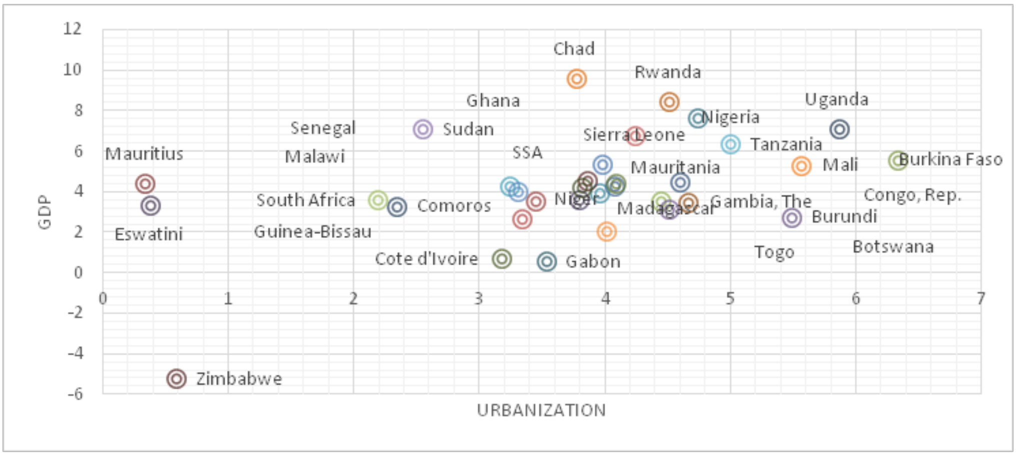
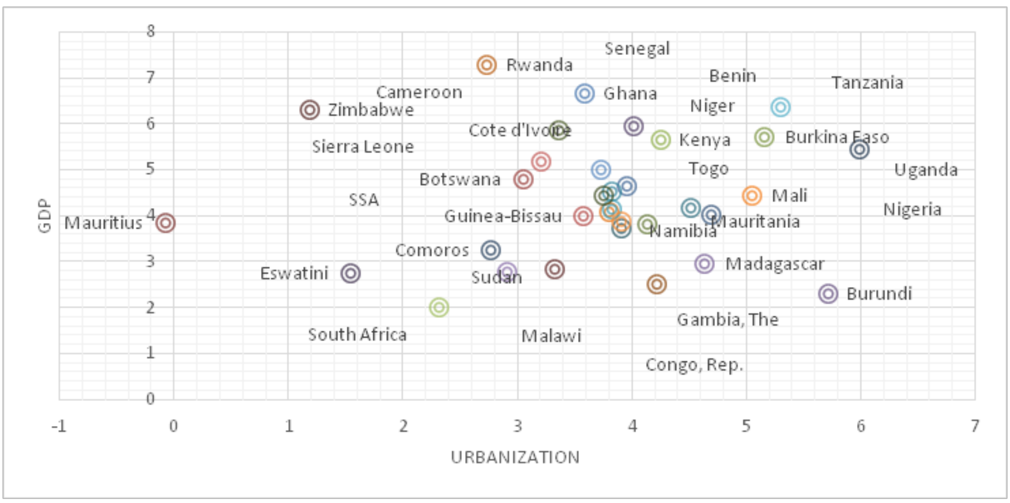


Figure 3: Relationship between urbanization and GDP over the period 2009-2018



Source: Authors, based on WDI - 2020

Interactions between temperature variability and urbanization

Figures 4, 5 and 6 present the relationship between temperature variability and urbanization. The decade 1990-1999 was characterized by negative effects of temperature variability in Sub-Saharan Africa. Two extreme cases are Rwanda and Zimbabwe. Rwanda reveals a high urbanization rate associated with the second lowest temperature variability, whereas the reverse is observed in Zimbabwe.

Figure 4: Relationship between urbanization and temperature over the period 1990-1999

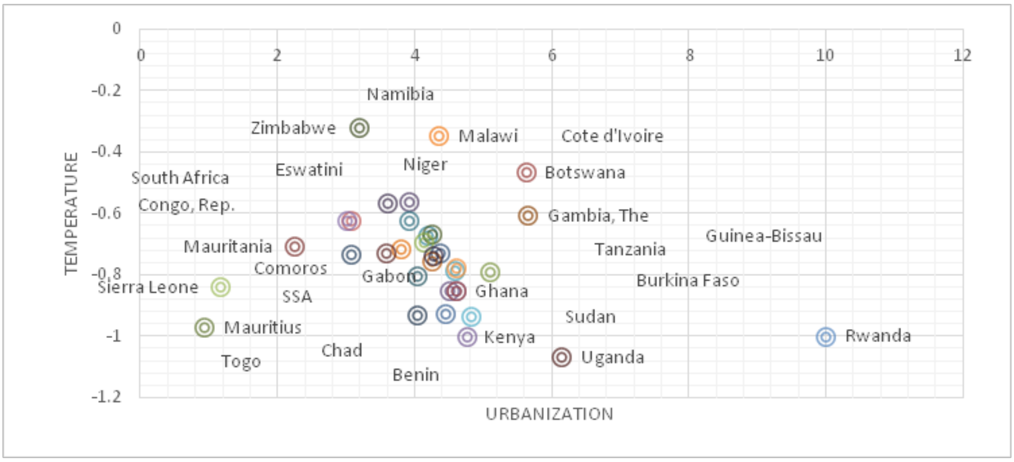


Figure 5: Relationship between temperature and urbanization over the period 2000-2009

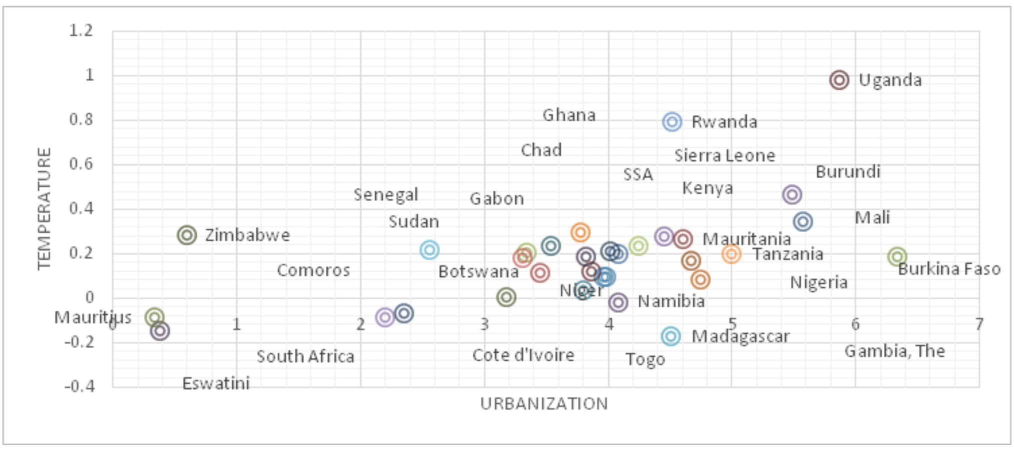
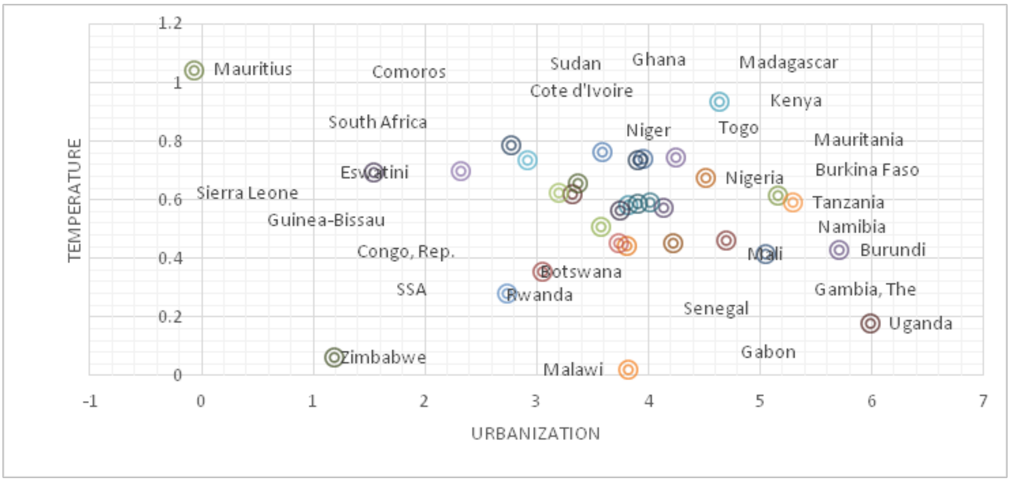


Figure 6: Relationship between urbanization and temperature over the period 2010-2018



Source: Authors, based on WDI - 2020

Mauritius, Sierra Leone and Mauritania are characterized by combinations of low urbanization rates and low temperature variability. In 2000-2009, the temperature in other countries gradually increased, except for Mauritius, Eswatini, South Africa, Comoros, Côte d'Ivoire, Namibia and Madagascar. In Uganda, the high urbanization was correlated with a relatively high temperature variability, whereas in Burkina Faso and Madagascar, the high urbanization rate commended a lower temperature variability. In the 2010s, temperature variability increased in all the countries, except Malawi and Zimbabwe.

Interactions between economic growth and temperature variability

Economic literature establishes a negative relationship between climate variability and economic growth. This is verified for several of the considered countries, especially Uganda, Mauritius, Zimbabwe, Malawi, and Cameroon (Figure 7). This pattern is maintained for Chad, Sudan, Burundi and Ghana over the 2000s (Figure 8). In the 2010s, Rwanda, Zimbabwe, and Uganda revealed high economic growth with low temperature, whereas Mauritius, Madagascar Comoros, Sudan, Eswatini and South Africa associated low economic growth with high temperature variability (Figure 9).

The observed mitigated features as concerns the relationships between climate variability, urbanization, and economic growth command some empirical evaluation of these relations.

Figure 7: Relationship between urbanization and temperature over the period 1990-1999

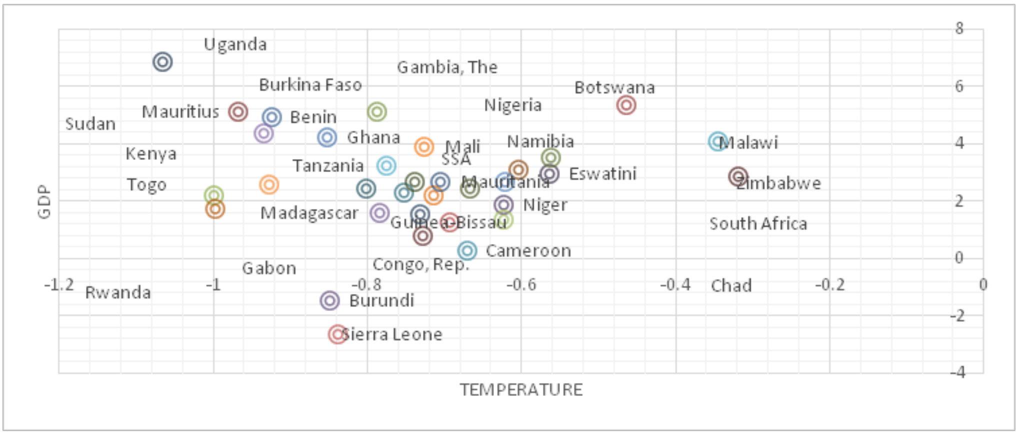


Figure 8: Relationship between urbanization and temperature over the period 2000-2009

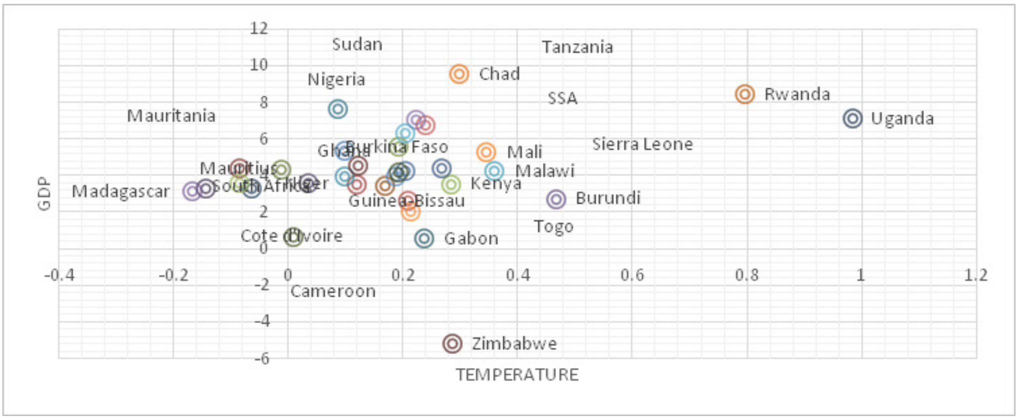
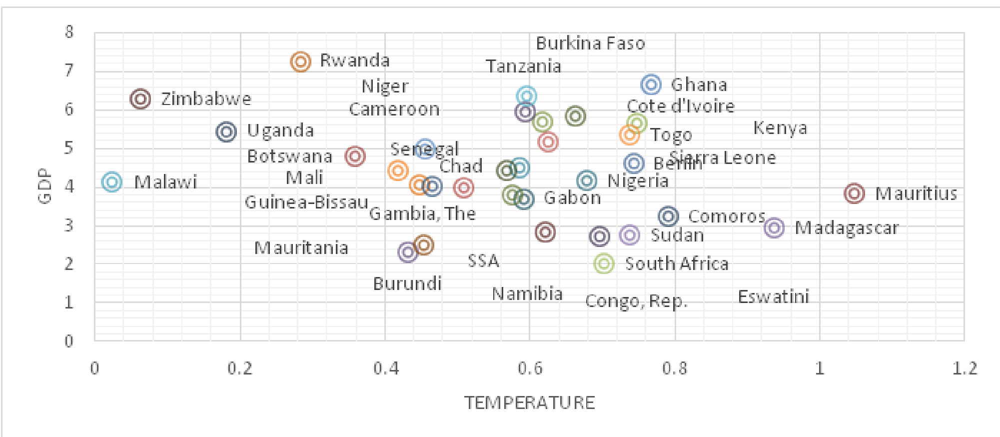


Figure 9: Relationship between urbanization and temperature over the period 2010-2018



Source: Authors, based on WDI - 2020

5. Evaluation of temperature thresholds for a virtuous relationship between economic growth and urbanization

The empirical strategy, comprising the models, variables of the study, and the sources of data for the study is first presented, followed by discussion of the threshold effects.

Empirical strategy

The model

The empirical model was constructed to determine the climate thresholds that make the urbanization-economic growth relationship a virtuous one. Since the analysis is based on panel data, a PSTR model (Panel Smooth Transition Regression), adapted from Gonzalez et al. (2005), was evaluated. We recall that the PSTR is an extension of the PTR method of Hansen (1999) for smoothing transitions between two extreme regimes to the left and to the right of an endogenously determined threshold. Under this specification, the basic model of Hansen (1999) is as follows:

$$Y_{it} = \mu_i + \theta_1 \delta_{it} + \theta_2 \delta_{it} F(q_{it}, \bar{b}) + \theta_3 q_{it} + \omega g_{it}^c + \eta_{it} \quad (1)$$

where, Y_{it} is the dependent variable (in the current case, rate of economic growth); μ_i corresponds to (unobserved) individual fixed effects ; $F(.)$ is the transition function which is a function of the smoothing parameter q_{it} (climatic variable), which allows to characterize the transition in the neighbourhood of the threshold value $\bar{b}$; δ_{it} is the explanatory variable (the rate of urbanization) directly affecting Y_{it} ; g_{it}^c is the matrix of control variables and η_{it} the disturbances. Moreover, the transition function is an indicator function specified as follows:

$$F(q_{it}, \bar{b}) = \begin{cases} 1 \; si \; q_{it} > 0 \\ 0 \; si \; q_{it} < 0 \end{cases} \quad (2)$$

The direct effect of climate change on economic growth is captured by the coefficient θ_3. The indirect effect is through urbanization and is measured by the coefficient θ_2.

Under this new specification, there is a linearity test which consists of checking whether the parameter θ_2 is different from zero. The hypotheses associated with this test are:

$$H_0:\ \theta_2 = 0 \quad vs \quad H_1:\ \theta_2 \neq 0$$

Under the assumption of linearity, the sensitivity of the growth rate with respect to urbanization would be equal to θ_1. Otherwise, it would be equal to $\theta_1 + \theta_2$.

Unlike the Hansen (1999) model, which assumes that the transition between two regimes is abrupt, the PSTR model of Gonzalez et al. (2005) argues that switching from one regime to the other is a gradual process. Thus, the transition function will not be an indicator but rather a continuous function. As a result, the PSTR model of the current study is as follows:

$$Y_{it} = \mu_i + \theta_1\delta_{it} + \theta_2\delta_{it} f(q_{it},\gamma,\bar{b}) + \theta_3 q_{it} + \omega g_{it}^c + \eta_{it} \tag{3}$$

where the transition function $f(q_{it},\gamma,\bar{b})$ is continuous and depends on q_{it} the transition variable (climate variability), γ is the slope of the transition function. Gonzalez et al. (2005) and Minea and Villieu (2008), use a logistic function, whose form is as follows:

$$f(q_{it},\gamma,\bar{b}) = \left[1+\exp(-\gamma(q_{it}-\bar{b}))\right]^{-1} \quad , \qquad \text{with} \qquad \gamma>0\,. \tag{4}$$

The PSTR model has several advantages over the Hansen (1999) PTR specification. In the current study, it allows the elasticity of economic growth relative to urbanization to vary not only over time, but also according to individuals depending on the level of climate change.

Given the threshold effect introduced by the transition function f, the sensitivity of economic growth to the urbanization of country i at the date t is given by the following expression:

$$s_{it} = \frac{\partial Y_{it}}{\partial \delta_{it}} = \theta_1 + \theta_2 f(q_{it},\gamma,\bar{b}) \tag{5}$$

Equation (9) shows that the sensitivity of economic growth to urbanization can be considered as a combination of θ_1 and θ_2, obtained in two extreme regimes.

One would note that following the linearity test in a PSTR, two important tests are: the test of parameter constancy and the test of remaining heterogeneity, along with the determination of the number of regimes. The imbedded test strategy is implemented until the acceptance of the hypothesis of no remaining heterogeneity.

Variables of the study

Beyond the variables of interest in the study, which are urbanization, climate variability and economic growth, along with the classical factors of production, labour and capital, we controlled for factors such as agricultural productivity, and political freedom. Investment was specified to account for capital, the rate of growth in active population measured by the capacity of the labour force. Inflation rate, and the value added of industrialization were accounted for to capture the buoyancy of the considered economies.

Economic growth, in this study, is captured by the rate of economic growth. It measures the variability of wealth created by economic agents from one period to the other. For a considered country, an improvement in the rate is synonymous of the productive dynamics of the country's economic system (Hossain, 2011; Nassori, 2017).

Urbanization is captured by the rate of growth in urban population. Unlike the expression as a percentage of total population (Nguyen and Nguyen, 2018), the growth rate conveys a better understanding of the level of variation experienced by urbanization in Sub-Saharan Africa from one period to the next.

Climate variability: Climate change commonly refers to significant changes in global temperature, precipitation, wind patterns and other measures of climate that occur over several decades or longer. Along those lines, the analysis of the effects of climate change on the economies of African countries appeared a bit too ambitious due to the long-term effect that it implies. Thus, the concept of climate variability, which is captured by the variations of precipitation and temperature, as highlighting climate anomalies in the climate literature (Nicholson, 1992; Munoz-Diaz and Rodrigo, 2004), was preferred. Following Marchiori et al. (2011), those anomalies were expressed as weighted deviations of the observed values from their long term mean in each of the considered countries. Therefore, for the period 1968-2018, the climate variabilities were determined as:

$$\Delta Clim_{i,t} = \frac{Clim_{i,t} - moy(Clim_{i,t}^{**})}{\sigma(Clim_{i,t}^{**})} \quad ;$$

where, $\Delta Clim_{i,t}$ represents the climate anomaly of temperature or precipitation of country *i* at time *t* ; $moy(Clim_{i,t}^{**})$ is the climatic mean in country **i** at time *t* over the longer run ; $\sigma(Clim_{i,t}^{**})$ is the standard deviation of the observation over the long run, for country *i* at time *t*; $Clim_{i,t}$ is the observed climatic variable of country i at time t.

Agricultural productivity, in the current study, is taken to be the ratio of total gross production (total output) to the total input (all the factors of production used, including land; Livestock capital; Machine capital; fertilizers, etc). There appeared a need to include an agricultural production variable given the strong dependence of the considered economies on agriculture. Indeed, in some cases, a declining agricultural productivity leads populations to invade forests, grasslands and swamplands that can influence rainfall variability, hence increasing the level of poverty and the likelihood of migration, as corroborated by authors such as Lewis (1954) and Todaro and Harris (1970). Those authors further pointed out that an increase in agricultural productivity leads to a surplus of labour that will migrate from rural to urban areas to constitute a labour force for the industrial sector. More specifically, the rate of growth in agricultural productivity is considered.

Political freedom has always played a key role in economic development in developing countries, especially in Sub-Saharan Africa. In effect, worsening climatic conditions, coupled with other factors such as political and ethnic conflicts, erosion of traditional safety nets and the deteriorating physical infrastructure, besides the absence of general security in rural areas, have forced some people to migrate to urban areas, exerting further pressure on cities, and compounding their socio-economic problems (Choguill, 1999).

Data sources

The data used in this study are those on a sample of 32 Sub-Saharan African countries: 14 of the 16 West African countries; 10 of the 18 countries in East Africa; 4 countries of 9 in Central Africa and 4 of the 5 southern African counties, as shown in Table A1 of the Appendix. The variables and their sources are defined in Table 1.

Table 1: Variables of the study and their sources

Variables	Variable description	Sources
Urban	Growth rate of urban population (%)	WDI (World Development Indicators, World Bank)
Vtemp50	Variation of temperature (°C)	CEDA (Center of Environnemental Documentation and Analysis)
Vprec50	Variation of rainfall (mm)	CEDA
gdp	Economic growth (%)	WDI
Prod	Agricultural productivity (%)	USDA (United State Department of Agriculture)
Control Variables		
Infl	Inflation rate (%) Variation in GDP deflator	WDI
labour	Working active population as a percentage of active population (%)	WDI
Political	Political freedom defined on a scale of 1 to 7 (score): a value between 1.0 and 2.5 indicates freedom; 3.0 – 5.5 indicates partial freedom and 5.5 – 7.0 indicates absence of freedom	Polity4
defi	Financial development (%) Defined as the ratio of domestic loans to the private sector to GDP	WDI
inv	Investment as a percentage of GDP (%) Fixed Capital as a percentage of GDP	WDI
Vaind	Industrial value added as a percentage of GDP (%)	WDI

Source: Authors' compilation

Threshold effects

The results are presented, then discussed, in terms of the descriptive characteristics of the variables, the interactions among climate variability, urbanization and economic growth, and of the climate variability threshold.

Descriptive characteristics of the variables

Table 2 presents the descriptive characteristics of the considered variables. Of the three (3) variables of primary interest, urbanization revealed the smallest variability over the considered period, and for the 32 Sub-Saharan African countries. Indeed, the average increase in the urban population of all the considered countries is 3.88% per year, with a minimum of -1.47% and a maximum of 17.50%.

However, this is not the case for economic growth, and climate variables. It appears that there were significant differences in levels of economic growth among Sub-

Saharan African countries. With an average of 3.80%, the economic growth rate of these countries was highly dispersed from a minimum of -50.25% to a maximum of 35.22% over the considered period. Similarly, the rainfall variability is widely dispersed from country to country with an average of 0.017 versus a higher variability in temperature, at a level of 0.91, and a mean of 0.55, indicating the presence of high heat in the study area. Table A2 in the Appendix presents the years in which and countries where the minimum or the maximum of each one the considered variables was observed. For instance, the maximum value of 35.22% for economic growth was observed in Rwanda in 1995, whereas the highest inflation rate of 159.267% was observed in Sudan in 1994.

Table 2: Descriptive characteristics of the variables

Variables	Observations	Mean	Standard Deviation	Minimum	Maximum
GDP	928	3.7992	5.0174	-50.24807	35.2241
Urban	928	3.8773	1.6882	-1.4768	17.4991
Prod	928	0.0056	0.0782	-0.4585	0.5420
Vprec50	928	0.0173	0.9069	-3.3384	4.0525
Vtemp50	928	0.5470	0.7116	-1.4523	2.4729
Labour	928	68.2384	12.6825	42.2200	91.5420
Inv	928	20.5142	8.6128	-2.4243	61.4690
Infl	928	10.2006	16.5807	-29.6911	159.2670
Vaind	928	23.5394	11.7770	2.0731	77.4137
Political	928	4.4526	1.8550	1	7
Defi	928	20.41112	11.777	0.4025806	160.1248

Source: Constructed by the authors

Empirical evidence

First, standard panel unit root tests were conducted to determine the order of integration of the respective variables. More specifically, the Levin et al. (2002), Im et al. (2003), and the ADF test were conducted. It will be recalled that the Levin et al. (2002) panel unit root test assumes homogeneity in the dynamics of the autoregressive coefficients for all panel units, whereas the Im et al. (2003) panel unit root test permits heterogeneity in the dynamics of the autoregressive coefficients. In addition, the Fisher-ADF panel unit root test was employed; all examining the null hypothesis of a unit root with the alternative hypothesis of the absence of a unit root. The results presented in Table A3 of the Appendix indicate I(0) variables, except the labour variable.

Second, a homogeneity test was performed on the two climatic variables, temperature (vtemp50) and rainfall (vprec50) to determine the suitability of those variables to serve as transition variables. Also, the homogeneity test served to determine the number of transition regimes necessary for the interaction between urbanization and economic growth to be a virtuous one in Sub-Saharan Africa.

Table 3 presents the results of the homogeneity tests for the two climatic variables. Not only the hypothesis of homogeneous linear model is rejected at the 1% significance level, but also the Lagrange (LM) and Fisher (LMf) statistics show that temperature variability can effectively serve as a transition variable in the PSTR model linking urbanization and economic growth.

Table 3: Nonlinearity test for two transition variables

	LMx		LMf		HACx		HACf	
	stat	pval	stat	pval	stat	pval	stat	pval
Transition variable - vprec50								
1	1.456	0.6925	0.4629	0.7083	0.9774	0.8067	0.3107	0.8177
2	6.550	0.3645	1.0370	0.3993	5.6850	0.4594	0.9005	0.4938
Transition variable - vtemp50								
1	21.67***	0.0001	6.889***	0.0001	7.84**	0.0494	2.492*	0.0589
2	38.02***	0.0000	6.022***	0.0000	13.18**	0.0402	2.088*	0.0523

Note: ***, **, * indicate 1%, 5% and 10% significance level, respectively.
Source: Authors' compilation

The results of the test for determining the number of regimes are presented in Table 4. Following the Heteroscedastic-autocorrelation (HAC) test, the two regimes model was chosen at the 5% significance level.

Table 4: Test of determination of the number of regimes

	LMx		LMf		HACx		HACf	
	stat	pval	stat	pval	stat	pval	stat	pval
Transition Variable vprec50								
1	1.456	0.6925	0.4629	0.7083	0.9774	0.8067	0.3107	1.5990
2	5.102	0.1645	1.6160	0.1840	5.0470	0.1684	1.5990	0.1881
Transition Variablevtemp50								
1	21.67***	0.0001	6.889***	0.0001	7.840**	0.04943	2.492*	0.05886
2	16.73***	0.0008	5.302***	0.0013	8.371**	0.03894	2.652**	0.04759

Note: ***, **, * indicate 1%, 5% and 10% significance level, respectively.
Source: Authors' compilation

The estimated PSTR model is presented in Table 5. The dependent variable is economic growth, whereas urbanization was defined as the main exogenous variable. The control variables are labour, investment, agricultural productivity, industrial value added, inflation, financial development, and political freedom, as specified in Table 1. The robustness tests, presented in Appendix Table A4 confirm the constancy of the parameters and no remaining heteroscedasticity.

Overall, the results from the PSTR model show that the gamma smoothing parameter is statistically significant at the 1% significance level, thus implying that the transition from one regime to the other is done smoothly. Temperature variability thresholds for the selected two intermediate regimes are both statistically significant at the 1% significance level, with a minimum threshold value of -0.4501 and a maximum threshold value of 1.5445. Therefore, a non-linear relationship between urbanization and economic growth exists even though the coefficient in the second regime is not statistically significant. Moreover, the sign of the coefficient of urbanization becomes negative as one moves from one regime to the other one. Similarly, there exists a non-linear and significant relationship between agricultural productivity and economic growth, which further increases as one moves to the second regime.

Table 5: Results of the PSTR model

Variables	Less than -0.4501	between -0.4501 and 1.5445	above 1.5445
labor	-0.0735	0.0075	-0.0660
	(0.097)	(0.04)	(0.078)
urban	0.4364***	-0.4956	-0.0593
	(0.139)	(0.816)	(0.773)
prod	9.9921***	26.7480**	36.7401***
	(3.059)	(12.026)	(12.965)
inv	0.0930***		
	(0.034)		
vaind	0.0209		
	(0.063)		
infl	-0.0164		
	(0.014)		
defi	-0.0493		
	(0.041)		
political	-0.7276***		
	(0.182)		
gamma			233.7***
			(36.564)
c1			-0.4501***
			(0.001)
c2			1.5445***
			(0.002)

Note: ***, **, * indicate 1%, 5% and 10% significance level, respectively. (.) represent standard errors
Source: Authors' compilation

Also, urbanization, investment and political rights do affect economic growth, especially in the first regime. More specifically, these two variables significantly and positively affect economic growth, while political rights have a statistically significant and negative effect on economic growth.

Economic evaluation of the thresholds

The empirical evidence is that the relationship between economic growth and urbanization would be virtuous for a temperature variability below the "c1" parameter, valued at -0.4501. Indeed, for a temperature variability below the minimum threshold of -0.4501, urban growth positively affects economic growth. Given that the average level of temperature variability in the Sub-Saharan zone is estimated at 0.5470, a value well above the minimum threshold of -0.450, it is reasonable to expect a negative relationship, as predicted by the PSTR model.

In addition, beyond the minimum threshold of -0.4501, an increase in the level of temperature might reduce agricultural yields, hence lead to a good deal of migration of rural dwellers to urban areas in search of well-being. In return, the implied congestions in urban areas would increase public spending in water supply, sanitation, schools, healthcare centres, and transportation, rather than creating wealth.

As concerns the effect of political rights, it has been widely shown that democracy (political rights) has a positive influence on economic growth (Barro and Sala-i-Martin, 1995; Sen, 1999). Indeed, an economy with good quality institutions (freedom) creates an environment that facilitates the development of economic activities (North, 1990, Acemoglu et al., 2001). However, Ben Doudou and Rahali (2018) pointed out that the positive effect of democracy on economic growth is conditioned on political stability. Given the construct of the political freedom variable, its significantly negative coefficient in the estimated equation, somehow, confirms the effects that have been found by previous studies.

Finally, when temperature variability exceeds -0.4501, only agricultural productivity positively affects economic growth. This result reaffirms the centrality of agricultural productivity in the interaction between economic growth, urbanization, and climate variability.

6. Conclusion and recommendations

Climate change and ever-increasing urbanization have been major challenges for African governments in general and for those in Sub-Saharan Africa in particular, who are already facing high levels of poverty.

To contribute to the understanding of this phenomenon, this study sought to analyze the interactions between climate variability, urbanization, and economic growth in Sub-Saharan Africa. Specifically, the study analyzed the extent to which climate variability could maintain the interaction between economic growth and urbanization a virtuous one.

An empirical strategy anchored on literature review, descriptive analysis, and PSTR model was designed to achieve the specified objectives. More specifically, the PSTR model was estimated using a panel data of 32 Sub-Saharan African countries over the period 1990-2018.

First, the review of literature indicates that existing research on the relationship between climate variability, urbanization and economic growth could be reinforced by research in three non-exclusive directions. More explicitly, future research should explore: (i) multivariate analyses of economic growth, urbanization, and climate change; (ii) measurement challenges with urbanization and climate change; and (iii) modelling approaches.

Second, the descriptive analysis highlighted a priori negative relations between either economic growth and urbanization, or economic growth and temperature, or between temperature and urbanization, in some countries.

Third, the study determined a climate variability threshold at which urbanization contributes positively to economic growth. In Sub-Saharan Africa, urbanization only has a positive effect on economic growth if the temperature variability is below the threshold of -0.4501, while the average temperature variability is around 0.5470. Unfortunately, the effect of urbanization becomes insignificant and sharply decreases between the temperature variability threshold achieving its lowest value in that regime. The effect of agricultural productivity even increased, although less significantly above the 1.5445 temperature variability threshold.

Some policy recommendations to mitigate the effect of the interaction between climate variability and urbanization on economic growth in Sub-Saharan Africa follow:

- Encourage measures that could significantly increase agricultural productivity.

- Encourage agricultural practices that mitigates climate variability.

- The ever-increasing urbanization should be sustained by strategies of smarter environment.

- In addition to the research avenues discussed in Section 3, it appears necessary to address the variability of climate thresholds in future research by determining the threshold by group of coastal, Sahelian countries, or by the degree of relative industrialization of these countries. Indeed, the climate threshold obtained may vary from country to country or group of countries to another one, depending on economic and climatic conditions. This study was unable to verify these heterogeneities given data constraints.

Notes

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Appendix

Table A1: List of countries in the Panel

Western Africa (13/14)
Benin - Burkina Faso - Côte d'Ivoire - Gambia - Ghana - Guinea Bissau -
Mali - Mauritania - Niger - Nigeria - Senegal - Sierra Leone – Togo
Eastern Africa (10/17)
Burundi - Comoros - Mauritius - Kenya - Madagascar - Rwanda - Soudan -
Tanzania – Ouganda – Zimbabwe
Central Africa (04/8)
Cameroon - Congo république - Gabon - Chad
Eastern Africa (04/9)
South Africa - Botswana - Namibia – Eswatini (Swaziland)

Source: Compiled by the Authors

Table A2: Years and countries where the minimum or maximum was observed

Variables	**Minimum**			**Maximum**		
	Value	**Country where it was observed**	**Year**	**Value**	**Country where it was observed**	**Year**
gdp	-50.24807	Rwanda	1994	35.22408	Rwanda	1995
Urban	-1.4767	Rwanda	1991	17.4990	Rwanda	1996
Prod	-0.4585	Namibia	1997	0.5419	Botswana	1991
Vprec50	-3.3384	Rwanda	2004	4.0525	Eswatini	2000
Vtemp50	-1.452284	Soudan	1992	2.4728	Soudan	2010
Labor	42.22	Comoros	1990	91.542	Burundi	1990
Inv	-2.4243	Sierra Leone	1997	61.4690	Mauritania	2005
Infl	-29.6910	Republic of Congo	2015	159.267	Soudan	1994
Vaind	2.0731	Soudan	2015	77.4136	Republic of Congo	2008
Political	1	Botswana (1990-1992); Gambia (1992); Ghana (2005-2018); Mauritania (1993-2018); South Africa (1995-2005)		7	Almost all the countries achieved a maximum of 7 in a given year over the considered period	

Source: Constructed by the Authors

Table A3: Unit roots tests: Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS) and Fisher-ADF

Variable	LLC		IPS		FISHER-ADF		Status
	level	First diff	level	First diff	level	First diff	
gdp	-5.1538	-	-15.2602	-	15.5679	-	I(0)
	(0.0000)		(0.0000)		(0.0000)		
labor	-3.1046	-	3.8199	-5.6570	9.0824	-	I(0)
	(0.0000)		(0.9999)	(0.0000)	(0.0000)		
urban	-13.6420	-	-3.0399	-	32.7538	-	I(0)
	(0.0000)		(0.0012)		(0.0000)		
inv	-2.3677	-	-6.9311	-	14.2431	-	I(0)
	(0.0089)		(0.0000)		(0.0000)		
infl	-9.6716	-	-14.9511	-	19.9981	-	I(0)
	(0.0000)		(0.0000)		(0.0000)		
prod	-15.7771	-	-19.6429	-	53.7002	-	I(0)
	(0.0000)		(0.0000)		(0.0000)		
vaind	-2.7059	-	-4.4321	-	13.5969	-	I(0)
	(0.0034)		(0.0000)		(0.0000)		
defi	-12.0167	-	-4.2167	-	8.1458	-	I(0)
	(0.0000)		(0.0000)		(0.0000)		
political	-4.5177	-	-4.4943	-	1.6705	-	I(0)
	(0.0000)		(0.0000)		(0.0474)		
vprec50	-9.8417	-	-16.9354	-	23.8272	-	I(0)
	(0.0000)		(0.0000)		(0.0000)		
Vtemp50	-7.3722	-	-14.5444	-	20.6187	-	I(0)
	(0.0000)		(0.0000)		(0.0000)		

Note: Values in parentheses express the p-values corresponding the Levin-Lin-Chu, Im-Pesaran-Shin and Fisher-ADF tests

Source: Authors' compilation

Table A4: Evaluation of the PSTR model

Régimes	LMx		LMf		HACx		HACf	
	Statistique	P-value	Statistique	P-value	Statistique	P-value	Statistique	P-value
Transition variable - vtemp50								
Parameter constancy - H0: PSTR vs Time Varying (TV)-PSTR								
1	60.35***	0.0000	5.167***	0.0000	15.27	0.1706	1.3070	0.2150
2	77.01***	0.0000	3.255***	0.0000	21.95	0.4629	0.9278	0.5576
No remaining heterogeneity - H0 : PSTR vs PSTR under 2 regimes								
1	29.56***	0.001858	2.531***	0.003798	12.29	0.3422	1.052	0.3977
2	42.39***	0.005600	1.792**	0.014140	19.85	0.5925	0.839	0.6775

Source: Authors' compilation

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