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RESEARCH ARTICLE

Does climate change influence state fragility? Evidence for the countries of sub-Saharan Africa

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Abstract

The aim of this paper is to analyse the role of climate change on state fragility in sub-Saharan Africa (SSA). To do this, we estimate a country-time fixed effects panel data model using the two-way fixed effects estimator over the period 1995 to 2020 for 45 SSA countries. Our results show that climate change increases fragility in SSA; specifically, rising temperatures and decreasing rainfall increase the social, economic, political and security fragility of SSA countries. The study also reveals that gross domestic product, population growth, migrant remittances, foreign direct investment, natural resources, inflation and agricultural price volatility are mechanisms through which climate change exacerbates state fragility. Based on these results, we recommend climate change adaptation measures such as increasing water storage to cope with periods of extreme drought, growing climate-smart crops, and the introduction of environmental public policies.

Keywords: climate change; state fragility; sub-Saharan Africa

JEL classification: C23; Q51; Q54

1. Introduction

Current conceptions of state fragility, a concept popularized by the World Bank in the 1990s to characterize the lack of capacity of certain states to implement economic reforms, have been broadened to include aspects such as territorial security, violence, provision of basic public services, political legitimacy and economic opportunities for all citizens (OECD, 2020; Fund for Peace Fund, 2022). While the African Development

Bank (AfDB, 2014) defines state fragility as a condition of high risk of institutional collapse, societal breakdown, and violent conflict, the World Bank (2006) highlights instead that a fragile state faces high risks emanating from the interaction of internal pressures and external shocks, and from the limited capacity of the state and its institutions to mitigate the adverse effects of these pressures and shocks. Following these conceptions, most rankings of fragile states according to various indicators show that sub-Saharan Africa (SSA) is the region in the world with the highest number of fragile states (McKay and Thorbecke, 2019). As an illustration, 31 of the 44 most fragile countries in the world in 2017 were SSA countries according to Marshall and Elzinga-Marshall (2017). Furthermore, 33 countries from SSA were among the 50 most fragile countries in the world in 2022 (Fund for Peace, 2022). In this part of the African continent, fragility exposes millions of people to shocks such as violence, poverty, inequality, and forced displacement (OECD/SWAG, 2022).

Some previous studies on state fragility have made it possible to group its determinants into several categories of factors: demographic, economic, social, political, and institutional (Dimitrova and Triki, 2018; McKay and Thorbecke, 2019). Alongside these so-called traditional determinants, Araya (2013) present climate change as a potential cause of state fragility. It is increasingly recognised that environmental shocks lead to deteriorating living conditions and worsening food insecurity in African countries (OECD/SWAG, 2022). Africa is the continent most at risk in terms of uncertainties and extreme climate conditions due to its ecological fragility and widespread poverty (Terdiman, 2007). Temperatures in SSA are increasing faster than the global average temperatures (IPCC, 2022). By 2040, rising temperatures and rainfall deficits are expected to lead to a reduction in agricultural land by 40 to 80 per cent and a reduction in agricultural productivity growth by 34 per cent, putting SSA countries at risk of acute food insecurity and malnutrition (World Bank, 2013).

Paradoxically, despite the potential significance of this issue, empirical studies linking climate change and state fragility in SSA are scarce and often suffer from limitations in how fragility is measured (Maino and Emrullahu, 2022; Jaramillo *et al*., 2023). For example, Maino and Emrullahu (2022) measure fragility using gross domestic product (GDP), while Jaramillo *et al*. (2023) evaluate fragility by examining the frequency of armed conflicts. These studies are limited as they concentrate on just one dimension of fragility. On a broader scale, empirical evidence supporting the hypothesis of a climatic origin of state fragility remains limited. This observation is echoed by Ziaja and Fabra (2010), who argue that current understanding of state fragility relies heavily on case studies,[1] while quantitative and comparative methods could yield valuable insights for future policymaking. As a consequence, in this study, we use a multidimensional index of fragility as defined by the State Fragility Index which is an annual assessment of 178 countries based on a measure of the social, economic, political, and environmental pressures each country faces (Messner *et al*., 2018). The advantage of this index lies in the fact that it could be useful in providing a more holistic understanding of the challenges and dynamics at play in fragile states, thereby offering more robust and effective recommendations for policy and intervention (Ziaja and Fabra, 2010).

From all of the above, three observations emerge: first, to the best of our knowledge, there appear to be no empirical studies highlighting the effect of climate change on state

[1] As an illustration, we can cite the World Food Program (WFP, 2023) report on climate change in southern Africa, the policy briefs on climate change and state fragility in the Sahel (Crawford, 2015), and the work by Mbaye and Signé (2022) on climate change, development and the link between conflict and state fragility.

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fragility as defined by the State Fragility Index (Fund for Peace, 2021). Second, the studies identified highlight the effect of climate change only on one dimension of state fragility. And third, the literature identifies several mechanisms through which climate change influences security, economic, political and social fragility, but these mechanisms have not yet been empirically validated. Thus, this article attempts to position itself as a major contribution to the verification and empirical measurement of the effects of climate change on State fragility in SSA. It has two contributions. (i) This study analyses the effect of climate change on the overall states fragility index obtained by applying the arithmetic mean on the disaggregated fragility indicators obtained by principal component analysis (PCA). (ii) Using the mediation analysis developed by Acharya *et al.* (2016), this study contributes to identifying and empirically verifying whether climate change influences state fragility in SSA through variables such as GDP, population growth, migrant remittances, foreign direct investment, natural resources, inflation and agricultural price volatility.

The rest of the paper is organized as follows. Section 2 presents some stylized facts about the links between climate change and state fragility. Section 3 reviews the literature. Section 4 describes the methodology used. Section 5 presents the results and section 6 presents some sensitivity and robustness tests, followed by discussion and some recommendations in section 7.

2. Stylized facts

2.1 Fragility and climate change in SSA: acute and correlated phenomena

Figure A1 in the online appendix shows that SSA is the most fragile region compared to South America, Europe and North America in 2023 (Fund for Peace, 2022). Several reasons could explain the severity of state fragility in this part of the world. The 1990s witnessed the emergence of state fragility in SSA, driven by economic shocks such as the 1995 recession, characterized by currency devaluations and falling oil prices. Subsequently, the 2008 food riots, exacerbated by the subprime crisis, coupled with recurring post-election crises and the rise of secessionist and jihadist movements, further compounded state fragility in the region (ACLED, 2021). In addition to all these reasons, climate change is identified as one of the factors exacerbating state fragility in SSA (IPCC, 2022).

Figure A2 in the online appendix shows the persistence of climate change in SSA. Average temperatures have risen from 27.1°C in 2000 to over 28°C in 2010 and averaged around 27.7°C in 2020. These findings are consistent with the IPCC (2019), which highlights the heightened vulnerability of the African continent to climate change impacts resulting from global temperature increases. Despite an observed increase in rainfall, the pattern is highly irregular, with significant variations in both timing and intensity (figure A2). This irregularity underscores a key aspect of climate change, i.e., a disruption of the predictable seasonal rainfall patterns.

The potential links between state fragility and climate change are highlighted in the correlation graphs (figure A3 in the online appendix). According to these graphs, the correlation between average temperatures and state fragility is positive. As temperatures rise, SSA states become increasingly fragile. Similarly, there is a negative correlation between overall fragility and average rainfall, such that any increase in average rainfall is associated with a decrease in fragility, and vice versa. Thus, like Mbaye and Signé (2022), our correlation analyses suggest a link between climate change and state fragility in SSA.

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2.2 Fragility in SSA: a heterogeneous phenomenon

Figure A1 in the online appendix highlights the heterogeneity of fragility in SSA, as shown by Ongo Nkoa and Song (2021). East Africa appears to be the region most affected by fragility. According to WFP (2023), almost 23 million people in Ethiopia, Kenya and Somalia are food insecure due to local conflicts, the Covid-19 pandemic, rising food prices due to the war in Ukraine and, most importantly, drought and reduced rainfall. Central and West Africa also show a significant fragility level. This is due to the security context and political instability resulting from multiple conflicts, as well as the weak capacity of states to respond to security and climate change issues (AfDB, 2019; Ateba and Ongo, 2024). While Southern Africa may exhibit lower fragility compared to other sub-regions, it still faces significant challenges. These include xenophobic conflicts and insurgencies, high levels of inequality and poverty (Baffi and Vivet, 2017), and the increasing frequency of extreme weather events, particularly tropical cyclones, in countries like Malawi, Mozambique, and Zimbabwe (AfDB, 2022).

3. Climate change and state fragility: an exploration of the link in the literature

3.1 A theoretical explanation through the multidimensional approach of State fragility

Carment *et al.* (2010) and Nay (2013) criticise the one-dimensional approach to State fragility insofar as it refers to isolated concepts such as weak institutional governance, state corruption, economic crises, civil conflict and war, extreme poverty, crime or food insecurity. As the notion of state fragility is inextricably linked to multidimensional issues, Carment *et al.* (2010) develop a theoretical framework for state fragility based on a multidimensional approach. This theory is based on the Authority-Legitimacy-Capacity triptych and refers to the conditions that must be met for a State to escape the category of 'fragile state'. *Authority* is understood as the coercive force of the state. *Legitimacy* refers to the recognition of the state by the people, and *Capacity* refers to the state's ability to regulate shocks. According to Faria (2011), fragility encompasses a number of concepts, such as the lack of authority and legitimacy of the state and its inability to meet its obligations in the event of shocks. In the context of climate change, Hamza and Corendea (2012) point out that fragility arises from the inability of authority to assert its power in regions affected by climate change, and its inability to mobilise and use the resources that would enable the population to access basic food and services in the event of climate change shocks. Huang (2018) states that climate change exerts pressure on the limited resources of vulnerable populations, and reduces the legitimacy of the state due to its inability to provide basic and necessary human services. One of the most serious consequences of climate change is the instability of states to recover from disasters and manage their inherent risks, due to the pressure it places on already weak institutions (Faria, 2011). Ultimately, in the event of climate change shocks, the lack of authority and legitimacy of the State and its inability to improve the well-being of the population exacerbate fragility (Stewart and Brown, 2009).

3.2 Climate change and state fragility: effects and mechanisms in empirical studies

3.2.1 Climate change and security fragility of states

The literature establishes direct and indirect links between climate change and security fragility (IPCC, 2023). Several studies indicate that climate change, through high temperatures, directly increases the risk of many forms of intergroup, political, and other

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forms of popular violence (Hsiang *et al.*, 2013). Sarsons (2015) shows that low rainfall increases the risk of communal conflicts, such as Hindu-Muslim riots in India.

However, other studies highlight the mechanisms through which climate change affects security fragility. Raleigh and Urdal (2007) point out that high levels of food shortage due to reduced rainfall in an area increase the risk of conflict. In the same vein, Hendrix and Salehyan (2012) argue that the rhythm of conflicts in rural areas corresponds to periods of climatic variation. Caruso *et al.* (2016) points out that extreme weather conditions exacerbate the volatility of agricultural product prices, which increases the emergence of conflicts. Indeed, drier climatic conditions reduce agricultural production, increase the price of products on the market, and lead to anti-government protests which are sources of conflict (Berazneva and Lee, 2013). Harari and Ferrara (2018) indicate that climate change can reduce agricultural productivity, leading to food insecurity, a source of social unrests and conflicts. Burke *et al.* (2009) show that climate change shocks reduce agricultural incomes and exacerbate poverty. This further increases security fragility. Finally, according to Demarest (2015), rising prices of basic agricultural commodities, a consequence of climate change, can intensify competition for scarce resources, ultimately fueling conflict.

3.2.2 Climate change and economic fragility of states

The literature examining the link between climate change and economic fragility focuses on how climate change affects economic growth (Burke *et al.*, 2015; Botzen *et al.*, 2019; Maino and Emrullahu, 2022; Jaramillo *et al.*, 2023). Hallegatte and Dumas (2009) point out that the decline in agricultural productivity associated with extreme climatic conditions reduces economic growth, thereby increasing economic fragility. The decline in agricultural production due to climate change significantly impacts the economic stability of states by reducing the income of households reliant on agriculture (Dell *et al.*, 2012). As a matter of fact, using time series data on temperature fluctuations across multiple countries, these latter authors found that a temperature increase by 1°C in a given year reduces economic growth by 1.3 per cent on average in poor countries. Also, extreme weather events can seriously damage infrastructure and reduce economic productivity, increasing economic fragility (Jaramillo *et al.*, 2023).

3.2.3 Climate change and political fragility of states

The responses to and effects of climate change on social and human conditions depend in part on the capacity and willingness of the state to act (Ubelejit, 2014). For example, the provision of essential goods and services such as water, education, or health care could be reduced, which would have a further negative impact on social and human conditions, thereby increasing political fragility (Ubelejit, 2014). All of these could exacerbate the vulnerability and fragility of weak states, making them less proactive in fulfilling their sovereign duties (Busby *et al.*, 2013).

3.2.4 Climate change and social fragility of states

The effects of climate change on social fragility are linked to the degradation of the quality of daily life, driven by pollution, and the scarcity of food and natural resources (Homer-Dixon, 1992). Carleton *et al.* (2016) highlight extensive research indicating that climate change is likely to reduce productivity and working conditions, affect living conditions standards, and impair food security, access to water, natural resources, and health care. In addition, Alam *et al.* (2017) reveal that climate change has a negative impact on profitability, employment, and health of farmers. Baptista *et al.* (2022) note that the

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intensification of the harmful effects of climate change on agricultural production worsens food insecurity, a source of social fragility. Migration due to climate change shocks can increase competition between local and migrating communities, thus accelerating social fragility (Abel *et al.*, 2019). Based on the notions of 'pollution havens' and 'race to the bottom', Gray (2002) suggests that foreign direct investment (FDI) degrades the environment, and thus the living conditions of the population. Conversely, Hussain *et al.* (2021) argue that remittances increase the population's resilience to climate change shocks, thereby reducing social fragility, and Santangelo (2018) argues that FDI reduces unemployment and helps improve health and education outcomes.

4. Empirical strategy: data, model and estimation technique

4.1 The model and the data

Our model is inspired by the work of Jaramillo *et al.* (2023) who analysed the effect of climate change on fragilities using a two-way fixed effects panel data model. In this study, we analyse the effects of climate change on all indicators of fragility and on the composite index of global fragility. The empirical model is written as follows:

$$Fragility_{k,it} = \beta + \gamma CC_{it} + X_{it}\lambda + \psi_i + \rho_t + \varepsilon_{it} \tag{1}$$

with $k =$ overall fragility, economic, social, political, and security; $i = 1, 2, \ldots, 45$, and $t = 1995, 1996, \ldots, 2020$.

For these specifications, the results of the Hausman tests (in online appendix table A1) justify the choice of fixed effects models rather than random effects models. Fixed effects models have the advantage of incorporating the temporal and individual dimensions, thus allowing endogeneity problems to be taken into account (Burke *et al.*, 2015; Jaramillo *et al.*, 2023). Fixed effects models can reduce omitted variable bias by addressing unobserved heterogeneity across individuals in the panel (Hill *et al.*, 2021). Thus, Ψ_i controls for time-invariant unobserved variables at the country level such as culture and geography, while time-fixed effects, ρ_t, control for time variant shocks that are common to all countries in the sample.

$Fragility_{k,it}$ is the column vector of dependent variables, including the composite index of overall fragility and the four disaggregated indices of fragility (see online appendix table A5).[2] Global fragility is captured by the Composite Fragility Index, which is constructed from state fragility indices. The disaggregated indices of overall fragility, including economic, political, security and social dimensions, are derived using PCA on 12 respective indicators[3] ranging from 0 for resilience to 12 for extreme fragility (Fund for Peace, 2022). By applying the arithmetic mean to these four disaggregated indices obtained through PCA, we obtain the composite fragility index, also known as the overall fragility index. Contrary to the work of the OECD (2020), we cannot include environmental fragility among the explained variables. This would lead to reverse causality bias,

[2] According to the think-tank Fund for Peace, these are economic, political, security and social fragility.

[3] In this study, the composite index of state fragility called Global Fragility Index is calculated from (i) economic fragility, approximated by countries' economic efficiency, which takes into account GDP per capita, the export share of manufacturing goods, net oil production/consumption, and commodity price fluctuations; (ii) political fragility, captured by political regime, political instability, democracy, autocracy, and ethnicity; (iii) social fragility, measured by the human development index, protection of human capital, level of education, level of life expectancy; and (iv) security fragility, captured by the number of civil wars and armed crises, and terrorist attacks.

as climate change is recognised as an indicator of environmental fragility. The Fragility Dimensions Index comes from the Fund for Peace's (2021) State Fragility Index database and has several advantages over other indices such as the Foundation for International Development Studies and Research, Economic Vulnerability Index and the World Bank Fragility Index. First, it provides information on a large panel of SSA countries. Second, the time horizon over which the index is calculated is longer, and third, the number of indicators used to derive the index is larger. CC_{it} is the matrix of climate change variables consisting of average temperatures in degrees Celsius (°C), denoted AT_{it}, and average precipitation in millimetres per years (mm/Year), denoted AP_{it}, obtained by averaging monthly values of temperature and precipitation. The World Meteorological Organisation (WMO, 2007) defines the average climate level as the mean temperature and precipitation over a 30-year period. Although our analysis relies on a slightly shorter period (1995–2020) due to data limitations, we believe this 26-year average provides a reasonable approximation for capturing climate change trends in our study. Our study utilizes a longer time horizon compared to previous research by Raleigh *et al.* (2015) and Burke *et al.* (2009), which employed 14- and 21-year periods, respectively. Monthly data are obtained from the World Bank Group's Climate Change Knowledge Portal (CCKP, 2021), a geo-referenced database primarily sourced from North American institutions such as the National Center for Atmospheric Research and the International Research Institute (Columbia Climate School).

X_{it} is the vector of control variables all taken from the World Development Indicator database (WDI, 2021). They can be considered as direct determinants of state fragility as well as mechanisms through which climate change influences fragility. Gdp/cap_{it} represents the GDP per capita. It measures the level of economic activity and corresponds to the ratio between the value of GDP and the number of inhabitants of a country. La and Xu (2017) argue that increasing GDP per capita, by improving the living conditions of the population, reduces the vulnerability of the state to exogenous shocks. $Popgro_{it}$ is the rate of population growth. The uncontrolled increase of the population growth rate can be a source of state fragility. Williams (2017) shows that the larger the population size and the faster it grows, the easier it is for the population to make demands that can lead to social, economic, and political issues.

$Natres_{it}$ represents natural resources approximated by profits from oil, gas, and mineral products as a percentage of GDP. According to Dupasquier and Osakwe (2006), when the natural resource curse hypothesis is true, natural resource abundance increases the fragility of states.

$Remf_{it}$ represents migrant remittances and the share of income earned abroad. Official remittances are only a small part of the remittances that circulate in the world and can exacerbate conflicts if they are used to purchase arms and munition (Avom *et al.*, 2020). However, for Clemens and McKenzie (2014), remittance funds could reduce economic fragility for recipient countries, as they can address urgent financing needs.

FDI_{it} stands for foreign direct investment (currents, net inflows). FDI exhibits multifaceted effects on state fragility. For Santangelo (2018), while FDI can reduce unemployment and improve social indicators like health and education, its influence on agriculture can be detrimental, leading to land appropriation and displacement of smallholder farmers. Furthermore, while FDI can enhance economic stability by facilitating technology transfer and driving growth in countries with adequate human capital (Hamid *et al.*, 2016), it can also increase security fragility by exacerbating macroeconomic instability (Mueller *et al.*, 2017). Finally, Gossel (2018) finds that FDI can contribute to a more stable political environment by curbing corruption and fostering democratic institutions.

Inf_{it} represents inflation. According to Akobeng (2016) and Avom *et al.* (2020), inflation is used to explain state fragility following Berazneva and Lee (2013) who showed that rising prices of consumer goods were the cause of food riots and conflicts in most African countries during the 2007–2008 period.

$VOFP_{it}$ represents the volatility of agricultural food prices (wheat), derived from monthly FAO data (FAOSTAT, 2021). Hugon and Mayeyenda (2003) use the coefficient of variation to capture price volatility, while in reference to Minot (2014), we used instead standard deviations on monthly food (wheat) consumer price index data. The choice of wheat price volatility is motivated by the fact that wheat, unlike other agricultural crops, is the most vulnerable crop to the effects of climate change (Nelson *et al.*, 2009). For Philipsz (2019), the impact of wheat price volatility on purchasing power generates conflict and riots. Based on the above, and taking into account the existing relationships between climate change, fragility and these control variables, considered in the literature as transmission channels, we construct the conceptual model shown in figure A4 in the online appendix.

Overall, there is little variation between variables in the descriptive statistics (see online appendix table A2). The information on the standard deviations suggests that there is a low level of volatility for all the variables analysed (table A2). Correlation analysis (see online appendix table A3) revealed low correlations among explanatory variables, suggesting a lack of multicollinearity. This was further confirmed by the variance inflation factor (VIF) test, which indicated no significant multicollinearity issues (see online appendix table A4).

4.2 Estimation method and control of endogeneity problems

Our estimation strategy, adapted from Hsiang *et al.* (2013) and Burke *et al.* (2015), employs the two-way fixed effects (TWFE) estimator. This approach mitigates endogeneity bias by effectively controlling for unobserved heterogeneity across individuals within the panel (Wooldridge, 2021). A number of arguments support the choice of this estimation strategy (Feeny *et al.*, 2015). First, the individual dimension allows us to account for the unobserved heterogeneity associated with the probability of a country being fragile or not, and to capture the individual characteristics that are invariant over time, such as the region of the country, the legal origin (colonisation) and specific climatic characteristics. Second, the introduction of the time dimension allows the estimator to mitigate endogeneity due to a suspected correlation between climate change and control variables such as population growth rate, education, natural resources and GDP per capita. Third, the time-specific effect allows us to control for economic or climatic shocks common to fragile countries, such as economic crises and natural disasters. The choice of this estimation technique is validated by the Fisher test which highlights the heterogeneity between individuals in the panel. The robustness of this estimation technique is controlled by the method of lagged explanatory variables (Bellemare *et al.*, 2017) and the system generalised method of moments (S-GMM) (Blundell and Bond, 1998).

5. Results of study

5.1 Baseline findings

The results in table 1 (specifications 1–5) show that climate change significantly affects all indicators of state fragility in SSA. We find that rising average temperatures increase

Table 1. Effects of climate change on state fragility

	Dependent variable: four dimensions of state fragility and global fragility index				
Independent variables (without control variables) Estimator	Security fragility (1) TWFE	Economic fragility (2) TWFE	Political fragility (3) TWFE	Social fragility (4) TWFE	Global fragility (5) TWFE
Average temperature	0.633 (0.249)	0.118 (0.00968)	0.397 (0.216)	2.266 (0.203)	1.126 (0.169)
Average precipitation	−0.181 (0.0503)	−0.00221 (0.000598)	−0.00669 (0.000614)	−0.00233 (0.000575)	−0.00344 (0.000481)
Constant	1.388 (0.836)	−2.906 (0.291)	−1.389 (0.711)	−6.838 (0.666)	−3.547 (0.557)
R^2	0.020	0.132	0.141	0.291	0.137
Fisher	0.88	6.42	7.08	17.37	6.73
Observations	1,170	1,170	1,170	1,170	1,170
Independent variables (with control variables) Estimator	Security fragility (6) TWFE	Economic fragility (7) TWFE	Political fragility (8) TWFE	Social fragility (9) TWFE	Global fragility (10) TWFE
Average temperature	0.0441 (0.00981)	0.117 (0.00920)	0.156 (0.206)	2.128 (0.199)	0.916 (0.153)
Average precipitation	−0.00120 (0.000631)	−0.00287 (0.000596)	−0.00606 (0.000613)	−0.00199 (0.000592)	−0.00303 (0.000456)

Continued.

Table 1. *Continued.*

Gross domestic product per capita	−0.00536 (0.000557)	−0.0187 (0.00523)	−0.0642 (0.00538)	−0.0834 (0.00520)	−0.0176 (0.00400)
Population growth	0.00638 (0.00584)	0.0289 (0.00544)	0.0252 (0.00560)	0.00232 (0.00540)	0.00824 (0.00416)
Natural resources	0.0640 (0.00331)	0.0313 (0.00318)	0.0351 (0.00327)	0.0248 (0.00316)	0.0388 (0.00243)
Remittance fund	0.0123 (0.00329)	−0.00856 (0.00309)	0.0145 (0.00318)	0.0351 (0.00307)	0.00555 (0.00237)
Foreign direct investment	0.03999 (0.00405)	0.0110 (0.00380)	−0.0424 (0.00390)	0.00639 (0.00377)	0.00338 (0.00290)
Inflation	0.000256 (0.000224)	0.00315 (0.000864)	0.00216 (0.000888)	0.00259 (0.000858)	0.00182 (0.000660)
Wheat price volatility	0.148 (0.0360)	0.00541 (0.000745)	0.0312 (0.00142)	0.01235 (0.00432)	0.00952 (0.000125)
Constant	−0.238 (0.312)	−0,325 (0.158)	−0.980 (0.675)	−0.201 (0.173)	−3.269 (1.502)
R^2	0.297	0.23	0.24	0.358	0.312
Fisher	14.10	11.84	10.67	16.76	15.08
Observations	1,170	1,170	1,168	1,168	1,168
Number of countries	45	45	45	45	45

Notes: Standard errors in parentheses.

social, economic, security, political and overall fragility, while lower average rainfalls decrease all these indicators. Regarding each dimension of fragility, we find that climate change exacerbates the security fragility of SSA countries. Swain and Öjendal (2018) have shown that climate change increases security fragility through its ability to exacerbate conflicts, while Raleigh and Urdal (2007) indicated that food shortages due to lack of rainfall exacerbate security fragility in SSA. According to Burke *et al.* (2015), we show that climate change exacerbates economic fragility in SSA countries. This finding is consistent with Hallegatte and Dumas (2009), who portray that economic fragility is driven by low agricultural productivity in SSA, as the sector's contribution to GDP remains very significant.[4] In line with Ubelejit (2014), we find that climate change increases political fragility. One possible explanation for this finding lies in the inability of African states to effectively mitigate the impacts of climate change shocks, leading to a decline in the provision of essential public goods and services such as water, education and health care, thereby exacerbating existing social and human vulnerabilities within the population. Climate change has also been found to contribute to social fragility. The living conditions of people, their food security and their access to water, natural resources and health care deteriorate rapidly in the face of climate change shocks (Carleton *et al.*, 2016; Baptista *et al.*, 2022). In terms of overall fragility, we find that climate change increases the global fragility of SSA countries accordingly to the finding of Huang (2018), who provides several explanations for this result. For example, the displacement of people due to drought may lead to a massive influx of climate refugees into foreign/new regions, which may foster local conflicts due to resource competition and/or cultural and ethnic differences. Rapid and prolonged changes in environmental conditions, such as drought, also have a direct impact on those who depend on natural resources.

Regarding control variables, all specifications (6–10) indicate that economic growth reduces fragility in SSA. This aligns with La and Xu (2017), who found that GDP per capita reduces overall fragility as well as its security, economic, political and social dimensions. The African Development Bank (AfDB, 2023) reports that eleven of the world's fastest-growing economies are in Africa. This strong economic growth has therefore the potential to reduce fragility when the provided benefits of growth are equitably shared across society. In line with Williams (2017), we find that population growth increases economic, political and global fragility in SSA. A densely populated and rapidly growing population generates increased demands that lead to fragility. In the context of widespread poverty in Africa, many governments struggle to meet the expectations of the population, leading to unrest and conflict.

Consistent with Bertocchi and Guerzoni (2012) and Norman (2009), natural resource endowments increase the overall, social, economic, political and security fragility in SSA. These findings can be explained by the natural resource curse that most resource-rich countries in SSA suffer from. We find that remittances increase security, political, social and global fragility, while reducing economic fragility. On the one hand, remittances are likely to engender social fragility by means of the exacerbation of income inequalities between the beneficiaries and the non-beneficiaries (Avom *et al.*, 2020). They increase security fragility when they are used to fund rebellions and armed groups in host countries, and they increase political fragility through their ability to corrupt rent-seeking

[4]In fact, the value added of the agricultural sector, which accounted for 44 per cent of GDP in 2004, has significantly declined to 17 per cent in 2021 (Blankespoor *et al.*, 2022) and the agricultural sector employs on average 55 per cent of the working population in these countries (International Labour Organization, 2017).

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politicians (Attila *et al.*, 2018). On the other hand, migrant remittances reduce economic fragility in recipient countries by meeting people's urgent financial needs (Ambrosius and Cuecuecha, 2016).

We show that FDI reduces political fragility and increases security, economic and social fragility in SSA. FDI reduces political fragility through good governance practices such as reducing corruption and improving democracy (Gossel, 2018). It exacerbates social fragility by favouring imported labour over local labour with lower human capital endowments (Santangelo, 2018). Additionally, it heightens economic fragility as the benefits due to technology transfer and resulting growth are limited to a segment of the population with sufficient human capital. Like Akobeng (2016), we find that inflation exacerbates fragility in SSA. Inflation increases political, economic, social, and global fragility because it reduces the population's purchasing power through external financial flows and challenges political projections (Avom *et al.*, 2020). Finally, our results indicate that wheat price volatility reinforces the global, security, economic, political and social fragility in SSA, consistent with Phillipsz (2019) and Caruso *et al.* (2016). Wheat price volatility due to climate change and the Russo-Ukrainian war has further exacerbated inequality, poverty and conflict in SSA (Mottaleb *et al.*, 2022).

Moreover, our results suggest that the control variables presented in this study are all potential mechanisms through which climate change affects state fragility in SSA. Econometrically, this intuition seems to be confirmed when we observe results in the specifications without and with control variables. When the control variables are introduced into the model, the magnitude of the coefficients associated with average temperature and precipitation decrease. Similarly, the introduction of these variables improves the R^2 and Fisher values, indicating that these variables have modified the density of the climate change effect on fragility. Finally, the inclusion of these control variables reduces the significance of the constant. This allows a better interpretation of the results in terms of causal effects, thus reducing any possible omitted variable bias (Vu, 2021). Based on the above, it is therefore urgent to test the mediation effect of these variables by means of mediation analysis and to analyse their effectiveness.

5.2 Mediation analysis

According to Acharya *et al.* (2016), the usual mediation analysis, which consists of introducing the treatment variable (climate change) and the mediator variable in the same equation in the baseline model, generally leads to biased and inconsistent estimators. Instead, these authors propose a two-step econometric procedure to test effectiveness of the mediation effect. The first step is to regress state fragility (the outcome variable) on the considered mediator variable(s), climate change, and a set of control variables. We then obtain the predicted values of the outcome by setting all the mediators to zero. This is the 'demediated' outcome. In the second step, we regress the 'unmediated' outcome on climate change and on the control variables that are pre-treatment confounders. The coefficients associated with climate change are referred to as the average conditional direct effect (ACDE) by Acharya *et al.* (2016). A change in the magnitude and significance of the ACDE from the baseline model reflects the effectiveness of the mediation effect.

Following Acharya *et al.* (2016), all regressions are estimated using a bootstrap method with 1,000 replications and incorporating country and time fixed effects. The estimation results are shown in table 2. In all specifications, the results support the

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existence of a mediation effect, suggesting that the considered mediating variables constitute transmission channels through which the effects of climate change can pass to reach state fragility in SSA. Indeed, we find that in all cases the magnitudes of the coefficients decrease with respect to the baseline model. Thus, the effects of climate change are weaker when the influence of mediating variables is added.

6. Some sensitivity and robustness tests

6.1 Sensitivity tests

To further address the omission of variables bias, the first sensitivity test is conducted by testing the model's sensitivity by adding groups of variables like basics social services access, digital, and historical-cultural variables. The second test focuses on the sub-regional heterogeneity of our panel in order to guide the development of specific analytical approaches.

6.1.1 Sensitivity for basics social services access

The population's access to basic social services such as education and water is a key factor in explaining state fragility (Musekiwa, 2016). Education can both reduce and accelerate state fragility. Education can reduce fragility by ensuring political stability and promoting security and good governance (Tendetnik *et al*., 2018), while inadequate education systems can further exacerbate fragility in already fragile states (Barakat *et al*., 2008). Lack of access to potable water increases state fragility (Pink, 2016; Huang, 2018). To contribute to the literature on the effects of basic social services on state fragility, we test the sensitivity of our model to education and water availability. Data on education and water access come from the WDI (2021) database and represent the number of students enrolled in secondary school and the availability of fresh water, respectively (Tendetnik *et al*., 2018).

The results presented in the online appendix table A6 show that education reduces state fragility in SSA in all specifications (1–3). The development of the education system focused on the ideals of citizenship and development can contribute to reduced fragility in SSA (Kirk, 2007; Tendetnik *et al*., 2018). We also show that the relationship between water availability and fragility is negative in SSA, such that lack of access to water increases fragility (Pink, 2016; Huang, 2018). The sensitivity of our model to basic social services does not change the nature of our baseline results.

6.1.2 Sensitivity for digitalization

Information and communication technologies (ICTs) in general, and the use of mobile phones and the internet in particular, appear to be a factor that increases state fragility in developing countries (Min, 2023; Song *et al*., 2024). For all specifications (1–3) in online appendix table A7, the ICT sensitivity results indicate that mobile phones and the internet increase global fragility in SSA. ICTs are the means by which individuals propagate notices of strikes, demonstrations and demands, thereby increasing security fragility (Song *et al*., 2024). The introduction of this sensitivity does not alter our baseline results.

6.1.3 Sensitivity to culture and history

Fenske (2010) shows that the failure of colonial powers to develop autonomous institutions has had an overwhelming impact on the emergence and spread of poverty in post-colonial SSA. Tusalem (2016) finds that colonisation increases state fragility and

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Table 2. Mediation analysis using the Acharya *et al.* (2016) approach

Dependent: security fragility	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ACDE of Average temperature	0.117 (0.00999)	0.118 (0.0101)	0.0383 (0.00846)	0.0325 (0.00880)	0.0291 (0.00913)	0.0276 (0.00903)	0.0312 (0.00916)
ACDE of Average precipitation	−0.00221 (0.000660)	−0.00274 (0.000699)	−0.00123 (0.000634)	−0.00223 (0.000780)	−0.00238 (0.000805)	−0.00232 (0.000797)	−0.00239 (0.000783)
Constant	0.641 (0.344)	0.00258 (0.0006)	−0.0384 (0.184)	0.674 (0.343)	0.622 (0.343)	0.508 (0.3413)	0.187 (0.0342)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Times fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	1,170	1,170	1,170	1,170	1,170	1,170	1,170
R^2	0.019	0.022	0.028	0.019	0.015	0.017	0.029
Dependent: economic fragility	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ACDE of Average temperature	0.119 (0.0102)	0.118 (0.0102)	0.114 (0.0101)	0.121 (0.0102)	0.118 (0.0102)	0.119 (0.0101)	0.119 (0.0101)
ACDE of Average precipitation	−0.00221 (0.000655)	−0.00287 (0.000588)	−0.00165 (0.000624)	−0.00234 (0.000661)	−0.00220 (0.000658)	−0.00220 (0.000659)	−0.00218 (0.000593)
Constant	−2.898 (0.290)	−2.895 (0.292)	−3.123 (0.294)	−2.934 (0.290)	−2.918 (0.291)	−2.982 (0.291)	−2.938 (0.290)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Times fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	1,170	1,170	1,170	1,170	1,170	1,170	1,196
R^2	0.132	0.121	0.128	0.117	0.132	0.112	0.132

Continued.

Table 2. *Continued.*

Dependent: political fragility	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ACDE of Average temperature	0.0526 (0.00617)	0.0521 (0.00618)	0.0523 (0.00619)	0.0522 (0.00617)	0.0524 (0.00616)	0.0527 (0.00614)	0.0520 (0.00612)
ACDE of Average precipitation	−0.00670 (0.000649)	−0.00709 (0.000686)	−0.00609 (0.000584)	−0.00647 (0.000632)	−0.00668 (0.000647)	−0.00666 (0.000645)	−0.00664 (0.000652)
Constant	−0.349 (0.298)	−0.365 (0.298)	−0.602 (0.285)	−0.327 (0.297)	−0.367 (0.299)	−0.372 (0.299)	−0.422 (0.300)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Times fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	1,170	1,170	1,170	1,170	1,170	1,170	1,170
R^2	0.151	0.153	0.139	0.137	0.141	0.141	0.144
Dependent: social fragility	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
ACDE of Average temperature	0.109 (0.00710)	0.108 (0.00708)	0.109 (0.00709)	0.107 (0.00706)	0.108 (0.00705)	0.110 (0.00704)	0.109 (0.00721)
ACDE of Average precipitation	−0.00670 (0.000649)	−0.00709 (0.000686)	−0.00609 (0.000584)	−0.00647 (0.000632)	−0.00214 (0.000593)	−0.00666 (0.000645)	−0.00664 (0.000652)
Constant	−2.255 (0.278)	−2.266 (0.278)	−2.433 (0.271)	−2.260 (0.278)	−2.279 (0.278)	−2.290 (0.277)	−2.294535 (0.280)

Continued.

Table 2. *Continued.*

Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Times fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	1,170	1,170	1,170	1,170	1,170	1,170	1,170
R^2	0.301	0.299	0.296	0.297	0.301	0.287	0.298
Dependent: global fragility	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ACDE of Average temperature	0.0304 (0.00100)	0.0403 (0.00100)	0.0467 (0.00559)	0.05072 (0.00604)	0.0521 (0.00606)	0.0527 (0.00605)	0.0529 (0.00622)
ACDE of Average precipitation	−0.00669 (0.000646)	−0.0070497 (0.000667)	−0.00267 (0.000442)	−0.00329 (0.000522)	−0.00335 (0.000526)	−0.00333 (0.000524)	−0.00336 (0.000520)
Constant	−1.214 (0.233)	−1.220 (0.233)	−1.494 (0.210)	−1.211 (0.233)	−1.235 (0.233)	−1.277 (0.233)	−1, 275 (0.235)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Times fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observation	1,170	1,170	1,170	1,170	1,170	1,170	1,170
R	0.141	0.147	0.138	0.134	0.139	0.135	0.137

Notes: This table presents the average controlled direct effects of climate change on indicators of state fragility, according to Acharya *et al*. (2016). These specifications correspond to different mediation variables, namely: (1) GDP per capita; (2) Population growth rate; (3) Natural resources; (4) Remittance funds; (5) Foreign direct investment; (6) Inflation; (7) Volatility of wheat prices. Bootstrap standard error in parentheses.
Source: Authors.

Bertocchi and Guerzoni (2012) find that ethnic and linguistic fractionalisation increases state fragility. We therefore test the sensitivity of our model to historical-cultural variables, with data coming from La Porta *et al.* (1999). The results in online appendix table A8 show that ethnic and cultural diversity increases global fragility in SSA for all specifications (1–4) (Bertocchi and Guerzoni, 2012; Tusalem, 2016). The sensitivity of the model to cultural variables does not change our baseline results.

6.1.4 Sensitivity to geographic heterogeneity

For Buhaug (2015), the different outcomes of climate change impacts on fragility, conflict and violence depend on the differences between regions. Ongo Nkoa and Song (2021) show that state fragility is a heterogeneous and persistent phenomenon in African sub-regions. However, even though state fragility varies across regions, the results in online appendix table A9 show that climate change increases global fragility for all specifications (1–4). This suggests that estimation by sub-region does not change the direction of our baseline results.

6.2 Robustness checks

6.2.1 Taking endogeneity into account by lagged explanatory variables

The non-parametric method based on lagged explanatory variables allows us to test the robustness of the results obtained by the TWFE estimator and to take into account the endogeneity problem associated with the omission of control variables. Bellemare *et al.* (2017) show that the use of this technique leads to biased and inconsistent estimators. However, they show that this technique is effective in addressing endogeneity in the following two situations. First, when endogeneity is related to the omission of variables, specifically unobserved heterogeneity. This technique applies when the unobserved factors are not dynamic. Second, in the case of reverse causality endogeneity, this technique is effective when there is a contemporaneous causal relationship between the dependent and independent variables. In our study, where endogeneity may be related to the omission of variables, we show that this technique is effective. We confirm that unobservable variables such as the probability of a country being fragile or not, the region in which the country is located, colonisation and climatic peculiarities are the basis of static variables in the African context. Gnimassoun and Do Santos (2021) point out that this approach ensures the robustness of the results and could mitigate endogeneity to some extent. Therefore, we estimate an equation with the explanatory variables lagged by one and two periods, including country and time fixed effects. This method allows us then to capture the lagged effects of exogenous variables on state fragility.

For all the specifications in online appendix tables A10 (lagged by one period) and A11 (lagged by two periods), the lagged values of temperature, rainfall, economic growth, natural resources, migrant remittances, FDI and inflation affect state fragility with the same expected sign as in the baseline results. Thus, this technique does not change the overall results on the effects of both interest and control variables on state fragility.

6.2.2 Taking endogeneity into account by using the S-GMM as an alternative estimator

Omission of relevant variables and measurement error are the main endogeneity biases that may exist between climate change and state fragility, given the purely exogenous nature of climate variability. Dynamic panel models are confronted with the correlation between unobservable country-specific effects and the lagged dependent variable, which leads to inconsistent estimators under ordinary least squares. Therefore, using

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additional moment conditions, Blundell and Bond (1998) proposed a robust alternative estimator called the system GMM estimator (or S-GMM), which combines equations in first difference with equations in levels, employing lagged instruments in difference equations.

We then use the S-GMM estimator for robustness checks. Indeed, several arguments justify the use of this estimator in our study: first, our specification is consistent with Roodman's (2009) condition that the number of countries (45) must be greater than the number of periods (26). Second, the persistence or inertia condition is verified because there is a strong correlation between fragility and its historical value.[5] Third, extending the approach developed by Arellano and Bover (1995), Roodman (2009) shows that the GMM estimator is biased when the estimation strategy imposes too many instruments, and overcomes this problem by limiting the number of instruments and maximising the sample size using the direct orthogonal deviation technique. And finally, unlike the difference GMM estimator, the S-GMM estimator corrects for endogeneity, heteroskedasticity and autocorrelation of the errors (Baum *et al.*, 2003).

In our study, S-GMM makes it possible to correct for omitted variable bias through the use of instrumental variables (Hill *et al.*, 2021). Specifically, this method allows us to: (i) control for unobserved heterogeneity across individuals in the panel, such as the probability that a country is more or less fragile, or more or less exposed to economic and climatic shocks; and (ii) correct for any endogeneity problems that may arise from a possible correlation between the error term and the lagged endogenous variable. To obtain an efficient and consistent estimator, we use internal instruments, i.e., explanatory variables lagged by at least two periods, such as GDP per capita, the demographic growth rate and natural resources. The choice of lagged exogenous variables as instruments put an end to the debate related to the subjectivity of external instruments, the choice of which is not unanimous in the literature (Mignamissi *et al.*, 2024). The use of S-GMM as a robustness check does not change the meaning and nature of our baseline results in table A12 (online appendix), for all specifications (1–9).

7. Conclusion and recommendations

The objective of this paper was to analyse the effect of climate change on state fragility in SSA. Specifically, the effects of precipitation and temperature on disaggregated fragility indices and overall fragility were examined. Using a TWFE model for a sample of 45 countries over the period 1995 to 2020, we find that: (i) rising temperatures and declining rainfall increase social, economic, political and security fragility in SSA; (ii) rising temperatures and decreasing rainfall increase overall fragility in SSA; (iii) all robustness and sensitivity tests conducted in this study confirm the baseline results on the role of climate change in increasing fragility; and (iv) control variables such as natural resource endowment, remittances, FDI, population size and inflation are likely to further increase fragility in SSA.

Thus, based on these results, we propose solutions that could reduce climate-related fragilities in SSA, and more specifically, implementing mitigation or adaptation measures against the harmful effects of climate change. For example, during periods of drought and/or low rainfall, it would be advisable to create and/or strengthen water management and storage infrastructure to meet the needs of the local population, particularly

[5] The correlation between global fragility and its value lagged by one period is 0.9306.

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farmers and livestock breeders, so as not to limit their means of subsistence. Water storage has proven to be an effective strategy that allows the population to adapt to climate change.

Regarding the influence of control variables, we propose the implementation of democratic and peaceful strategies capable of regulating and limiting strikes and riots. To counter the role of inflation in fragility, we call for methods that could stabilise rising food prices by increasing the level of national and regional stocks of various foodstuffs to limit or delay the influence of climatic shocks, such as drought, on social conditions. Furthermore, the influence of FDI and remittances on fragility allows us to propose the establishment of formal mechanisms for transferring external funds to fragile countries in SSA. External funds channelled through formal channels, instead of being used for terrorist activities and rebellions, are more likely to help finance productive investments capable of accelerating economic growth. Finally, fragile states must set up legal frameworks for the exploitation of natural resources between local populations, the private sector and the government to avoid or reduce conflicts between these stakeholders.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X25000087.

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