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Sub-Saharan Africa: Building Resilience to Climate-Related Disasters

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ABSTRACT: This paper assesses the impact of climate-related disasters on medium-term growth and analyzes key structural areas that could substantially improve disaster-resilience. Results show that (i) climate-related disasters have a significant negative impact on medium-term growth, especially for sub-Saharan Africa; and (ii) a disaster's intensity matters much more than its frequency, given the non-linear cumulative effects of disasters. In sub-Saharan Africa, electrification (facilitating irrigation) is found to be most effective for reducing damage from droughts while improved health care and education outcomes are critical for raising resilience to floods and storms. Better access to finance, telecommunications, and use of machines in agriculture also have a significant impact.

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Contents

I. Introduction

Sub-Saharan Africa (SSA) is increasingly suffering from climate change. In recent years, the frequency and intensity of droughts, floods, and storms—such as cyclones Idai and Kenneth, and droughts caused by the El Niño–Southern Oscillation (ENSO)—have grown. These disasters are taking a serious toll on the region's economic performance, particularly through agriculture, trade, and services given SSA's reliance on rain-fed agriculture (Jones and Olken, 2010; Garcia Verdu et al., 2019). The consequences are most pronounced for lower income households who are least equipped to handle the consequences of these shocks. The COVID-19 pandemic and other recent health and agriculture-related epidemics (e.g., Ebola, locust infestations) have further heightened SSA's vulnerabilities to climate shocks by substantially weakening the population's economic and health conditions.

In designing post-pandemic recovery strategies, SSA policymakers may be considering urgently needed climate-resilience measures to preserve the region's growth and development prospects. However, the pandemic's steep economic toll has limited governments' financial and human resources. Governments must prioritize across policy measures. To assist in this process, this paper examines how climate-related disasters impact medium-term economic growth and which structural areas would be most effective in reducing its adverse economic and social consequences in SSA.

The first part of our analysis finds a significant negative impact of climate-related disasters on medium-term growth, especially for SSA. For example, the impact of a drought is about three times larger in SSA than in other emerging and developing economies. We also confirm past findings (Cavallo et al., 2013; Fomby et al., 2013) that a disaster's intensity matters more than its frequency, as higher adverse effects on medium-term growth are found to be associated with intensity. This is explained by the non-linear cumulative effects of successive disasters and highlights the fact that the growth impact of natural disasters is best estimated with disasters of large magnitude.[1] All these results are based on a model we built to understand medium-term growth in SSA based on macroeconomic variables as well as the frequency and the intensity of disasters (following Barro, 1991; Loayza et al., 2012). The model accounts for the potentially unrecoverable loss of human capital (from deaths, malnutrition, or lower school enrollment) after a disaster negatively affects long-term growth—even though the near-term damage from disasters to economic activity is often offset by foreign financial assistance, remittances, and reconstruction.

The second part of our analysis highlights structural areas most critical for building resilience to climate-related disasters. Given SSA's limited contribution to greenhouse gas emissions, this paper focuses on strategies for adaptation rather than mitigation.[2] In particular, electrification combined with irrigation is key to building resilience to droughts; health care and education are most important for minimizing the damage from floods and storms; and access to finance, telecommunications, and use of machinery in agriculture also make

[1] Cavallo et al (2013) demonstrates that *"[…] the threshold for what constitutes a natural disaster in some datasets may be lenient"*.

[2] Tackling the challenges of climate change requires investment on two fronts: (1) Adaptation—defined by the Intergovernmental Panel on Climate Change (IPPC) as *"the process of adjustment to actual or expected climate and its effects"*—which depends mostly on individual country strategies; and (2) Mitigation—defined by the IPPC as *"a human intervention to reduce the sources or enhance the sinks of greenhouse gases"*—which requires a coordinated global effort and has been part of the international community's global agenda over the past 30 years (e.g., United Nations Framework Convention on Climate Change, Kyoto Protocol, Conference of the Parties). However, a significant reduction of greenhouse gases has not been achieved mainly due to divergent strategies across important stakeholders.

significant contributions to resilience-building. These findings are based on a policy response analysis performed on specific types of disasters. For completeness, in the current pandemic environment, the analysis also includes epidemics but the results were inconclusive.

This paper contributes to the existing literature through a number of channels. By developing a model that shows how various policy variables can improve resilience to climate change in SSA, it is related to the branch of climate change research that assesses the economic impact associated with various types of disasters (Loayza et al., 2012; Cavallo et al., 2013). Notably, the bulk of past research in this area has focused on the consequences of global warming, by providing global scenarios and estimating the impact of increasing temperatures on outcomes (Dell et al., 2008; Tol, 2009; Acemoglu et al., 2012; Burke et al., 2015). This paper also contributes to the literature on growth models that are estimated with panel data and climate change variables. Specifically, it follows the strategies proposed by Islam (1995) and Loayza et al. (2012), as the introduction of climate change proxies requires use of a sparse growth model. However, unlike the latter, our analysis includes a simultaneous assessment of the impact associated with the intensity and the frequency of disasters. Finally, this paper contributes to the development of strategies for improving resilience to climate-related natural disasters (Laframboise and Loko, 2012; Marto et al., 2018; Cantelmo et al., 2019; Melina and Santoro, 2021).

The remainder of the paper is organized as follows. Section II presents the data applied in our analyses, including how climate-related disasters are quantitatively proxied. Section III applies an impact analysis, quantifying the effects of climate-related disasters on medium-term growth. Section IV details the policy response analysis which measures the extent to which selected structural reform areas can improve resilience to climate-related disasters. Section V concludes.

II. Data: Proxies for Climate-Related Disasters and Other Variables

A. Quantitative Proxies of Climate-Related Disasters: Intensity and Frequency

In accordance with the Emergency Events Database (EM-DAT) compiled by the Centre for Research on the Epidemiology of Disasters (CRED), and throughout the paper, climate-related disasters are defined as climate-related hazards that lead minimally to one of the following tolls: *at least 10 people dead, at least 100 people affected, a declaration of a state of emergency, or a call for international assistance*. The econometric strategies for both sections III and IV rely on introducing quantitative proxies of disasters into a growth model à la Barro (1991).

Climate-related disasters can impact economic outcomes through their intensity and frequency. Therefore, their quantitative proxies must factor in these two dimensions. Our strategy, in this regard, is to adopt two distinctive (but not exclusive) proxies.

Intensity proxy

The intensity proxy is defined with a dummy variable that provides information on whether the total annual effect of disasters weighs on over 0.01 percent of the population. To be specific, following Fomby et al. (2013), the intensity, during the year *t*, of disasters of type *k* in country *i*, is measured as follows:

$$Intensity_{i,t}^{k} = \begin{cases} 1, & \text{if } \dfrac{Fatalities_{i,t}^{k} + 0.3 \cdot Affected_{i,t}^{k}}{Population_{i,t}} > 0.0001 \\ 0, & \text{otherwise} \end{cases} , \quad (1)$$

where $Fatalities_{i,t}^{k}$ and $Affected_{i,t}^{k}$ represent the total deaths and total affected that are associated with disasters of type *k* in country *i* during year *t*.[3] $Population_{i,t}$ is the population of country *i* in year *t*.

Frequency proxy

The frequency proxy considers the total effects related to the occurrence of disasters during the year. Because of the non-linear cumulative effects of successive disasters, considering only the number of disasters as the frequency proxy would be misleading.[4] For this purpose, following Loayza et al. (2012), the frequency proxy associated with disasters of type *k*, during the year *t* in country *i*, is defined as follows:

$$Frequency_{i,t}^{k} = \frac{Fatalities_{i,t}^{k}}{Population_{i,t}} , \quad (2)$$

where $Fatalities_{i,t}^{k}$ and $Population_{i,t}$ are defined as previously. A frequency proxy that considers both fatalities and affected people in its numerator is applied as a robustness check (Annex 3).[5]

Our proxies build on human capital destruction (as opposed to physical capital destruction). This strategy is mainly driven by data availability, as the EM-DAT database provides information mostly on fatalities and affected people associated with natural disasters. A strategy based on physical capital destruction could also be used, but the data on economic costs are scarce. However, physical capital deterioration could be captured through conventional growth model controls.

Note that, although both types of proxies gather information on the overall severity of disasters, the intensity proxy aims at distinguishing disasters that have a priori significant macroeconomic impacts while the frequency proxy includes all disasters without any ex-ante consideration with regard to their severity.

B. Other Variables

Our analysis is based on a panel database covering 181 countries during 1960-2018, selected based on availability. The panel sources information from the World Economic Outlook (WEO), the World Development Indicators (WDI), and the Emergency Events Database (EM-DAT).
To correct for short-term disturbances and avoid noisy results from our growth regressions, we follow Islam (1995) and aggregate the annual figures into five-year windows with the new values being averages over the windows. Thus, the final panel has 12 five-year periods. However, the intensity and the frequency proxies are

[3] For more details on the weights allocated to fatalities and affected people see Fomby et al. (2013). Note that the disaster data are annualized. Therefore, the annual figures associated with a disaster of type *k* are the sum of all the effects associated with this type of disaster during the year.

[4] For example, when two consecutive disasters hit, the damage toll of the second could include a part of the first since part of the population (especially the poorest) may not be able to fully recover before the second disaster.

[5] See Annex 3 for results with the frequency proxy $Frequency2_{i,t}^{k} = \frac{Fatalities_{i,t}^{k} + 0.3 * Affected_{i,t}^{k}}{Population_{i,t}}$.

not aggregated the same way, as the aggregated intensity proxy aims at capturing the proportion of disruptive disasters while the aggregated frequency proxy gives the ratio between the disaster-related fatalities and the population.

The control variables for the impact analysis are these of Loayza et al. (2012), which proposes a growth model that includes disaster proxies. The control variables of Barro (2003) are applied in Annex 1 as a robustness check. The policy response analysis is based on a large set of control variables aiming to capture various socioeconomic aspects of the panel countries. Table 1 provides data sources for all the variables.

Table 1: Description of variables

Variable	Description (source)
Variables used for the impact analysis (growth model)	
Intensity/Frequency of droughts, floods, epidemics and storms	Defined by the proxies
Log of per capita GDP	Real per capita GDP, PPP (WEO)
Education	Gross rate of enrollment in the secondary (WDI)
Investment	Gross fixed capital formation, percent of GDP (WEO)
Government consumption	Percentage of per capita GDP government consumption (PWT)
Inflation	Consumer Prices, period average, percent change (WEO)
Trade openess	Ratio (Import+Export) to GDP (WEO)
Change in terms of trade	Change ratio, price export to price import (PWT)
Variables used for the policy response analysis	
Telecommunication	Mobile cellular subscriptions per 100 people (WDI)
Financial depth	Domestic credit to private sector, percent of GDP (WDI)
Education	Gross rate of enrollment in the secondary (WDI)
Health	Life expectancy at birth (WDI)
Agri. Machinery	Agricultural machinery, total tractors (WDI)
Electricity	Access to electricity, percent of population (WDI)

Irrigation, sanitation, quality of fiscal policy and quality of roads are variables that were excluded from the policy response analysis because of data issues.

III. Impact Analysis: How Do Climate-Related Disasters Impact Growth in SSA?

A. Econometric Strategy and Estimation

We first consider the following panel growth model:

$$\begin{aligned} G_{i,t+1} &= Log(Y_{i,t+1}) - Log(Y_{i,t}) \\ &= aLog(Y_{i,t}) + b_1 Inten_{i,t}^k + b_2 Freq_{i,t}^k + B_3 X_{i,t} + c_{1,t} + d_{1,i} + \eta_{i,t} \ , \end{aligned} \quad (3)$$

where $Y_{i,t}$ is the per capita GDP in country *i* and year *t*, $G_{i,t}$ is the per capita GDP growth between years *t* and *t+1*, $Inten_{i,t}^k$ and $Freq_{i,t}^k$ are the intensity and the frequency proxies for climate-related disasters of type *k* in country *i* and year *t*, $X_{i,t}$ is the matrix of additional control variables, $c_{1,t}$ and $d_{1,i}$ are the year and country specific effects, respectively, and $\eta_{i,t}$ is the error term.

Our analysis is based on a five-year aggregation of the yearly model above (following Islam, 1995). Therefore, the model that assesses the effects, on growth, of the frequency and intensity of climate-related disasters is as follows:

$$\overline{G}_{i,p} = a\overline{Log(Y_{i,p})} + b_1\overline{Inten}_{i,p}^{k} + b_2\overline{Freq}_{i,p}^{k} + B_3\overline{X}_{i,p} + c_{2,p} + d_{2,i} + \varepsilon_{i,p} \qquad (4)$$

where *p* is a 5-year period, going from t_{p1} to t_{p5}, $\overline{Inten}_{i,p}^{k} = \frac{1}{N_k}\sum_{t=t_{p1}}^{t_{p5}} Inten_{i,t}^{k}$ (with N_k the number of disasters of type *k* during the 5-year period) and $\overline{Freq}_{i,p}^{k} = \frac{1}{5}\sum_{t=t_{p1}}^{t_{p5}} Freq_{i,t}^{k}$. Moreover, $\bar{G}_{i,p}$, $\overline{Log(Y_{i,p})}$ and $\bar{X}_{i,p}$ are the averages, over the 5 years, of per capita GDP growth, per capita GDP and additional controls, respectively, $c_{2,p}$ and $d_{2,i}$ are time and country specific effects, respectively, and $\varepsilon_{i,p}$ is the error term. In this new specification, the intensity and frequency proxies are the rate of disruptive disasters and the average relative fatalities over 5 years, respectively.

The parameters in equations (3) and (4) are not necessarily the same, given that the latter is not a simple average of the former. However, to simplify, the same notations are used in both models.[6] Our analysis uses Model (4). In this specification, the frequency and intensity proxies correspond to the average frequency and the relative intensity over a 5-year window, respectively. The model is estimated using GMM methods to correct for potential correlation between the unobserved effects and the lagged regressor, as the model builds on a dynamic panel. The instruments are selected to ensure exogeneity while the endogenous variables are the per-capita GDP and the disaster proxies.[7]

B. Results

Table 2 presents the estimation results for emerging market and developing economies (EMDEs) and SSA. We find:

- There is a significant negative impact of climate-related disasters on medium-term growth, with most of the significant effects originating from droughts and floods.[8]

[6] The transition between (3) and (4) is presented to explain the concept behind the 5-year panel model that is used in the subsequent analyses.

[7] All available lagged regressors (i.e., without ex-ante lag-related restrictions) are used as instruments which are later collapsed to reduce the many-instrument bias. Other specifications of the set of instruments were tested, whose associated results are available upon request. The chosen specifications are the ones that give the most significant results regarding instrument exogeneity (Arellano-Bond and Hansen tests).

[8] Scarcity of data on epidemics and storms could justify the inconclusive results associated with these two types of disasters.

- Climate-related disasters prominently weigh on SSA growth—with droughts having the strongest effect, possibly reflecting their prolonged nature. This indicates the region's lack of resilience and dependence on rain-fed agriculture.[9]

- A disaster's intensity impacts medium-term growth more than its frequency (when both intensity and frequency are controlled), as the marginal effects associated with the intensity proxy are consistently higher than these associated with the frequency proxy. Figure 1 shows that the growth decline associated with an increase in frequency/severity of a disaster is higher for the intensity proxy. More precisely, the predicted growth increase associated with a reduction of the proxies, from their average values to 0, is higher for the intensity proxy.

    - This result, which is consistent with the findings of Cavallo et al. (2013) and Fomby et al. (2013),[10] can be explained by the cumulative effects of consecutive natural disasters. An immediate successive and very intense disaster would be particularly disruptive for lower income households, who would not have had enough time to recover from the first. This highlights the fact that a disaster's intensity matters much more than its frequency with regard to the adverse impact on growth. However, since the two proxies are not exclusive and are positively correlated, it is relevant to consider both the intensity and the frequency of disasters when analyzing the adverse effects of climate-related disasters on growth.[11]

- The results for epidemics and storms are not conclusive. This is explained by the limited data availability on epidemics and the limited data coverage on storms. However, results for floods can help understand the effects of storms on medium-term growth, as floods include the after-effects of extreme storms such as cyclones.

Besides the disaster proxies, the marginal effects associated with the controls seem to be consistent with the literature (particularly for the models with droughts or floods). Education, investment, and trade openness would favorably impact growth while inflation would impact it negatively.

C. Complementary Results

The null hypothesis on the exogeneity of instruments is not rejected in our estimations. However, the high p-values of some of the Hansen and Difference-in-Hansen tests indicate potential issues with the instruments.[12] Therefore, we use another estimation strategy to confirm the previous results. For that purpose, we re-estimate the model by using the minimum distance estimation (MDE) method, which is applied on growth dynamic panels by Islam (1995).

The minimum distance estimation method builds on Chamberlain (1982, 1983). As applied by Islam (1995), it consists of (i) building a time-related augmented model in which the lagged dependent variables are substituted

[9] Additional models, whose specifications include an interaction between an SSA dummy variable and the intensity proxy, show that drought-related adverse impacts on growth are higher in SSA than in any other region. These results are available upon request.

[10] These papers show that the macroeconomic impacts of natural disasters are driven by large/intense disasters. Cavallo et al (2013) explain this result by the fact that the threshold for natural disasters in some datasets is too low.

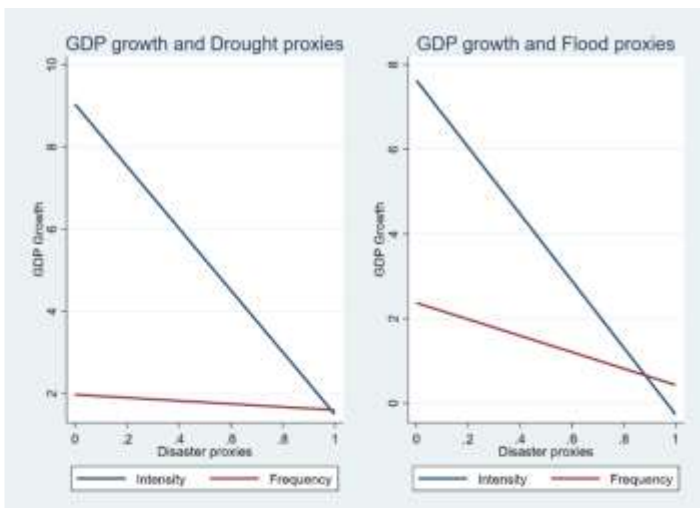
[11] Since the difference between intensity and frequency of disasters is not accurately characterized by our proxies for very extreme disasters, the result does not necessarily apply to disasters that have an extremely high death toll (e.g., more than 1 percent of the population, as shown by Figure 1).

[12] To avoid any doubt regarding the exogeneity of the instruments or the instrument subsets, Roodman (2009) recommends seeking p-values between 0.1 and 0.25.

by their expressions and (ii) estimating the final model by assuming that the t_0-dependent variable is a linear function of the exogenous variables.[13] The main limitation of this approach is that an additional assumption is made on the initial state (t_0). That additional assumption implies that the results from the current analysis are expected to be quantitatively different from what has been obtained with the GMM model. The focus is therefore on confirming the qualitative patterns associated with the effects of natural disasters on growth.

The new results are consistent with the previous GMM results (Table 3). Droughts and floods are the disasters for which results are significant, with droughts having the biggest effects on growth. If a drought intensifies by 10 percentage points, medium-term annual per capita growth can decline by almost 0.8 to 1 percentage points in SSA. An intensification of floods by the same amount takes one-fifth to one-fourth the toll on medium-term growth. To provide some perspective, SSA's medium-term annual per capita growth was projected at 1.8 percent in the October 2019 WEO—prior to the COVID-19 pandemic and assuming no climate shocks. Also, the negative impact of droughts on SSA growth can be up to three times that in emerging and developing economies.

Figure 1: EMDEs: Model-based predicted growth and disaster proxies



Note: The figure, which presents the predicted GDP growths (y-axis) associated with various values of the disaster proxies (x-axis), illustrates the negative correlation between intensity/frequency of disasters and GDP growth. The more the disaster proxy increases, the more growth declines. Marginal effects on growth, which are given by the slopes, are higher for the intensity proxy in case of both droughts and floods. The comparison excludes very extreme disasters (dead toll higher than 1 percent of the population) since the breakdown between intensity and frequency, as measured by our proxies, does not necessarily hold for such extreme disasters. Note that disasters that have a cumulative dead toll of over 1 percent of the population represent less than 2.6 percent of floods and less than 1.6 percent of droughts in our sample. The scale of the x-axis is "0 to 1" for the intensity proxy (average of dummies) and "0 to 1 percent" for the frequency proxy (as disasters with dead tolls of more than 1 percent of the population are excluded from the comparison).

Source: Authors' calculations

[13] By design, fixed effect methods are particular cases of this estimation strategy.

Table 2: Selected economies: Growth models with disaster Indicators (GMM)

	EMDEs				SSA			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log of per capita GDP	-10.368***	-3.254***	5.166**	-4.933**	-2.774*	3.090	0.039	4.239
	(3.910)	(1.159)	(2.238)	(2.130)	(1.422)	(2.340)	(1.329)	(2.597)
Drought intensity	-7.540**				-11.328*			
	(2.948)				(6.118)			
Drought frequency	-0.373***				-0.448***			
	(0.089)				(0.076)			
Flood intensity		-7.892***				-3.216***		
		(2.467)				(1.219)		
Flood frequency		-1.939				-0.053		
		(1.863)				(0.115)		
Epidemic intensity			-1.183				-0.770	
			(0.851)				(0.633)	
Epidemic frequency			0.051				0.169	
			(0.224)				(0.175)	
Storm intensity				-1.098				1.071
				(0.814)				(1.381)
Storm frequency				0.376*				-1.106
				(0.223)				(6.585)
Education	0.256***	0.070**	-0.109**	0.134**	0.056	-0.113*	-0.004	-0.131
	(0.097)	(0.028)	(0.055)	(0.057)	(0.047)	(0.068)	(0.036)	(0.083)
Investment	0.087*	0.151***	0.026	0.164***	0.040**	0.031	0.041	0.001
	(0.051)	(0.045)	(0.045)	(0.053)	(0.019)	(0.038)	(0.027)	(0.064)
Government consumption	-0.038	-0.059***	0.002	-0.103***	0.012	-0.002	-0.031	-0.041
	(0.045)	(0.022)	(0.040)	(0.037)	(0.026)	(0.039)	(0.020)	(0.046)
Inflation	0.002	-0.003***	-0.002**	-0.010***	0.001	-0.002***	-0.002***	0.070
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.000)	(0.001)	(0.066)
Trade openess	3.376**	0.550	-0.539	0.363	2.842*	-0.081	3.412**	1.724
	(1.631)	(0.587)	(1.394)	(0.572)	(1.586)	(1.483)	(1.564)	(1.449)
Change in terms of trade	-0.003	0.036	-0.015	0.268**	-0.275***	0.084	0.046	0.008
	(0.108)	(0.069)	(0.080)	(0.110)	(0.095)	(0.093)	(0.060)	(0.284)
Intercept	77.161***	29.142***	-34.732**	35.147**	31.844**	-15.730	-1.006	-27.931
	(27.336)	(8.847)	(15.143)	(14.675)	(14.145)	(14.860)	(8.775)	(19.670)
Observations	211	513	312	325	113	163	158	67
Number of instruments	39	68	39	40	45	46	46	45
Arellano-Bond test for AR(1)	0.019	0.004	0.005	0.012	0.048	0.024	0.015	0.062
Arellano-Bond test for AR(2)	0.090	0.351	0.293	0.867	0.269	0.527	0.119	0.431
Hansen test	0.193	0.257	0.125	0.340	0.945	0.601	0.698	0.910
Difference-in-Hansen test	0.100	0.113	0.103	0.383	0.115	0.011	0.900	0.879

Note: (1), (2), (3) and (4) represent models for droughts, floods, epidemics and storms, repectively. *, ** and *** indicate statistical significance at 10, 5 and 1 percent, respectively. Year-dummy parameters are not presented.

D. Additional Robustness Checks

Our models build on adding climate-related disasters in conventional growth models according to the strategy used by Loayza et al (2012).[14] This section proposes an additional robustness check that consists of using the growth controls from Barro (2003). Concretely, life expectancy, fertility and democracy are added to the set of

[14] Loayza et al (2012) also find that drought and floods have significant negative impacts on growth in EMDEs.

controls initially used in Model (4). The focus remains on confirming the qualitative results associated with the effects of disaster on medium-term growth.[15]

Tables A1 and A2 in Annex 1 confirm that the results are robust to the new specification. The marginal effect associated with the intensity of disasters is higher than that of the frequency of disasters. Also, the negative growth effect of droughts from the fixed-effect model seems to be larger in SSA than in EMDEs, droughts and floods being the two disasters for which the adverse effects on growth are significant in EMDEs. From the baseline results (GMM estimates), the marginal effects associated with the control variables are broadly consistent with the initial model and indicate that higher fertility reduce medium-term growth prospects while better democratic systems improve them.

Table 3: Selected economies: Growth models with disaster indicators (Fixed effects)

	EMDEs				SSA			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log of per capita GDP	-2.091**	-2.034***	-2.524**	-1.061	-2.369	-1.566	-1.509	6.724
	(0.984)	(0.655)	(0.994)	(1.163)	(1.433)	(1.373)	(1.069)	(3.936)
Drought intensity	-2.657***				-7.810***			
	(0.744)				(2.157)			
Drought frequency	-0.340***				-0.412***			
	(0.053)				(0.042)			
Flood intensity		-1.308***				-1.192**		
		(0.441)				(0.564)		
Flood frequency		-0.061**				-0.178**		
		(0.031)				(0.084)		
Epidemic intensity			-0.198				-0.532	
			(0.331)				(0.409)	
Epidemic frequency			-0.001				-0.010	
			(0.129)				(0.161)	
Storm intensity				-0.383				0.320
				(0.473)				(0.996)
Storm frequency				-0.187**				-12.262
				(0.084)				(11.267)
Education	-0.066**	-0.069***	-0.048*	-0.065***	-0.051	-0.075*	-0.056	-0.159
	(0.032)	(0.018)	(0.028)	(0.021)	(0.059)	(0.039)	(0.050)	(0.160)
Investment	0.025***	0.086***	0.067***	0.023	0.032***	0.049*	0.046**	0.088
	(0.009)	(0.023)	(0.018)	(0.035)	(0.010)	(0.024)	(0.021)	(0.062)
Government consumption	-0.006	0.016	0.050**	-0.023	-0.006	0.060*	0.055**	0.084
	(0.020)	(0.029)	(0.025)	(0.035)	(0.021)	(0.030)	(0.025)	(0.058)
Inflation	0.002***	-0.002**	-0.001***	-0.009***	0.001	-0.001***	-0.001***	0.065
	(0.000)	(0.001)	(0.000)	(0.002)	(0.001)	(0.000)	(0.000)	(0.058)
Trade openess	0.357	0.047	0.146	-0.290	0.628	1.741	4.524**	-1.525
	(0.378)	(0.642)	(1.057)	(0.698)	(1.268)	(1.416)	(1.869)	(4.765)
Change in terms of trade	0.005	-0.020	0.034	0.092*	-0.115	0.069	0.063*	-0.027
	(0.072)	(0.065)	(0.045)	(0.055)	(0.088)	(0.062)	(0.036)	(0.357)
Intercept	21.370***	20.312***	20.608**	14.345	26.846***	12.288	7.993	-46.390
	(7.526)	(5.234)	(7.980)	(10.140)	(9.383)	(9.117)	(8.791)	(27.146)
Observations	211	513	312	325	113	163	158	67
R2	0.560	0.399	0.393	0.387	0.666	0.514	0.536	0.503

Note: (1), (2), (3) and (4) represent models for droughts, floods, epidemics and storms, repectively. *, ** and *** indicate statistical significance at 10, 5 and 1 percent, respectively. Year-dummy parameters are not presented.

[15] Note that more robustness checks were performed, notably on using a frequency proxy that considers both the fatalities and the number of affected people (Annex 3).

IV. Policy Response Analysis: Resilience-Building in SSA

At an economy-wide level, raising resilience requires reforms tailored to a country's specific climate change challenges. Strong macroeconomic, institutional, and structural policies as well as measures to ensure food security are a must. However, beyond that, there are critical combinations of structural reform areas, based on specific climate change challenges, where improvement could lead to substantial gains in containing the impact of climate-related natural disasters on economic growth and inequality. Ultimately, high resilience could avoid disastrous results altogether. This section focuses on these structural reform areas, while specific policies to make progress in any individual structural area is comprehensively discussed in the literature (IMF, 2015, 2019).

The areas that are considered for the analysis are: telecommunication, access to finance, education, health, mechanization, and electricity. The specific variables, along with the data sources, that are used for each area are presented in Table 1.

A. Econometric Analysis and Results

The following model is considered:

$$\overline{G}_{i,p} = a\overline{G}_{i,p-1} + b_1\overline{Dis}_{i,p}^{k} + b_2\overline{Dis}_{i,p}^{k} \cdot z_{i,p} + b_3 z_{i,p} + c_p + d_i + \varepsilon_{i,p} \,, \tag{5}$$

were *i* represents countries, *p* is a 5-year period, $\bar{G}_{i,p}$, c_p and d_i are defined as in equation (4), $z_{i,p}$ is a policy variable—representing a structural area—and $\overline{Dis}_{i,p}^{k}$ is either the intensity proxy or the frequency proxy associated with a climate-related disaster of type *k* in country *i* and period *p*. This model is fundamentally different from the previous model (4). It helps investigate the growth effects of policy variables that are not necessarily relevant for growth models and each policy variable is included separately. As disaster proxies are not "natural" controls for growth model à la Barro, trying to add the interaction term as an additional explanatory variable in (4) would lead to inconsistent results. The inclusion of lagged growth helps control for the effects associated with the previous control variables used in (4). Also, to mitigate any potential multicollinearity issues, the intensity and the frequency proxies are included separately.

The analysis focuses on the sign and significance of parameter b_2 (which is the slope for the interaction term). Policy variables (or structural reform areas) are analyzed one at a time. In accordance with the results from the previous section, b_1 would be negative. Hence, a positive and significant estimate for b_2 would mean that the policy variable (or structural area) helps improve resilience to the type of climate-related disaster being analyzed. The estimation strategy is the same as before, with GMM and MDE models. For this exercise, we only focus on cases for which b_2 is significant. The variables are described in Table 1.

The results, summarized in Table 4, show that resilience to climate-related disasters is significantly improved by raising access to telecommunication, finance (proxied by financial depth), and electricity as well as improving health, education, and mechanization (proxied by use of agricultural machinery). The detailed regression results for each type of climate-related disaster, quantified using the intensity and frequency proxies separately, are reported in Annex 2. Although the analysis for epidemics (applying the intensity proxy) does not lead to a significant value of the parameter b_2, all the policy variables that have been considered (except mechanization) tend to be positively associated with raising the resilience of economic growth to epidemics.

The results from the two estimation strategies (GMM and the fixed effects) are consistent for the parameter of interest b_2. For the GMM, as in the impact analysis in section III and besides the disaster proxies, the signs of the parameters associated with controls are largely in line with the growth literature (with a positive impact of health and education on growth). On the other hand, the fixed effect method provides results that are consistent with those from the GMM method for the disaster proxies.

Table 4: b_2 estimates in model (5)

	Intensity (GMM)				Intensity (Fixed effects)			
	Droughts	Floods	Epidemics	Storms	Droughts	Floods	Epidemics	Storms
Telecommunication		0.014**	0.017**	0.009**		0.009**		
Access to finance	0.026*	0.022***		0.015*	0.026*	0.016**		
Education				0.032***				0.028**
Health		0.084**		0.113***		0.086**		0.083**
Mechanization		0.000*				0.000**		
Electricity	0.057*			0.020*	0.114***			

Note: The table focuses on significant values of the parameter b2. *, ** and *** indicate statistical significance at 10, 5 and 1 percent, respectively.

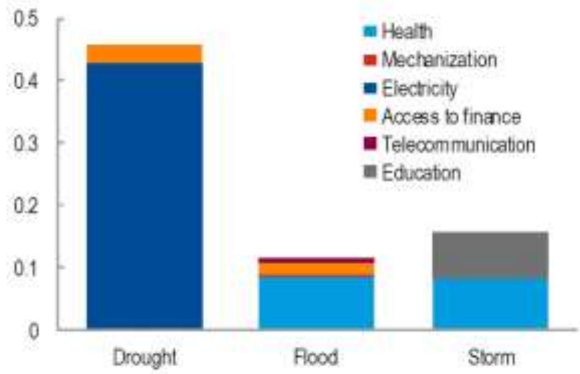
B. Policy Implications

To better understand the policy implications of the econometric results from Section IV.A above, we apply the results to a scenario where a climate-related disaster strikes. The analysis investigates the relative gains in resilience to climate-related disasters from advancing each structural area above (in Table 1)—taking into account SSA's current level of advancement in each area. Effectively, for a given climate-related disaster, the gap between the SSA and the EMDE average for each structural reform area is multiplied by the estimates for the parameter b_2—the marginal impact of a structural area in improving the resilience of growth—and an increase in the intensity proxy by 10 percentage points. The intensity proxy, rather than the frequency proxy, for climate-related disasters is applied in this analysis since section III finds that intensity has a stronger impact on economic growth.

The results show the per capita economic growth in SSA that is protected from loss when a climate-related disaster strikes—owing to SSA improving a given structural reform area to the average EMDE level (Figure 2). The combinations of structural reform areas that are most effective for specific types of climate-related disasters are discussed below.

While the exact magnitudes of this analysis should be interpreted as suggestive, the relative impact of these structural areas is a robust indication of their importance. Note that the impacts illustrated in Figure 2 are separate from each structural area's impact on growth through all other channels (the marginal impact through other channels is represented by b_3 in equation 5 above with estimates in Annex 2).

Figure 2: Reduction in impact of disasters on SSA's medium-term growth if structural factors improve



Note: The figure shows SSA's reduction in the impact of disasters on per capita annual medium-term growth, when structural factors are improved to the EMDEs average and when the intensity proxy increases by 10 percentage points.

Droughts

Better access to electricity and finance can halve the medium-term economic loss from a drought. When a drought intensifies by 10 percentage points, medium-term per capita annual growth declines by at least 0.8 percentage points (Section III above). Applying the results from the policy response analysis, we find that 0.43 percentage points of this loss could be avoided—especially by closing gaps with EMDEs in electricity (Figure 2).

Why electricity? It is essential for powering irrigation systems and deep tube-well pumps, which are critical for rural populations and the urban poor during prolonged dry spells and water shortages. Due to a lack of adequate data, these variables were not explicitly incorporated into the analysis. This line of thinking would suggest that improvements in irrigation systems and deep tube-well pumps could raise resilience beyond the 0.43 percentage points estimated in this paper—where the benefits from greater access to electricity are assessed based on existing irrigation and pumping systems. Governments can help by prioritizing public investment in appropriate irrigation, water, and electricity systems.

A major component in increasing access to electricity will be diversification of electricity sources towards geothermal, solar, and wind power (IMF 2020: April 2020 REO). Coal-generated electricity, the source for most of SSA, is expected to be gradually phased out as climate change mitigation efforts progress. Hydropower, generating one fifth of SSA's electricity, is susceptible to droughts (Castellano et al., 2015). Building more reservoirs, dams, and power plants are a near-term solution. Over the long-term, decentralization of renewable energy sources may be a more sustainable solution while supporting electrification and job creation. Reduced reliance on hydroelectricity also facilitates water management, where improvements in water access, constructing and rehabilitating small dams and boreholes, and setting up solar irrigation schemes will be key.

Access to finance for households and small and medium enterprises allows them to invest in weather-resilient infrastructure (such as irrigation systems and electricity) and provides post-disaster buffers. For example, it can finance farmers' investment in methods to mitigate crop damage; and enable households to buy food when prices rise after a drought devastates crops. Central banks and governments can play an important role in improving access to finance by reducing informational asymmetries (e.g., supporting credit bureaus) and improving property rights. Even when access to finance is available, often the amount of financing available to a household is limited by its low-income level and asset values. In these cases, targeted government subsidies could fill the gap.

Floods and storms

Policies for containing the impact of floods and storms are similar given extreme storms, such as tropical cyclones, also result in severe flooding. Our analysis indicates that the bulk of the medium-term growth loss from floods and storms could be avoided with better health care, education and access to finance, telecommunication, and mechanization—raising these areas to the EMDE average (Figure 2). For example, when a flood intensifies by 10 percentage points, medium-term per capita annual growth declines by at least 0.15 percentage points (Section III above). Based on application of the policy response analysis, improving health care alone to the EMDE level can save almost 0.1 percentage points of this damage.[16]

Health care acts through several channels to protect economies from the adverse consequences of floods and storms—especially in terms of food security, income, and employment. People who are in good health before a climate-related disaster strikes are less likely to fall ill in response to the disaster (e.g., fever and spread of diseases like malaria are often associated with severe flooding). This means they can return to work sooner after a disaster, preserving the household's income flow. Reduced out-of-pocket healthcare spending also safeguards household savings which may be needed to pay for repairs or afford higher food prices when crops are damaged by the disaster.

Education also plays an important role. Combined with better health care, education can improve a household's productivity and income potential. Higher incomes support investment in protection of homes and crops from floods and storms and food security—including building of more robust homes and drinking water, sanitation and drainage systems, as well as erosion protection for crops and more adaptable seeds.[17] Governments can help build these areas of resilience with (i) programs that widen accessibility to quality building materials for the poor; (ii) appropriate standards for building codes and regulations; and (iii) effective land-use planning and zoning rules. Raising farmers' awareness and facilitating access to many of these measures will accelerate their implementation.

More broadly, improved health care and education, particularly for children, can help reduce gender inequalities and support better-informed decision-making (Hallegatte et al., 2019); and higher incomes facilitate greater access to finance and insurance.[18] However, it takes time for these improvements to have an impact. In the meantime, targeted social assistance can support reliance-building and compensate for lost income and purchasing power in the aftermath of a climate-related disaster.

Modernization of telecommunications and agricultural machinery are also resilience-building areas. Solid mobile phone coverage and availability, especially in rural areas, can broaden the reach of early warning

[16] The estimates for loss in economic growth from storms (Section III.B) are not significant. Given the similarities in the channels of economic impact between storms and floods, the medium-term economic growth lost from storms can be approximated by that from floods.

[17] In the case of droughts, higher incomes also permit some investment in electrification and irrigation. However, these investments tend to require substantial complementary public investment.

[18] In SSA, use of insurance is less common than in other regions of the world as it often relies on government subsidies and improvements in financial literacy (Giné and Yang, 2009; Mobarak and Rosenzweig, 2013; Cole et al., 2013; Hill, Hoddinott, and Kumar, 2013; Hallegatte et al., 2017).

systems and information on food prices and weather (even with simple text or voice messages) that inform farmers' decisions on when to plant, irrigate, or fertilize—enabling climate-smart agriculture. Meanwhile, use of modern farming machinery can facilitate the creation of dikes, erosion protection, and deeper seed planting.

Epidemics

The characteristics of epidemics vary more than those of climate-related disasters. Consider for example the large variation across epidemics that are health-related (e.g., COVID-19, Ebola) and those that are related to agriculture (e.g., locusts). Even across health-related epidemics, they do not all spread the same way (e.g., malaria vs. COVID-19). Consequently, it is not surprising that the estimations in Sections III. B and IV.A do not yield significant results for epidemics. To improve the results and our understanding, each category of epidemic would need to be analyzed separately. This is beyond the scope of this paper.

Nevertheless, based on anecdotal findings, some of the structural areas discussed above can have a substantial impact in raising resilience to epidemics. Better health care outcomes is obviously critical for health-related pandemics. If a person is in good health before an epidemic strikes, their body may be in a better position to fight the disease. Higher quality drinking water, sanitation and drainage systems can help prevent the spread of water-borne diseases, which are often spread through floods. Similarly, measures that improve the resilience of crops—such as stepped-up crop protection, more resilient seeds, and irrigation—can help counter the adverse consequences of agriculture-related epidemics.

V. Conclusion

Urgent policy action is needed to build SSA's resilience to rapidly growing climate-related disasters, which damage economic growth and development prospects. However, in the wake of the COVID-19 pandemic, governments have limited financial and economic resources and must prioritize across policies.

To assist in this process, this paper examines how climate-related disasters impact medium-term economic growth and structural areas that would be most effective in reducing its adverse economic and social consequences on SSA.

The results from the impact analysis show that climate-related disasters, especially droughts, have a substantial impact on medium-term growth in SSA—much more than in other regions of the world; and they confirm past findings that a disaster's intensity matters much more than its frequency, given the non-linear cumulative effects of successive disasters. The analysis is based on a growth model, applying panel data that includes macroeconomic variables and the frequency and intensity of disasters.

A policy response analysis, examining specific types of climate-related disasters, finds that electrification combined with irrigation is key to building resilience to droughts; health care and education are most important for minimizing the damage from floods and storms; and access to finance, telecommunications, and use of machinery in agriculture also make significant contributions to resilience-building.

In the context of the COVID-19 pandemic, future work could focus on designing epidemic-specific models—separately examining various categories of epidemics—to assess their impact on economic growth and explore structural reform areas that would be most effective in reducing their economic and social damage. The analysis could also be extended by analyzing and comparing the specificities of the effects of disasters on growth in various regions of the world.

Annex I. Robustness checks (impact analysis) - Different controls

The growth model (4) remains as presented in the paper with the exception that, besides the disaster proxies, the control variables are from Barro (2003). In addition to the controls used in the paper, they include life expectancy, fertility and democracy. Fertility is proxied by the total fertility rate (from the WEO) and democracy is proxied by the Polity4 index (from the Center for Systemic Peace).

Table 5 (A1): Baseline model with controls from Barro (2003) – GMM estimation

	EMDEs				SSA			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log of per capita GDP	-9.976***	-4.179***	1.779	-2.048	-0.868	4.735**	5.887***	5.343***
	(3.534)	(1.195)	(1.898)	(1.629)	(1.929)	(1.921)	(1.971)	(1.829)
Intensity drought	-6.597***				-8.713**			
	(2.249)				(3.686)			
Frequency drought	-0.451***				-0.426***			
	(0.069)				(0.023)			
Intensity flood		-7.040***				-1.582		
		(2.389)				(1.057)		
Frequency flood		-2.107				-0.084		
		(1.867)				(0.080)		
Intensity epidemic			-0.424				-1.029	
			(0.637)				(0.808)	
Frequency epidemic			0.114				0.012	
			(0.205)				(0.271)	
Intensity storm				-0.835				-1.912
				(0.692)				(1.352)
Frequency storm				0.249				-2.329
				(0.189)				(6.550)
Education	0.112*	-0.010	-0.057	-0.003	-0.004	-0.153***	-0.169**	-0.132**
	(0.066)	(0.028)	(0.036)	(0.033)	(0.069)	(0.056)	(0.075)	(0.066)
Investment	0.072*	0.129***	0.065**	0.077**	0.014	-0.000	-0.023	-0.062
	(0.037)	(0.040)	(0.033)	(0.034)	(0.018)	(0.042)	(0.037)	(0.066)
Government consumption	-0.036	-0.043*	-0.015	-0.055**	-0.002	-0.007	0.018	-0.018
	(0.042)	(0.024)	(0.030)	(0.028)	(0.020)	(0.047)	(0.041)	(0.057)
Inflation	0.003***	-0.003***	-0.002**	-0.010***	-0.000	-0.002***	-0.002***	0.084
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.000)	(0.000)	(0.056)
Trade openess	2.517*	0.285	0.362	0.198	2.686**	1.248	1.193	4.249**
	(1.318)	(0.493)	(0.802)	(0.429)	(1.350)	(1.425)	(1.508)	(1.846)
Change in terms of trade	0.021	0.024	-0.003	0.259***	-0.184**	-0.014	-0.102	-0.040
	(0.112)	(0.071)	(0.056)	(0.084)	(0.088)	(0.103)	(0.074)	(0.278)
Life expectancy	0.297**	0.206**	-0.061	0.087	0.031	-0.080	-0.091	-0.050
	(0.151)	(0.081)	(0.093)	(0.090)	(0.043)	(0.068)	(0.093)	(0.102)
Fertility	-0.999*	-0.947***	-0.816**	-1.025***	0.015	0.079	0.373	1.506*
	(0.576)	(0.298)	(0.320)	(0.362)	(0.490)	(0.729)	(0.742)	(0.832)
Democracy	-1.199	-0.213	0.988	-0.824	2.558*	6.629***	8.834***	8.487***
	(1.711)	(1.002)	(1.572)	(0.845)	(1.531)	(1.809)	(3.223)	(2.600)
Intercept	67.822***	31.794***	-4.314	18.013**	11.540	-28.831	-40.460***	-46.104***
	(21.462)	(7.195)	(10.229)	(7.707)	(15.244)	(17.718)	(15.176)	(14.039)
Observations	204	495	303	305	106	155	150	67
Number of instruments	40	71	42	43	38	41	41	40
Arellano-Bond test for AR(1)	0.018	0.005	0.001	0.017	0.038	0.047	0.141	0.059
Arellano-Bond test for AR(2)	0.145	0.528	0.099	0.502	0.715	0.221	0.668	0.469
Hansen test	0.186	0.245	0.149	0.135	0.711	0.615	0.414	0.984
Difference-in-Hansen test	0.080	0.157	0.046	0.043	1.000	0.626	0.056	0.234

Note: (1), (2), (3) and (4) represent models for droughts, floods, epidemics and storms, repectively. *, ** and *** indicate statistical significance at 10, 5 and 1 percent, respectively. Year-dummy parameters are not presented.

Table 6 (A2): Alternative model with controls from Barro (2003) – Fixed effect estimation

	EMDEs				SSA			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log of per capita GDP	-2.562**	-2.099***	-2.684***	-0.767	-3.436***	-2.283*	-1.816	6.390*
	(1.059)	(0.707)	(0.991)	(1.235)	(1.139)	(1.252)	(1.136)	(3.164)
Intensity drought	-2.392***				-5.730***			
	(0.771)				(1.873)			
Frequency drought	-0.403***				-0.441***			
	(0.036)				(0.040)			
Intensity flood		-1.321***				-0.986		
		(0.455)				(0.596)		
Frequency flood		-0.071**				-0.200***		
		(0.030)				(0.070)		
Intensity epidemic			-0.088				-0.418	
			(0.320)				(0.461)	
Frequency epidemic			-0.016				-0.031	
			(0.143)				(0.174)	
Intensity storm				-0.340				0.425
				(0.476)				(1.158)
Frequency storm				-0.174**				-12.901
				(0.075)				(12.239)
Education	-0.058*	-0.076***	-0.047*	-0.086***	-0.047	-0.045	-0.017	-0.047
	(0.034)	(0.023)	(0.024)	(0.027)	(0.064)	(0.044)	(0.051)	(0.115)
Investment	0.024**	0.079***	0.065***	0.007	0.025**	0.042*	0.048**	0.097
	(0.009)	(0.023)	(0.019)	(0.044)	(0.009)	(0.023)	(0.021)	(0.076)
Government consumption	-0.007	0.018	0.056**	-0.018	-0.011	0.060*	0.058***	0.122***
	(0.019)	(0.029)	(0.022)	(0.034)	(0.015)	(0.030)	(0.020)	(0.039)
Inflation	0.001***	-0.002**	-0.001***	-0.009***	0.000	-0.001**	-0.001***	0.073*
	(0.000)	(0.001)	(0.000)	(0.002)	(0.001)	(0.000)	(0.000)	(0.039)
Trade openess	0.107	0.077	0.232	-0.381	0.585	1.626	5.509***	-1.498
	(0.456)	(0.637)	(1.091)	(0.692)	(1.248)	(1.538)	(1.943)	(3.939)
Change in terms of trade	0.039	-0.026	-0.006	0.098	-0.091	0.080	-0.012	-0.237
	(0.071)	(0.064)	(0.054)	(0.063)	(0.068)	(0.063)	(0.044)	(0.325)
Life expectancy	0.011	0.011	0.155**	0.062	-0.084*	0.079	0.209***	-0.135
	(0.044)	(0.058)	(0.068)	(0.109)	(0.046)	(0.092)	(0.073)	(0.112)
Fertility	0.471	0.012	-0.293	-0.337	1.597**	0.477	0.130	0.749
	(0.413)	(0.391)	(0.469)	(0.609)	(0.600)	(0.975)	(0.495)	(2.475)
Democracy	-0.461	-0.499	0.267	0.780	0.639	-0.445	1.559	8.406***
	(1.268)	(0.753)	(1.096)	(0.927)	(1.804)	(1.286)	(1.817)	(1.988)
Intercept	21.072**	20.589***	15.619	10.780	24.139***	10.273	-0.560	-47.417**
	(8.073)	(7.093)	(9.792)	(11.359)	(7.955)	(10.724)	(11.371)	(19.626)
Observations	204	495	303	305	106	155	150	67
R2	0.549	0.402	0.420	0.408	0.698	0.523	0.603	0.592

Note: (1), (2), (3) and (4) represent models for droughts, floods, epidemics and storms, repectively. *, ** and *** indicate statistical significance at 10, 5 and 1 percent, respectively. Year-dummy parameters are not presented.

Annex II. Policy response analysis - Tables

This section presents the complete results of Section IV (policy response analysis). The focus is on the intensity proxies, which have the most significant impact on medium-term growth.

Table 7 (A3): Policy response analysis with the drought proxies (intensity)

	GMM						Fixed effects					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.157**	0.133*	0.138*	0.080	0.208**	0.029	0.061	0.042	-0.015	0.066	0.078	0.142
	(0.069)	(0.074)	(0.073)	(0.073)	(0.087)	(0.094)	(0.059)	(0.067)	(0.074)	(0.061)	(0.078)	(0.107)
Intensity Disaster	-1.790***	-2.349***	-2.056*	-3.339	-1.671**	-6.390**	-1.885***	-2.920**	-2.341*	-10.069	-1.383	-14.198***
	(0.628)	(0.817)	(1.240)	(4.159)	(0.705)	(3.259)	(0.695)	(1.198)	(1.399)	(6.811)	(1.043)	(3.398)
Disaster * Telecommunication	0.003						0.002					
	(0.007)						(0.006)					
Disaster * Access finance		0.026*						0.026*				
		(0.015)						(0.014)				
Disaster * Education			0.006						-0.010			
			(0.018)						(0.021)			
Disaster * Health				0.032						0.128		
				(0.062)						(0.099)		
Disaster * Mechanization					0.000						-0.000**	
					(0.000)						(0.000)	
Disaster * Electricity						0.057*						0.114***
						(0.037)						(0.037)
Telecommunication	0.002						-0.018					
	(0.010)						(0.012)					
Access to finance		-0.006						-0.022				
		(0.012)						(0.015)				
Education			0.012						-0.123***			
			(0.018)						(0.031)			
Health				0.060						-0.037		
				(0.064)						(0.111)		
Mechanization					-0.000						0.000**	
					(0.000)						(0.000)	
Electricity						-0.035						-0.061
						(0.035)						(0.052)
Intercept	1.796	3.872***	2.051*	-0.567	2.339**	5.991**	3.383***	4.291***	6.905***	7.107	2.926**	11.691***
	(1.284)	(0.911)	(1.168)	(4.361)	(0.941)	(3.076)	(0.809)	(1.141)	(1.915)	(7.383)	(1.394)	(3.825)
Observations	326	299	256	324	175	196	326	299	256	324	175	196
R2							0.281	0.260	0.391	0.293	0.300	0.299
Number of instruments	79	79	77	79	52	55	-	-	-	-	-	-
Arellano-Bond test for AR(1)	0.005	0.009	0.006	0.004	0.017	0.256	-	-	-	-	-	-
Arellano-Bond test for AR(2)	0.125	0.146	0.067	0.149	0.894	0.333	-	-	-	-	-	-
Hansen test	0.545	0.761	0.709	0.605	0.346	0.158	-	-	-	-	-	-
Difference-in-Hansen test	0.264	0.387	0.062	0.563	0.238	0.138	-	-	-	-	-	-

Note: (1) - (6) represent the policy response models estimated with telecommunication, access to finance, education, health, mechanization and electricity, respectively. The interaction paramaters are the b2, which are the parameters of interest. A positive sign indicates an effective mitigation effect. Year-dummy parameters are omitted.

Table 8 (A4): Policy response analysis with flood proxies (intensity)

	GMM						Fixed effects					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.132**	0.097	0.100	0.121**	0.030	0.206***	0.101***	0.062*	0.110**	0.092**	0.127***	0.073*
	(0.058)	(0.060)	(0.068)	(0.060)	(0.078)	(0.052)	(0.037)	(0.036)	(0.045)	(0.036)	(0.043)	(0.041)
Intensity Disaster	-1.063***	-1.315***	-0.951	-5.933**	-0.684**	-0.552	-1.296***	-1.524***	-1.103*	-6.594**	-0.963***	-0.048
	(0.330)	(0.500)	(0.642)	(2.296)	(0.340)	(0.718)	(0.325)	(0.459)	(0.638)	(2.420)	(0.356)	(0.784)
Disaster * Telecommunication	0.014**						0.009**					
	(0.006)						(0.004)					
Disaster * Access finance		0.022***						0.016**				
		(0.008)						(0.006)				
Disaster * Education			0.008						0.005			
			(0.008)						(0.009)			
Disaster * Health				0.084**						0.086**		
				(0.034)						(0.036)		
Disaster * Mechanization					0.000*						0.000**	
					(0.000)						(0.000)	
Disaster * Electricity						0.007						-0.013
						(0.009)						(0.011)
Telecommunication	-0.018**						-0.031***					
	(0.007)						(0.007)					
Access to finance		-0.014***						-0.029***				
		(0.004)						(0.006)				
Education			-0.002						-0.039***			
			(0.007)						(0.012)			
Health				-0.018						0.047		
				(0.023)						(0.055)		
Mechanization					-0.000						-0.000	
					(0.000)						(0.000)	
Electricity						0.001						0.056***
						(0.007)						(0.021)
Intercept	3.306***	3.437***	2.617***	0.000	3.288***	1.203*	3.146***	3.739***	4.320***	1.218	3.317***	-1.566
	(0.473)	(0.637)	(0.610)	(.)	(0.512)	(0.692)	(0.488)	(0.576)	(0.701)	(3.205)	(0.519)	(1.376)
Observations	933	844	768	932	497	616	933	844	768	932	497	616
R2							0.168	0.148	0.138	0.149	0.152	0.104
Number of instruments	79	79	77	79	56	55	-	-	-	-	-	-
Arellano-Bond test for AR(1)	0.000	0.000	0.000	0.000	0.003	0.001	-	-	-	-	-	-
Arellano-Bond test for AR(2)	0.350	0.382	0.451	0.323	0.572	0.101	-	-	-	-	-	-
Hansen test	0.191	0.150	0.116	0.139	0.091	0.019	-	-	-	-	-	-
Difference-in-Hansen test	0.865	0.820	0.198	0.600	0.257	0.667	-	-	-	-	-	-

Note: (1) - (6) represent the policy response models estimated with telecommunication, access to finance, education, health, mechanization and electricity, respectively. The interaction paramaters are the b2, which are the parameters of interest. A positive sign indicates an effective mitigation effect. Year-dummy parameters are omitted.

Table 9 (A5): Policy response analysis with epidemic proxies (intensity)

	GMM						Fixed effects					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.362***	0.319***	0.366***	0.372***	0.254***	0.336***	0.160***	0.119**	0.137**	0.158***	0.135**	0.137*
	(0.051)	(0.047)	(0.055)	(0.051)	(0.064)	(0.109)	(0.051)	(0.050)	(0.067)	(0.054)	(0.054)	(0.081)
Intensity Disaster	-0.775	-0.671	-0.688	-4.261	-0.859*	0.301	-0.133	-0.090	-0.787	-2.402	-0.088	-0.172
	(0.517)	(0.631)	(0.712)	(3.201)	(0.506)	(0.868)	(0.446)	(0.502)	(0.659)	(2.392)	(0.427)	(0.847)
Disaster * Telecommunication	0.017**						0.010					
	(0.008)						(0.007)					
Disaster * Access finance		0.017						0.004				
		(0.013)						(0.010)				
Disaster * Education			0.013						0.015			
			(0.011)						(0.013)			
Disaster * Health				0.067						0.040		
				(0.049)						(0.038)		
Disaster * Mechanization					0.000						-0.000	
					(0.000)						(0.000)	
Disaster * Electricity						-0.004						0.007
						(0.011)						(0.011)
Telecommunication	-0.009						-0.028**					
	(0.006)						(0.011)					
Access to finance		-0.003						-0.027***				
		(0.006)						(0.006)				
Education			0.007						-0.055**			
			(0.007)						(0.024)			
Health				0.018						0.089		
				(0.025)						(0.059)		
Mechanization					-0.000						-0.000	
					(0.000)						(0.000)	
Electricity						0.015**						0.038*
						(0.007)						(0.022)
Intercept	1.606*	1.871*	-0.946	0.997	2.906***	0.817	2.505***	2.867***	2.749***	-1.420	2.725***	-0.981
	(0.898)	(1.055)	(0.682)	(1.870)	(0.793)	(0.508)	(0.739)	(0.825)	(0.902)	(2.646)	(0.889)	(1.054)
Observations	483	460	394	483	239	342	483	460	394	483	239	342
R2							0.217	0.177	0.242	0.211	0.170	0.141
Number of instruments	78	78	75	78	47	50	-	-	-	-	-	-
Arellano-Bond test for AR(1)	0.003	0.004	0.002	0.003	0.002	0.080	-	-	-	-	-	-
Arellano-Bond test for AR(2)	0.702	0.652	0.691	0.597	0.358	0.501	-	-	-	-	-	-
Hansen test	0.438	0.342	0.753	0.304	0.563	0.306	-	-	-	-	-	-
Difference-in-Hansen test	0.153	0.161	0.725	0.016	0.562	0.412	-	-	-	-	-	-

Note: (1) - (6) represent the policy response models estimated with telecommunication, access to finance, education, health, mechanization and electricity, respectively. The interaction paramaters are the b2, which are the parameters of interest. A positive sign indicates an effective mitigation effect. Year-dummy parameters are omitted.

Table 10 (A6): Policy response analysis with storm proxies (intensity)

	GMM						Fixed effects					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.085	0.054	0.204***	0.093	0.039	0.279***	0.086	0.035	0.114*	0.083	0.064	0.084
	(0.092)	(0.088)	(0.078)	(0.088)	(0.111)	(0.074)	(0.065)	(0.068)	(0.060)	(0.063)	(0.066)	(0.061)
Intensity Disaster	-0.599	-0.804*	-2.449**	-7.709**	-0.309	-1.521*	-0.441	-0.263	-2.232**	-5.855**	-0.406	-1.770*
	(0.376)	(0.486)	(0.871)	(2.280)	(0.509)	(0.836)	(0.415)	(0.477)	(0.974)	(2.569)	(0.612)	(1.033)
Disaster * Telecommunication	0.009**						0.006					
	(0.004)						(0.004)					
Disaster * Access finance		0.015*						0.002				
		(0.009)						(0.006)				
Disaster * Education			0.032***						0.028**			
			(0.011)						(0.013)			
Disaster * Health				0.113***						0.083**		
				(0.032)						(0.036)		
Disaster * Mechanization					0.000						0.000	
					(0.000)						(0.000)	
Disaster * Electricity						0.020*						0.018
						(0.011)						(0.013)
Telecommunication	-0.012***						-0.022***					
	(0.004)						(0.004)					
Access to finance		-0.009***						-0.025***				
		(0.003)						(0.005)				
Education			-0.013**						-0.033**			
			(0.006)						(0.015)			
Health				-0.008						0.073		
				(0.025)						(0.074)		
Mechanization					-0.000						-0.000	
					(0.000)						(0.000)	
Electricity						-0.006						0.011
						(0.005)						(0.015)
Intercept	2.128***	2.003***	2.749***	0.000	3.482***	0.000	3.171***	3.977***	3.674***	-0.649	3.781***	0.647
	(0.597)	(0.762)	(0.944)	(.)	(0.599)	(.)	(0.485)	(0.539)	(0.930)	(4.560)	(0.550)	(1.204)
Observations	694	626	587	691	374	469	694	626	587	691	374	469
R2							0.076	0.077	0.066	0.069	0.058	0.071
Number of instruments	79	79	77	79	56	55	-	-	-	-	-	-
Arellano-Bond test for AR(1)	0.004	0.007	0.000	0.002	0.036	0.007	-	-	-	-	-	-
Arellano-Bond test for AR(2)	0.610	0.817	0.547	0.528	0.825	0.577	-	-	-	-	-	-
Hansen test	0.216	0.342	0.127	0.158	0.207	0.428	-	-	-	-	-	-
Difference-in-Hansen test	0.591	0.761	0.232	0.224	0.344	0.707	-	-	-	-	-	-

Note: (1) - (6) represent the policy response models estimated with telecommunication, access to finance, education, health, mechanization and electricity, respectively. The interaction paramaters are the b2, which are the parameters of interest. A positive sign indicates an effective mitigation effect. Year-dummy parameters are omitted.

Annex III. Impact analysis with a different frequency proxy

The impact analysis is replicated, with a frequency proxy that accounts for both the fatalities and the affected people ($Frequency2_{i,t}^{k} = \frac{Fatalities_{i,t}^{k} + 0.3*Affected_{i,t}^{k}}{Population_{i,t}}$). The results of the GMM model, which are consistent with the results obtained in the paper, are presented below.

Table 11 (A7): Growth models with disaster indicators (different frequency proxy, GMM)

	EMDEs				SSA			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log of per capita GDP	-10.111***	-2.468**	5.593**	-5.790***	-2.838*	3.090	0.213	3.626*
	(3.630)	(1.104)	(2.182)	(2.079)	(1.521)	(2.340)	(1.327)	(1.964)
Drought intensity	-6.856**				-13.136*			
	(3.491)				(7.042)			
Drought frequency	0.033				0.071			
	(0.142)				(0.072)			
Flood intensity		-6.795***				-3.216***		
		(2.052)				(1.219)		
Flood frequency		0.691**				-0.053		
		(0.273)				(0.115)		
Epidemic intensity			-1.194				-0.669	
			(1.012)				(0.975)	
Epidemic frequency			0.006				0.864	
			(0.623)				(0.846)	
Storm intensity				-1.081				0.673
				(0.897)				(0.854)
Storm frequency				-0.061				-0.095
				(0.146)				(0.145)
Education	0.256***	0.061**	-0.121**	0.154***	0.067	-0.113*	-0.011	-0.110
	(0.092)	(0.027)	(0.053)	(0.056)	(0.047)	(0.068)	(0.035)	(0.067)
Investment	0.088*	0.124***	0.028	0.178***	0.043**	0.031	0.037	0.011
	(0.053)	(0.035)	(0.046)	(0.051)	(0.022)	(0.038)	(0.028)	(0.056)
Government consumption	-0.043	-0.048**	0.009	-0.117***	0.015	-0.002	-0.029	-0.044
	(0.044)	(0.023)	(0.041)	(0.037)	(0.028)	(0.039)	(0.021)	(0.039)
Inflation	0.002	-0.003***	-0.002**	-0.010***	0.001	-0.002***	-0.002***	0.073
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.000)	(0.001)	(0.054)
Trade openess	3.214**	0.551	-0.700	0.404	2.867*	-0.081	3.363**	1.954*
	(1.529)	(0.548)	(1.461)	(0.621)	(1.484)	(1.483)	(1.588)	(1.139)
Change in terms of trade	0.048	0.075	-0.030	0.271**	-0.154	0.084	0.029	-0.090
	(0.113)	(0.065)	(0.084)	(0.119)	(0.099)	(0.093)	(0.058)	(0.238)
Intercept	74.438***	21.400**	-37.729**	41.322***	32.758**	-15.730	-2.125	-23.335*
	(25.789)	(8.326)	(14.758)	(14.392)	(16.126)	(14.860)	(8.794)	(14.173)
Observations	211	513	312	325	113	163	158	67
Number of instruments	40	68	39	40	46	46	46	44
Arellano-Bond test for AR(1)	0.029	0.000	0.009	0.020	0.032	0.024	0.017	0.055
Arellano-Bond test for AR(2)	0.055	0.068	0.341	0.967	0.153	0.527	0.109	0.387
Hansen test	0.373	0.146	0.199	0.266	0.984	0.601	0.791	0.997
Difference-in-Hansen test	0.078	0.078	0.137	0.254	0.634	0.011	1.000	0.999

Note: (1), (2), (3) and (4) represent models for droughts, floods, epidemics and storms, repectively. *, ** and *** indicate statistical significance at 10, 5 and 1 percent, respectively. Year-dummy parameters are not presented.

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