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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 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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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 the 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 the 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 more than ever before. Governments must prioritize across policy measures. 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 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, given the cumulative effects of disasters. All of these results are based on a model we built to understand medium-term growth in SSA based on macroeconomic variables and 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 affecting longer-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 work 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

[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.

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. 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.

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:

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

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 cumulative non-linear 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:

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

where $Fatalities_{i,t}^{k}$ and $Population_{i,t}$ are defined as previously.[5]

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 the averages over the windows. Thus, the final panel has 12 five-year periods. However, the intensity and the frequency proxies are 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.

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[3] For more details on the weights allocated to deaths and affected people see Fomby et al. (2013).

[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] 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.

The control variables for the impact analysis are selected following Loayza et al. (2012). 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)-GDP (WEO)
Change in terms of trade	Change, ratio price export-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:

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

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*, $Intens_{i,t}^k$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_t^1 and d_i^1 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. Therefore, the model that assesses the effects, on growth, of the frequency and intensity of climate-related disasters is as follows:

$$\overline{G}_{i,p} = a\overline{Log(Y_{i,p})} + b_1\overline{Inten}^k_{i,p} + b_2\overline{Freq}^k_{i,p} + B_3\overline{X}_{i,p} + c^2_p + d^2_i + \varepsilon_{i,p} \qquad (4)$$

where p is a 5-year period, going from t_{p1} to t_{p5}, $\overline{Intens}^k_{i,p} = \frac{1}{N_j}\sum_{t=t_{p1}}^{t_{p5}} Intens^k_{i,t}$ (with N_k the number of disasters of type k during the 5-year period) and $\overline{Freq}^k_{i,p} = \frac{1}{5}\sum_{t=t_{p1}}^{t_{p5}} Freq^k_{i,t}$. Moreover, $\bar{G}_{i,p}$, $\overline{Log(Y_{\iota,p})}$ 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_ι are time and country specific effects, respectively, and $\varepsilon_{i,p}$ is the error term.

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] Equation (4) is estimated through the fixed-effect method with country and year-fixed effects. An alternate estimation that stems on a GMM method is proposed in the robustness-checks section to correct for potential correlation between the unobserved effects and the lagged regressor.

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 droughts having the strongest effect, possibly reflecting their prolonged nature. If a drought intensifies by 10 percentage points, medium-term annual per capita growth can decline by almost 0.8 percentage points in SSA. An intensification of floods by the same amount takes one-fifth the toll on medium-term growth.[7] 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.

- Climate-related disasters weigh on growth substantially more in SSA than elsewhere, reflecting the region's lack of resilience and dependence on rain-fed agriculture. For droughts, the impact is about 3 times that in other emerging and developing economies.

- A disaster's intensity matters much more than its frequency. This is consistent with the findings of Cavallo et al. (2013) and Fomby et al. (2013) and can be explained by the cumulative effects of consecutive natural disasters. An immediate successive and

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[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] Floods include the after-effect of extreme storms such as cyclones.

very intense disaster would be particularly disruptive for lower income households, who would not have had enough time to recover from the first.

Table 2: Selected Economies: Growth Models with Disaster Indicators

	EMDEs				SSA			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log of per capita GDP	-2.09**	-2.03***	-2.52**	-1.06	-2.37	-1.57	-1.51	6.72
Intensity drought	-2.66***				-7.81***			
Frequency drought	-0.34***				-0.41***			
Intensity flood		-1.31***				-1.49**		
Frequency flood		-0.06**				-0.18**		
Intensity epidemic			-0.20				-0.53	
Frequency epidemic			-0.00				-0.01	
Intensity storm				-0.38				0.32
Frequency storm				-0.19**				-12.26
Education	-0.07**	-0.07***	-0.05*	-0.07***	-0.05	-0.07*	-0.06	-0.16
Investment	0.03***	0.09***	0.07***	0.02	0.03***	0.05*	0.05**	0.09
Government consumption	-0.01	0.02	0.05**	-0.02	-0.01	0.06*	0.05**	0.08
Inflation	0.00***	-0.00**	-0.00***	-0.01***	0.00	-0.00***	-0.00***	0.06
Trade openess	0.36	0.05	0.15	-0.29	0.63	1.74	4.52**	-1.52
Change in terms of trade	0.00	-0.02	0.03	0.09*	-0.11	0.07	0.06*	-0.03
Intercept	21.37***	20.31***	20.61**	14.34	26.85***	12.29	7.99	-46.39
Country fix effect (y/n)	y	y	y	y	y	y	y	y
Year fix effect (y/n)	y	y	y	y	y	y	y	y
Clustered std (country level)	y	y	y	y	y	y	y	y
Numbers of observations	211	513	312	325	113	163	158	67

Note: Dependent variable is the 5-year average per-capita growth. (1), (2), (3) and (4) represent models for droughts, floods, epidemics and storms, respectively. *, ** and *** indicate statistical significance at 10, 5 and 1 percent, respectively.

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).

A. Econometric Analysis and Results

The following model is considered:

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

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 $\overline{Dis}^k_{i,p}$ is either the intensity proxy or the frequency proxy associated with a climate-related disaster of type k in country i and period p.

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 fixed-effect method with time-related dummies is used for the estimation and the variables are described in Table 1.

The results, summarized in Table 3, 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 1. 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.

Table 3: b_2 estimates

	Intensity				Frequency			
	Droughts	Floods	Epidemics	Storms	Droughts	Floods	Epidemics	Storms
Telecomunication		0.009**					0.004**	
Access to finance	0.026*	0.016**			0.033*			
Education				0.028**		0.017**		
Health		0.086**		0.083**	0.018***	0.027***		0.009**
Mechanization		0.000**				0.000***	0.000***	
Electricity	0.114***							

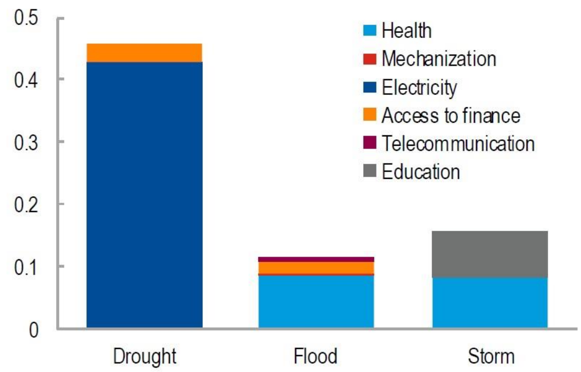
Note: The table focuses on significant values of the parameter b2. *, ** and *** indicate statistical significance at 10, 5 and 1 percent, respectively.

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 result is 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 1). The combinations of structural reform areas that are most effective for specific types of climate-related disasters are discussed below.

Figure 1: Reduction in impact of disasters on SSA's medium-term growth if structural factors improve



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.

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 1 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 1).

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 0.8 percentage points (Section III.B 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 1).
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 1). For example, when a flood intensifies by 10 percentage points, medium-term per capita annual growth declines by 0.15 percentage points (Section III.B 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.[8]

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 to afford higher food prices when crops are damaged by the disaster.

[8] 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.

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.[9] Governments can help build these areas of resilience with programs that widen accessibility to quality building materials for the poor and require high standards for building codes and regulations, effective land-use planning, and zoning rules are important. 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.[10] 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 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

[9] 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.

[10] 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 and others 2013; Hill, Hoddinott, and Kumar 2013; Hallegatte and others 2017).

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 cumulative effects of successive disasters. The analysis is based on a growth model, applying panel data that includes macroeconomic variables and the frequency and the 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.

ANNEX 1: COMPLETE RESULTS FROM THE POLICY RESPONSE ANALYSIS

This Annex contains complete results from the policy response analysis (Section IV). The dependent variable is the 5-year average of per-capita GDP growth.

Table: Policy response analysis with the drought proxies

	Intensity						Frequency					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.061	0.042	-0.015	0.066	0.078	0.142	0.092	0.045	0.073**	0.086	0.061	-0.054
	(0.059)	(0.067)	(0.074)	(0.061)	(0.078)	(0.107)	(0.062)	(0.080)	(0.036)	(0.059)	(0.060)	(0.109)
Disaster	-1.885***	-2.920**	-2.341*	-10.069	-1.383	-14.198***	-0.265***	-0.567***	-0.445***	-1.099***	-0.179***	-5.383
	(0.695)	(1.198)	(1.399)	(6.811)	(1.043)	(3.398)	(0.061)	(0.199)	(0.064)	(0.260)	(0.037)	(18.674)
Disaster * Telecommunication	0.002						-5.227					
	(0.006)						(2.925)					
Disaster * Access to finance		0.026*						0.033*				
		(0.014)						(0.018)				
Disaster * Education			-0.010						0.006			
			(0.021)						(0.007)			
Disaster * Health				0.128						0.018***		
				(0.099)						(0.005)		
Disaster * Mechanization					-0.000**						-0.000	
					(0.000)						(0.000)	
Disaster * Electricity						0.114***						-2.837
						(0.037)						(2.229)
Telecomunication	-0.018						-0.025***					
	(0.012)						(0.006)					
Access to finance		-0.022						-0.022***				
		(0.015)						(0.004)				
Education			-0.123***						-0.021**			
			(0.031)						(0.009)			
Health				-0.037						0.110***		
				(0.111)						(0.032)		
Mechanization					0.000**						-0.000	
					(0.000)						(0.000)	
Electricity						-0.061						0.042***
						(0.052)						(0.015)
Const.	3.383***	4.291***	6.905***	7.107	2.926**	11.691***	2.923***	3.457***	2.951***	-3.244*	3.262***	-1.506
	(0.809)	(1.141)	(1.915)	(7.383)	(1.394)	(3.825)	(0.323)	(0.361)	(0.444)	(1.844)	(0.309)	(0.986)
N	326	299	256	324	175	196	1642	1409	1332	1640	920	906

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: Policy response analysis with flood proxies

	Intensity						Frequency					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.101***	0.062*	0.110**	0.092**	0.127***	0.073*	0.095	0.046	0.076**	0.088	0.060	-0.056
	(0.037)	(0.036)	(0.045)	(0.036)	(0.043)	(0.041)	(0.062)	(0.080)	(0.036)	(0.059)	(0.060)	(0.109)
Disaster	-1.296***	-1.524***	-1.103*	-6.594***	-0.963***	-0.048	-0.261**	-0.484*	-0.978**	-1.925***	-0.648***	-0.012
	(0.325)	(0.459)	(0.638)	(2.420)	(0.356)	(0.784)	(0.132)	(0.270)	(0.377)	(0.479)	(0.171)	(0.540)
Disaster * Telecommunication	0.009**						0.019					
	(0.004)						(0.013)					
Disaster * Access to finance		0.016**						0.018				
		(0.006)						(0.017)				
Disaster * Education			0.005						0.017**			
			(0.009)						(0.007)			
Disaster * Health				0.086**						0.027***		
				(0.036)						(0.007)		
Disaster * Mechanization					0.000**						0.000***	
					(0.000)						(0.000)	
Disaster * Electricity						-0.013						0.000
						(0.011)						(0.006)
Telecomunication	-0.031***						-0.026***					
	(0.007)						(0.006)					
Access to finance		-0.029***						-0.023***				
		(0.006)						(0.004)				
Education			-0.039***						-0.024**			
			(0.012)						(0.009)			
Health				0.047						0.109***		
				(0.055)						(0.033)		
Mechanization					-0.000						-0.000	
					(0.000)						(0.000)	
Electricity						0.056***						0.042***
						(0.021)						(0.015)
Const.	3.146***	3.739***	4.320***	1.218	3.317***	-1.566	2.927***	3.459***	3.051***	-3.144*	3.337***	-1.514
	(0.488)	(0.576)	(0.701)	(3.205)	(0.519)	(1.376)	(0.322)	(0.358)	(0.445)	(1.876)	(0.296)	(1.036)
N	933	844	768	932	497	616	1642	1409	1332	1640	920	906

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: Policy response analysis with epidemic proxies

	Intensity						Frequency					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.160***	0.119**	0.137**	0.158***	0.135**	0.137*	0.094	0.045	0.078**	0.088	0.065	-0.054
	(0.051)	(0.050)	(0.067)	(0.054)	(0.054)	(0.081)	(0.062)	(0.080)	(0.037)	(0.059)	(0.060)	(0.110)
Disaster	-0.133	-0.090	-0.787	-2.402	-0.088	-0.172	-0.072	-0.021	-0.094	-0.561	-0.094	-0.050
	(0.446)	(0.502)	(0.659)	(2.392)	(0.427)	(0.847)	(0.050)	(0.146)	(0.239)	(0.493)	(0.066)	(0.160)
Disaster * Telecommunication	0.010						0.004**					
	(0.007)						(0.001)					
Disaster * Access to finance		0.004						0.003				
		(0.010)						(0.011)				
Disaster * Education			0.015						0.003			
			(0.013)						(0.006)			
Disaster * Health				0.040						0.010		
				(0.038)						(0.009)		
Disaster * Mechanization					-0.000						0.000***	
					(0.000)						(0.000)	
Disaster * Electricity						0.007						0.003
						(0.011)						(0.005)
Telecomunication	-0.028**						-0.025***					
	(0.011)						(0.006)					
Access to finance		-0.027***						-0.022***				
		(0.006)						(0.004)				
Education			-0.055**						-0.023**			
			(0.024)						(0.009)			
Health				0.089						0.112***		
				(0.059)						(0.033)		
Mechanization					-0.000						-0.000	
					(0.000)						(0.000)	
Electricity						0.038*						0.042***
						(0.022)						(0.015)
Const.	2.505***	2.867***	2.749***	-1.420	2.725***	-0.981	2.906***	3.427***	2.963***	-3.335*	3.217***	-1.562
	(0.739)	(0.825)	(0.902)	(2.646)	(0.889)	(1.054)	(0.323)	(0.361)	(0.446)	(1.864)	(0.303)	(0.989)
N	483	460	394	483	239	342	1642	1409	1332	1640	920	906

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: Policy response analysis with storm proxies

	Intensity						Frequency					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.086	0.035	0.114*	0.083	0.064	0.084	0.093	0.045	0.077**	0.088	0.061	-0.055
	(0.065)	(0.068)	(0.060)	(0.063)	(0.066)	(0.061)	(0.062)	(0.080)	(0.036)	(0.059)	(0.060)	(0.109)
Disaster	-0.441	-0.263	-2.232**	-5.855**	-0.406	-1.770*	-0.225***	-0.210*	-0.179	-0.714***	-0.226***	0.418
	(0.415)	(0.477)	(0.974)	(2.569)	(0.612)	(1.033)	(0.045)	(0.108)	(0.153)	(0.195)	(0.039)	(0.377)
Disaster * Telecommunication	0.006						-0.009***					
	(0.004)						(0.001)					
Disaster * Access to finance		0.002						-0.007				
		(0.006)						(0.008)				
Disaster * Education			0.028**						-0.004			
			(0.013)						(0.007)			
Disaster * Health				0.083**						0.009**		
				(0.036)						(0.004)		
Disaster * Mechanization					0.000						-0.000	
					(0.000)						(0.000)	
Disaster * Electricity						0.018						-0.010
						(0.013)						(0.007)
Telecomunication	-0.022***						-0.026***					
	(0.004)						(0.006)					
Access to finance		-0.025***						-0.022***				
		(0.005)						(0.004)				
Education			-0.033**						-0.023**			
			(0.015)						(0.009)			
Health				0.073						0.110***		
				(0.074)						(0.033)		
Mechanization					-0.000						-0.000	
					(0.000)						(0.000)	
Electricity						0.011						0.043***
						(0.015)						(0.015)
Const.	3.171***	3.977***	3.674***	-0.649	3.781***	0.647	2.922***	3.450***	3.040***	-3.244*	3.250***	-1.616
	(0.485)	(0.539)	(0.930)	(4.560)	(0.550)	(1.204)	(0.323)	(0.363)	(0.441)	(1.859)	(0.307)	(1.008)
N	694	626	587	691	374	469	1642	1409	1332	1640	920	906

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 2: ROBUSTNESS CHECKS - GROWTH MODELS WITH DIFFERENT CONTROL VARIABLES

The growth model remains as presented in the paper, except that the control variables, other than the disaster proxies, are from Barro (2003) and include the same controls as in the main model plus 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: Growth model with additional controls from Barro (2003)

	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)
N	204	495	303	305	106	155	150	67
R-sq	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.

ANNEX 3: ROBUSTNESS CHECKS – POLICY RESPONSE ANALYSIS WITH A DIFFERENT FREQUENCY PROXY

The policy response analysis is replicated with a different frequency proxy, which is defined as $Freq_{i,t}^{k} = \frac{Affected_{i,t}^{k}}{Population_{i,t}}$ for disasters of type k during the year t in country i.

Table: Policy response analysis with a different frequency proxy

	Analysis for droughts						Analysis for floods					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.096	0.044	0.078**	0.088	0.063	-0.057	0.094	0.044	0.079**	0.088	0.059	-0.057
Disaster	-0.075*	-0.085	-0.168**	-0.442	-0.092**	-0.097	-0.051	-0.062	-0.165***	-0.526**	-0.060	0.160*
Disaster * Telecommunication	0.001						0.002**					
Disaster * Access to finance		0.003						0.001				
Disaster * Education			0.002						0.003***			
Disaster * Health				0.007						0.009**		
Disaster * Mechanization					0.000***						0.000***	
Disaster * Electricity						0.002*						-0.002*
Telecomunication	-0.026***						-0.026***					
Access to finance		-0.023***						-0.023***				
Education			-0.023**						-0.025***			
Health				0.101***						0.107***		
Mechanization					-0.000						-0.000	
Electricity						0.039***						0.047***
Intercept	2.922***	3.466***	3.010***	-2.716	3.287***	-1.340	2.916***	3.456***	3.103***	-3.067*	3.310***	-1.943*
N	1642	1409	1332	1640	920	906	1642	1409	1332	1640	920	906

	Analysis for epidemics						Analysis for storms					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.094	0.045	0.078**	0.088	0.062	-0.055	0.093	0.045	0.079**	0.088	0.060	-0.056
Disaster	-0.162***	-0.343***	-0.135	-1.558***	-0.134***	-0.114***	0.169	0.212	-0.187	-1.351	0.329*	-0.191
Disaster * Telecommunication	0.007**						-0.003*					
Disaster * Access to finance		0.010**						-0.004				
Disaster * Education			0.005						0.003			
Disaster * Health				0.026**						0.022*		
Disaster * Mechanization					-0.000						0.000	
Disaster * Electricity						0.003						0.002
Telecomunication	-0.026***						-0.026***					
Access to finance		-0.022***						-0.021***				
Education			-0.023**						-0.023**			
Health				0.111***						0.116***		
Mechanization					-0.000						-0.000	
Electricity						0.041***						0.042***
Intercept	2.905***	3.436***	2.954***	-3.299*	3.238***	-1.440	2.893***	3.403***	2.987***	-3.568*	3.218***	-1.519
N	1642	1409	1332	1640	920	906	1642	1409	1332	1640	920	906

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 4: ROBUSTNESS CHECKS – ANALYSIS USING THE GMM METHOD

The models in the paper build on a dynamic panel on growth. Therefore, some unobserved panel effects could be correlated with the lagged variables. We re-estimate the models by using the Arellano-and-Bond estimator, which is a GMM estimator that helps overcome this issue (Arellano and Bond, 1991).

Table: Selected Economies: Growth Models with Disaster Indicators (GMM method)

	EMDEs				SSA			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
Log of per capita GDP	-2.681***	-2.320***	-0.292	-1.486***	-2.695***	-1.066**	-1.060**	-0.515
	(0.411)	(0.375)	(0.422)	(0.327)	(0.636)	(0.453)	(0.434)	(0.637)
Intensity drought	-1.942***				-6.696**			
	(0.749)				(3.328)			
Frequency drought	-0.393***				-0.382***			
	(0.074)				(0.076)			
Intensity flood		-2.105***				-0.939		
		(0.456)				(0.614)		
Frequency flood		-0.206				-0.049		
		(0.190)				(0.095)		
Intensity epidemic			0.207				-0.085	
			(0.535)				(0.622)	
Frequency epidemic			0.029				0.096	
			(0.125)				(0.130)	
Intensity storm				-0.616				-0.868
				(0.488)				(0.832)
Frequency storm				0.187				-0.877
				(0.147)				(4.599)
Education	0.086***	0.062***	0.025**	0.044***	0.067***	0.030**	0.025*	0.024
	(0.011)	(0.010)	(0.012)	(0.010)	(0.021)	(0.015)	(0.015)	(0.024)
Investment	0.043***	0.118***	0.078***	0.112***	0.026**	0.058***	0.052***	0.009
	(0.010)	(0.014)	(0.016)	(0.021)	(0.011)	(0.017)	(0.018)	(0.056)
Government consumption	-0.027*	-0.065***	-0.046***	-0.062***	-0.007	-0.031*	-0.034**	-0.072**
	(0.014)	(0.012)	(0.013)	(0.017)	(0.018)	(0.016)	(0.014)	(0.029)
Inflation	0.001	-0.003***	-0.003***	-0.010***	0.000	-0.002***	-0.002***	0.025
	(0.001)	(0.000)	(0.000)	(0.001)	(0.002)	(0.000)	(0.000)	(0.028)
Trade openess	1.648***	0.698**	0.870**	0.565	3.156***	2.084***	3.645***	3.880***
	(0.361)	(0.285)	(0.380)	(0.352)	(0.600)	(0.683)	(0.658)	(1.441)
Change in terms of trade	-0.036	0.044	0.021	0.068	-0.184***	0.238***	0.080	-0.044
	(0.049)	(0.041)	(0.049)	(0.056)	(0.060)	(0.083)	(0.058)	(0.209)
Intercept	20.011***	18.057***	1.824	10.990***	24.024***	7.382**	5.978**	3.331
	(2.995)	(2.650)	(2.916)	(2.335)	(5.954)	(3.002)	(2.835)	(4.349)
N	211	513	312	325	113	163	158	67

Note: (1), (2), (3) and (4) represent models for droughts, floods, epidemics and storms, repectively.

The policy-response analysis with GMM focuses on the drought proxies. The other tables are available upon request.

Table: Policy response analysis with the drought proxies (GMM)

	Intensity						Frequency					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
Lagged growth	0.229***	0.210***	0.168**	0.153**	0.223***	0.361***	0.225***	0.191***	0.294***	0.250***	0.145***	0.119***
Disaster	-2.179**	-3.044***	-2.023	-2.852	-1.992**	-3.052	-0.286***	0.084	-0.337	-0.621	-0.326	-8.830
Disaster * Telecommunication	0.004						-4.050					
Disaster * Access to finance		0.032						-0.027				
Disaster * Education			-0.000						-0.003			
Disaster * Health				0.016						0.007		
Disaster * Mechanization					0.000						0.000	
Disaster * Electricity						0.005						-2.230
Telecomunication	-0.003						-0.005***					
Access to finance		-0.017						-0.007***				
Education			0.022						0.005*			
Health				0.054						0.024***		
Mechanization					0.000						0.000	
Electricity						0.011						0.007**
Const.	3.369***	3.911***	2.340	0.090	3.022***	3.510	1.671***	1.760***	1.011***	-0.114	1.688***	1.267***
N	326	299	256	324	175	196	1642	1409	1332	1640	920	906

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.

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