

Building Resilience to Extreme Weather Shocks in Africa: The Role of Climate-Proofing Infrastructure

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Abstract: Natural disasters such as storms, floods and drought are common and increasing shocks in Africa. In addition to deaths toll they inflict, natural disasters destroy public and private infrastructure needed for the economy to function, disrupting economic and social activities with long-lasting effects. They also put considerable strains on government finances, frequently demanding a swift reconstruction of damaged infrastructure. However, there may be a limited room for fiscal adjustment such as raising additional revenues or cutting expenditures on the one hand and accessing external financing on the other. We study the macroeconomic impacts and fiscal costs of extreme weather events in Africa and examine ex ante how African countries can building resilience strategies, such as climate-proofing infrastructure and accumulation of contingency fiscal buffers. Ex post, we study the debt sustainability concerns of financing the reconstruction of public infrastructure over the medium term. The results reveal the following. First, investing in resilient infrastructure is useful in attenuating the impact of the natural disaster. Second, building contingency fiscal buffers can smooth out the fiscal adjustment needed to finance post-disaster reconstruction. Finally, governments cannot face damages alone: grant-financing is key for debt sustainability and reducing the social cost of abrupt adjustment. Thought there are principal-agent issues linked with such a strategy, the donor community would need to significantly scale up its financial contributions following the disaster shock.

I. Introduction

Natural disasters such as storms, floods and drought are common and increasing shocks in Africa. Recent events such as Tropical Cyclone Idai that devastated Southern African countries in March 2019 and Tropical Cyclone Kenneth that hits Southern and Eastern Africa a month later—with total estimated US\$4 billion in economic damage—have received worldwide media coverage. The two storms have also created a sense of awareness among the general public and policy makers about the destructive nature of disasters in Africa and the need to build resilience.¹ According to the UN World Risk Report 2016, the countries with the highest vulnerabilities to extreme weather events can be found mainly on the African continent.² Except for Haiti and Afghanistan, all 15 countries with the highest levels of vulnerability worldwide are in Africa. Likewise, the report shows that the continent is also the region with the highest lack of adaptive capacities, especially the West Africa region and the Sahel Zone (Table 1). The increased vulnerability and lack of adaptive capacity expose the continent to natural disaster. For instance, according to the African Development Bank projections, Africa will be affected by extreme weather events by 2040, with associated economic costs expected to be \$45–50 billion per year.

Table 1: Top 15 countries with highest vulnerability and lack of adaptive capacity worldwide

Country	Vuln. (%)	Rank	Country	Lack A. C (%)	Rank
Central Africa Republic	74.80	1	Eritrea	74.80	1
Eritrea	74.23	2	Central Africa Republic	74.23	2
Chad	72.86	3	Djibouti	72.86	3
Afghanistan	72.12	4	Niger	72.12	4
Haiti	71.85	5	Afghanistan	71.85	5
Liberia	71.54	6	Liberia	71.54	6
Niger	70.80	7	Chad	70.80	7
Sierra Leone	69.69	8	Benin	69.69	8
Madagascar	69.52	9	Sierra Leone	69.52	9
Guinea-Bissau	68.99	10	Guinea-Bissau	68.99	10
Mozambique	68.28	11	Mali	68.28	11
Guinea	68.21	12	Guinea	68.21	12
Burundi	67.98	13	Haiti	67.98	13
Sudan	67.37	14	Pakistan	67.37	14
Zimbabwe	67.24	15	Burkina Faso	67.24	15

Source: World Risk Report 2016

In addition to deaths toll they inflict, natural disasters can destroy public and private infrastructure needed for the economy to function, disrupting economic and social activities with long-lasting effects. The damages to public and private capital by extreme weather-related shocks can be higher in Africa. This is the result of poor quality of installed capital, and hence low efficiency of public investment, poor planning of development, increasing demographic growth and rapid urbanization (Figure 1).³ These factors cause a rapid degradation of existing

¹ Throughout the paper, natural disaster is understood as extreme weather-related shocks such as drought, floods, storms and cyclones which are common events in Africa. It excludes events such as earthquakes, tsunamis and hurricanes. Therefore, we use natural disaster and extreme weather events interchangeably.

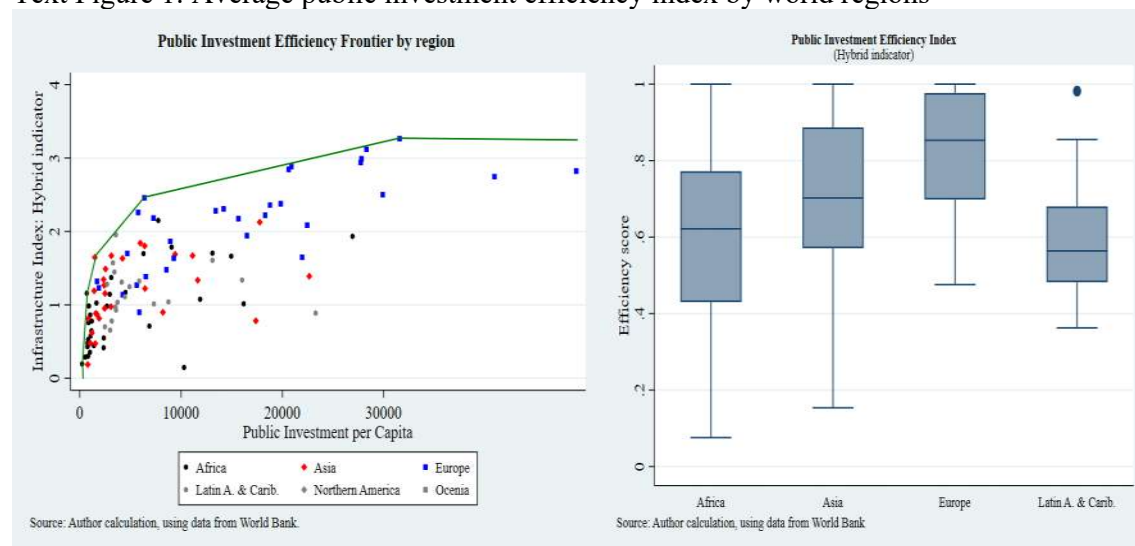
² The full report is available here

https://collections.unu.edu/eserv/UNU:5763/WorldRiskReport2016_small_meta.pdf

³ Our estimates show an average efficiency gap of 39% in public infrastructure investment for Africa.

capital stock, compounded by disaster shocks and often poor post-disaster maintenance. Extreme weather events can suddenly stop or shorten the life span and hence the service life of infrastructure by increasing the depreciation rate and leading to greater costs of reconstruction over time. Consequently, they reduce the returns on infrastructure capital. Lower returns in turn weaken the crowding-in effects of infrastructure on private capital and ultimately economic growth. Indeed, what matters for growth is the sustained flow of productive capital input which raises the return on private capital, thus leading the higher economic growth rate. Degraded or deficient infrastructure imposes costs on users and, in the long run, the lack of maintenance in a timely manner can lead to greater fiscal costs of reconstruction and maintenance.

Text Figure 1: Average public investment efficiency index by world regions



The costs to the users can be high and result in loss of productivity. Indeed, firms often react to poor and deficient infrastructure conditions, and attempt to invest themselves to fill the void. It is not uncommon to see firms investing in power generators in time of power outages and rationing. As a result of these extra expenditures, however, firms tend to reduce their investment in non-infrastructure capital needed for their productive activities, and this reduction in investment leads to a decrease in productive capacity.

Particularly important in this context are the links between infrastructure and climate change. The links run in two directions. First, certain types of infrastructure may contribute to climate change (e.g., coal power plants increase greenhouse gas emissions) or environmental degradation (such as dams or roads). Second, given that climate change will manifest itself in an increased frequency and severity of extreme weather events, building resilient infrastructure capable of withstanding such events becomes necessary. It is thus critical to be mindful of the tradeoffs involved in deciding how much and what type of infrastructure to install and to take mitigating measures where and when necessary. Otherwise, economic and social costs after storms and other climate-related shocks will be unbearable.

With that background in mind, this paper extends the Buffie et al (2020)'s model to analyze how African economies could build resilience to natural disasters. In the extended model, the government can invest in standard infrastructure (e.g., roads without drainage facilities) as well as in adaptation capital (e.g., climate-resilient buildings). Adaptation capital, in addition to contributing to the overall quality of infrastructure in the country (which enters the production function of private firms), reduces the damages inflicted by a natural disaster. It is combined with standard public capital in a Constant Elasticity of Substitution (CES) function, which permits exploring the implications of different degrees of complementarity between standard and adaptation capital. Thus, the characterization by the CES function allows to define different degrees of complementarity and strong substitutability (resemblance) between the two types of capital. Under strong substitutability for instance, standard infrastructure can be assimilated to climate-proofing capital that withstands stronger natural disasters.

However, building climate-proofing infrastructure can be costly than standard infrastructure, but the cost of reconstruction can be even paramount and difficult to finance. The main issue with financing reconstruction is that when the economy is hit by climate even, investors become risk averse, creating a pullback from domestic assets and increasing borrowing costs. In this context, there are a number of financing options. The government can finance the reconstruction through the intervention of bilateral and multilateral donors as a lender of last resort. Alternatively, the government can accumulate external commercial to finance the fiscal gap even at a higher cost. Another option is for the government to borrow domestically. The government can also take precautionary measures by saving resources in an external contingency fund that can then be drawn down to finance reconstruction and maintenance activities. The contingency fund is a saving in an external account and pays interest rate.

The paper is at the crossroad of three strands of the literature. First, the paper is related to the recent literature on the linkage between public investment and growth and the implications on debt sustainability (see Buffie et al. (2012); Melina et al. (2016); Buffie et al. (2020)). The second is related to the branch of the literature on the economic and public finance implications of natural disaster occurrence in Africa, both in the medium and long run. Finally, the paper is related to the literature on risk management, particularly the one that focuses on building resilience against future occurrences of natural disasters and accumulating precautionary savings to be spent in the event of disaster.

The literature on the economic impacts of disasters remains inconclusive as to the economic impacts of large disasters. On the theoretical literature, traditional neo-classical growth models predict that the destruction of capital (physical or human) does not affect the rate of technological progress and hence, it might only enhance short-term growth prospects as it drives countries away from their balanced-growth steady states. In contrast, endogenous growth models provide fewer clear-cut predictions with respect to output dynamics. For example, models based on Schumpeter's creative destruction process may even ascribe higher growth as a result of negative shocks, as these shocks can be catalysts for re-investment and upgrading of capital goods (see, for example, Caballero and Hammour (1994)). In contrast, AK-type endogenous growth models in which technology exhibits constant returns to capital predict no

change in the growth rate following a negative capital shock; while endogenous growth models that exploit increasing returns to scale in production generally predict that a destruction of part of the physical or human capital stock results in a lower growth path and consequently a permanent deviation from the previous growth trajectory.

Fewer studies have addressed the economic impact of disasters from theoretical perspective. For instance, Hallegatte and Dumas (2009) considered a vintage capital model and showed that under plausible parameter ranges, disasters never promote economic growth through the accelerated replacement of old capital. Using numerical simulations, Narita, Tol, and Anthoff (2009) quantitatively calculated the direct economic impact of tropical cyclones. Ikefuji and Horii (2012) present an endogenous multi-region growth model, where individual regions are subject to hurricane shocks to physical and human capital. Their framework focuses on pollution taxation and growth, with pollution as a disaster risk. They consider the potential implications of human capital risk on long-run growth. Akao and Sakamoto (2014) present a two-sector endogenous growth model with different disaster shock processes and study the channels through which these affect long-run growth. McDermott, Barry, and Tol (2014) study the impact of capital markets to mitigate the harmful growth impacts of natural disasters. Finally, Kousky et al. (2007) analyze the interaction between private capital markets and public hazard protection.

A common limitation of these studies is that they are theoretical and, as such, they are not taken to data, which limits their capacity to empirically quantify their results. Our analysis complements these studies by considering a three-sector endogenous general equilibrium growth model with two types of public capital, including standard capital and adaptation capital. Both types of capital enter three production functions as inputs in addition to private capital and labor. The model thus allows to analyze the following issues. First, adaptation vs. reconstruction or maintenance. Building more resilient infrastructure is costly, but it reduces the immediate impact of natural disasters on output as well as the cost of post-disaster recovery. The second has to do with financial buffers vs. physical resilience. With limited access to financial markets, financing a post-disaster recovery presents a challenge for policymakers which may need to prepare *ex ante*. Alternatively, the government can accumulate assets in a contingency fund to be used after a natural disaster. Finally, the model also allows to contrast alternative paths of post-disaster reconstruction and can compare the implications for growth and debt sustainability of alternative trajectories for rebuilding public capital after a given natural disaster as well as of alternative financing modes as in Buffie et al. (2020).

Empirically, our model is calibrated for average Africa. We then use data for the size and duration of disaster shocks from EM-DAT, an online emergency disaster database sponsored by the United States Agency for International Development (USAID) and the Center for Research on the Epidemiology of Disasters (CRED). The database has worldwide coverage and contains data on the occurrence and effects of natural disasters from 1900 to the present. There exist few empirical related studies in the literature with yield mixed results regarding the impacts of natural disaster on growth (see Bakkensen and Barrage (2017); Borensztein et al. (2017); Marto et al. (2017); Raddatz (2007); Noy (2009)).

We study the macroeconomic impacts and fiscal costs of extreme weather events in Africa and examine ex ante how African countries can building resilience strategies, such as climate-proofing infrastructure and accumulation of contingency fiscal buffers. Ex post, we study the debt sustainability concerns of financing the reconstruction of public infrastructure over the medium term. The results reveal the following. First, investing in resilient infrastructure is useful in attenuating the impact of the natural disaster. Second, building contingency fiscal buffers can smooth out the fiscal adjustment needed to finance post-disaster reconstruction. Finally, governments cannot face damages alone: grant-financing is key for debt sustainability and reducing the social cost of abrupt adjustment. Though there are principal-agent issues linked with such a strategy, the donor community would need to significantly scale up its financial contributions following the disaster shock.

The rest of the paper is organized as follows. We present the model in Section II and discuss the data used for the calibration of the model parameters, the size and duration of the disaster shocks in Section III. Section IV analyses the macroeconomic and fiscal cost of the disaster shock and alternative financing mechanism of reconstruction. Section V concludes.

II. The Model

We extend the model in Buffie et al. (2020) to study the macroeconomic and fiscal impacts of building resilient infrastructure prior to a disaster. Government invests in adaptation infrastructure in addition to standard infrastructure. Both types of infrastructure are complementary to some degree through a CES function and enter the production function of firms operating in the traded, nontraded and in the informal sector. There are five channels through which the economy is impacted by the natural disaster along the lines of Marto et al. 2017: (i) through permanent damages to public infrastructure; (ii) permanent damages to private capital; (iii) temporary losses of productivity resulting from the economic and social disruption; (iv) increased inefficiencies in public investment during the reconstruction period; and (v) damages to the sovereign's creditworthiness. The framework accounts for all the ingredients involved in building resilience prior to a disaster—namely government investment in adaptation infrastructure and fiscal buffers—to study a country's response to an extreme weather event.

1. Firms

Firms operate in three sectors including tradable (x) and non-tradable (n) and informal sectors (i). The production technologies of the different sectors x , n and i in period t are given:

$$q_{x,t} = a_x z_{t-1}^{\psi_x} k_{x,t-1}^{\alpha_x} S_{x,t-1}^{\theta_x} H^\chi (e_{b,t} L_{x,t})^{(1-\alpha_x-\theta_x-\chi)} \quad (1)$$

$$q_{n,t} = a_n z_{t-1}^{\psi_n} k_{n,t-1}^{\alpha_n} S_{n,t-1}^{\theta_n} (e_{n,t} e_{b,t} L_{n,t})^{(1-\alpha_n-\theta_n)} \quad (2)$$

$$q_{i,t} = a_i z_{t-1}^{\psi_i} k_{i,t-1}^{\alpha_i} S_{i,t-1}^{\theta_i} (e_{b,t} L_{i,t})^{(1-\alpha_i-\theta_i)} \quad (3)$$

where the firms combine private capital k , low-skill labor L , high-skill labor S , land or some natural resource H and government-supplied infrastructure z . The variable e_b links the quantity and quality of primary education to human capital of low-skilled labor, and e_n denotes work effort which improves the productivity of low-skilled labor in the informal sector.

The maximization of profit by competitive firms gives rise to the following factor demand equation.

$$(1 - \alpha_x - \theta_x - \chi) \frac{q_{x,t}}{L_{x,t}} = w_{x,t}, \theta_x \frac{q_{x,t}}{S_{x,t}} = w_{s,t}, \alpha_x \frac{q_{x,t}}{k_{x,t-1}} = r_{x,t}, \chi \frac{q_{x,t}}{H} = r_{h,t} \quad (4)$$

$$P_{n,t}(1 - \alpha_n - \theta_n) \frac{q_{n,t}}{L_{n,t}} = w_{n,t}, P_{n,t}\theta_n \frac{q_{n,t}}{S_{n,t}} = w_{s,t}, P_{n,t}\alpha_n \frac{q_{n,t}}{k_{n,t-1}} = r_{n,t} \quad (5)$$

$$P_{i,t}(1 - \alpha_i - \theta_i) \frac{q_{i,t}}{L_{i,t}} = w_{i,t}, P_{i,t}\theta_i \frac{q_{i,t}}{S_{i,t}} = w_{s,t}, P_{i,t}\alpha_i \frac{q_{i,t}}{k_{i,t-1}} = r_{i,t} \quad (6)$$

where w_s is the skilled wage, w_j (with $j=x, n, i$) are the low-skilled wages in the three sectors, r_j (with $j=x, n, i$) are rental return of private capital in the three sectors and r_h is the rental return on land. P_n is the unit price of nontraded goods and P_i is the unit price of informally-produced goods.

Specification of public infrastructure and natural disaster

Infrastructure is a public good that enhances productivity in all sectors. We expand existing models in the literature by specifying the infrastructure input as a combination of standard and normal infrastructure z^s and adaptation capital z^a . The later capital has a productivity v_a .

$$z_t = \left[\rho_z^\xi (z_t^s)^\frac{\xi-1}{\xi} + (1 - \rho_z)^\frac{1}{\xi} (v_a z_t^a)^\frac{\xi-1}{\xi} \right]^\frac{\xi}{\xi-1} \quad (7)$$

where ρ_z is a weight parameter and ξ is the intra-temporal elasticity of substitution between public capital inputs (standard and adaptation). This functional form is particularly useful in discussing adaptation because it allows us to view it either as a substitute or a complement to standard infrastructure.

The natural disaster affects the three sectors but causes disparate damages $D_j \in [0, 1]$ to output by permanently destroying public and private capital and resulting in a loss of productivity. The impact of the natural disaster can however be counteracted by public investments in adaptation activities that reduce the extent of the damages. For the three sectors x, n and i , we capture the natural disaster effect as follows:

$$Disaster_{j,t} = 1 - \frac{D_j}{(1 + \pi_j z_{t-1}^a)^{v_D}} \quad (8)$$

where $j = x, n, i$ and π_j and v_a are scaling factors that allow to measure the extent of the damage caused by the natural disaster.

We then multiply each sector production function in (1), (2) and (3) by this factor to get,

$$Q_{j,t} = Disaster_{j,t} q_{j,t} \quad (9)$$

Note that damages can be decomposed into damages to public, private capital, land as well as losses of productivity according to $(1 - D_{zj}) = \left(1 - \frac{D_j}{(1 + \pi_j z_{t-1}^a)^{v_D}}\right)^{\varpi_z}$, $(1 - D_{kj}) = \left(1 - \frac{D_j}{(1 + \pi_j z_{t-1}^a)^{v_D}}\right)^{\varpi_k}$, $(1 - D_L) = \left(1 - \frac{D_j}{(1 + \pi_j z_{t-1}^a)^{v_D}}\right)^{\varpi_L}$ and $(1 - D_{aj}) = \left(1 - \frac{D_j}{(1 + \pi_j z_{t-1}^a)^{v_D}}\right)^{(1 - \psi_j \varpi_z - \alpha_j \varpi_k - \chi \varpi_L)}$ respectively. The severity of the damages to public and private infrastructures and land is controlled by ϖ_z , ϖ_k and ϖ_L respectively, such that the larger ϖ_z is, the greater public infrastructure was destroyed relative to private capital and TFP (with $1 - \psi_j \varpi_z - \alpha_j \varpi_k - \chi \varpi_L > 0$).

The literature on natural disasters distinguishes between damages from economic losses and damages to infrastructure. We thus target the size of damage to TFP D_{aj} as representing economic losses and D_{zj} and D_{kj} as damages to physical infrastructure.

The disruption in the functioning of public and private infrastructure has a persistent effect on the TFP because infrastructure takes some time to rebuild and workers may have to spend their time rebuilding their houses or being locked at home, so aggregate productivity is assumed to recover slowly.

Return to standard and adaptation infrastructure

Plugging Eq. (4) in (6) and taking the first derivative with respect to each type of infrastructure gives the marginal return to infrastructure

$$R_t^Z = P_{j,t} \psi_j \frac{Q_{j,t}}{z_{t-1}} \quad (10)$$

which can be expressed in terms of the return to standard and adaptation infrastructure as

$$R_t^Z \left(\frac{z_{t-1}^s}{\rho_z z_{t-1}^s} \right)^{1/\xi} \text{ and } R_t^Z \left(\frac{v_a^{1-\xi} z_t^s}{(1-\rho_z) z_{t-1}^s} \right)^{1/\xi}, \text{ respectively.}$$

2. Government

Our model specification of the government sector introduces that government investment expenditures are either directed to investments in standard and adaptation infrastructure i_{zs} and i_{za} . There is a weak association between public investment acceleration and output growth because of low efficiency and, as a result, infrastructure stocks are limited in many African countries despite high levels of investment (See Figure 1). To capture this, Buffie et al. (2020) assumes a public investment efficiency parameter s which takes its values between 0 and 1 in the capital accumulation equation. Low efficiency in this setting is the result of poor public investment management. However, in time of natural disaster, the efficiency of public investment can be hardest hit. First, the destruction of the physical infrastructure creates a sudden damage of efficiency. Second, the natural disaster has a direct negative effect on government capacity, which undermines public investment efficiency. Third, building adaptation infrastructure might require certain set of capacity and skill that are not readily available in developing countries. Low domestic capacity in this case will likely reduce investment efficiency.

To account for the increased inefficiencies that arise post-disaster, the efficiency parameter s is time-varying and affected by D_s at the time of disaster. In particular, the ability to improve efficiencies during a disaster shock takes some time to materialize. In the interim, public spending is marred with leakages. Public capital therefore evolves according to

$$z_t^s = (1 - \delta_{zs,t})z_{t-1}^s + (1 - D_s)si_{zs,t} \quad (11)$$

$$z_t^a = (1 - \delta_{za,t})z_{t-1}^a + (1 - D_s)si_{za,t} \quad (12)$$

It is worth noting that the two types of infrastructure depreciate at rates δ_{zs} and δ_{za} and that the depreciation rate are time-varying. However, adaptation infrastructure is believed to withstand extreme climate events, so its depreciation rate is assumed to be lower than that of the standard infrastructure, $\delta_{zs,0} > \delta_{za,0}$.

In addition to building standard and adaptation infrastructures, the government also spends on maintenance m_t which is assumed to extend the service life of infrastructure, through minor repair routine in adaptation infrastructure and major repair in standard infrastructure. Therefore, the two depreciation rates are expressed as follows which is in line with Buffie et al. except that here we distinguish between two types of infrastructure:

$$\delta_{zs,t} = \delta_{zs,0} e^{-\Lambda_s m_t / z_{t-1}^s}, \quad \Lambda_s > 1 / \delta_{zs,0} \quad (13)$$

$$\delta_{za,t} = \delta_{za,0} e^{-\Lambda_a m_t / z_{t-1}^a}, \quad \Lambda_a > 1 / \delta_{za,0} \quad (14)$$

Another channel through which natural disasters can affect fiscal policy is through market-based borrowing cost. In fact, natural disasters can, in addition to the physical destruction of infrastructure, damage a sovereign's creditworthiness and create a sudden stop in capital flows. Thus, the natural disaster shock is assumed to weaken the sovereign's rating by a risk premium $D_{r,t}$. In addition, in line with Schmitt-Grohe and Uribe (2003), large accumulations of external debt (in deviations from its steady state level) aggravate the country risk premium. Therefore, given the risk-free world interest rate r_f and nominal GDP ($y_t = Q_{x,t} + p_{j,t}Q_{j,t} + p_{n,t}Q_{n,t}$), the real interest rate on external commercial debt follows

$$r_{dc,t} = (1 + D_{r,t}) \left(r_f + v_g e^{\eta_g \left(\frac{d_t + d_{c,t}}{y_t} - \frac{d + d_c}{y} \right)} \right) \quad (15)$$

In addition to building resilience with adaptation infrastructure, the government can decide to set up a fund to build up precautionary savings to be spent in the event of future natural disaster. Let \mathcal{S}_t be government's accumulation of foreign assets, paying real interest rate r_f . The fund can only be drawn down in case of a major natural disaster to finance the fiscal deficit that arises with reconstruction activities. Moreover, the government can finance through other types of financing instrument including grants, external concessional debt, external commercial debt and domestic debt.

Furthermore, the government also spends on transfers (T), on investment in education (i_s) and on interest payment on the three types of debt. The government also collects revenue from consumption tax, capital and labor income taxes and user fees on public capital, defined as $\mu =$

$f\delta_{zs}P_{zs}$. f refers to the fraction of the recurrent cost ($\delta_{zs}P_{zs}$) devoted for maintenance of standard infrastructure. The public sector budget constraint is expressed as follow:

$$P_t\Delta b_t + \Delta d_{c,t} + \Delta d_t - \Delta \mathcal{S}_t = \frac{r_d - g}{1+g}d_{t-1} + \frac{r_{dc} - g}{1+g}d_{c,t-1} + \frac{r_{t-1} - g}{1+g}P_t b_{t-1} + P_{zs,t}(i_{zs,t} + m_t) + P_{za,t}i_{za,t} + T_t + P_{s,t}i_{s,t} - \mu_t z_{t-1} - r_f \mathcal{S}_{t-1} - h_t(P_{n,t}c_{n,t} + g_i P_{i,t}c_{i,t} + g_x c_{x,t} + g_m c_{m,t}) - \sum_{q=i,n,x}[f_{q,t}(r_{q,t} - \delta P_{q,t})k_{q,t-1} + f_{wq,t}w_{q,t}L_{q,t}] - f_{ws,t}w_{s,t}\mathcal{S}_t - f_{h,t}r_{h,t}H \quad (16)$$

where $\Delta b_t = b_t - b_{t-1}$, $\Delta d_{c,t} = d_{c,t} - d_{c,t-1}$, $\Delta d_t = d_t - d_{t-1}$, $\Delta \mathcal{S}_t = \mathcal{S}_t - \mathcal{S}_{t-1}$, and r_d and r_{dc} are interest rates (in dollar) on concessional debt d and commercial debt dc , respectively. P_t is GDP deflator, $c_{n,t}$, $c_{i,t}$, $c_{x,t}$ and $c_{m,t}$ are consumption of nontraded, informal-produced traded and imported traded goods respectively; h_t is the consumption tax rate and the parameters g_i , g_x and g_m serve to broaden the consumption tax-base; f_{wx} and f_{wi} are ad valorem taxes on low-skill wage income; f_{ws} is ad valorem tax on skill wage income; f_q is ad valorem tax on capital income in the three sector and f_h is ad valorem tax on land income.

$P_{zs,t}$ and $P_{za,t}$ are supply prices of standard and adaptation public capital respectively. $P_{s,t}$ is the supply price of education capital. It is assumed that infrastructures (standard (zs) and adaptation (za)), private capital (k) and education capital (s) are built by combining a_{jm} units of imported machines with a_{jn} and a_{ji} ($j=zs, za, k, s$) units of formal and informal sector inputs. The supply prices of the four types of capital are thus given by $P_{zs,t} = a_{zsm} + a_{zsn}P_{n,t} + a_{zsi}P_{i,t}$, $P_{za,t} = a_{zam} + a_{zan}P_{n,t} + a_{zai}P_{i,t}$, $P_{k,t} = a_{km} + a_{kn}P_{n,t} + a_{ki}P_{i,t}$ and $P_{s,t} = a_{sm} + a_{sn}P_{n,t} + a_{si}P_{i,t}$.

Finally, we define a random walk process for the accumulation of the contingency fund as follows

$$\mathcal{S}_t = \mathcal{S}_{t-1} + inflow - outflow \quad (17)$$

where *inflow* refers to new saving in the fund and *outflow* refers to a drawdown of the fund.

3. Households

The model has two representative households: non-savers and savers who derive their utility from domestically-produced goods and from imported traded goods. The non-saving class comprises unemployed individuals and low-skill workers in the informal sector. They live hand-to-mouth and consume all their income each period and receive transfers from the government and their earnings in agriculture may include a share of land rents. The saving class

comprises skilled workers and low-skill labor in the formal sector. They maximize an intertemporal utility function subject to a budget constraint. Unlike the non-savers, this class of households have access to capital and financial assets and or liabilities and have therefore the possibility to smooth their consumption subject to a discount factor which measures their preference for the future or the present.

On the spending side of their budget constraint, savers pay tax on capital income, on land rent and on wage income in the formal sector. In addition, they pay user fees charged on infrastructure services. Furthermore, they face adjustment costs in accumulating capital, and portfolio adjustment costs in accumulating debt. The spending side of non-savers budget constraint is similar except that this class is exonerated from payment of user fees on infrastructure services. Moreover, they do not accumulate capital and debt.

The budget constraint of the representative non-saver is given by:

$$P_{c,t}c_{1,t} = (1 - f_{wx})(w_{x,t}L_{x,t} + \sigma r_h H) + (1 - f_{wj})w_{j,t}L_{j,t} + a_t T_t \quad (18)$$

where $L_{x,t}$ and $L_{j,t}$ are the supply of low-skill labor in the formal tradable and informal sectors, respectively; $w_{x,t}$ and $w_{j,t}$ are the corresponding real wages; f_{wx} and f_{wj} are ad valorem taxes on low-skill wage income; and c_1 is consumption of this class of households and P_c the corresponding consumer price index; T_t represents public transfers and the coefficient a_t measures the share of transfers going to this class, with $(1 - a_t)$ the share of transfer going to the counterpart savers.

The savers maximize the following intertemporal utility function:

$$V = \sum_{t=0}^{\infty} \beta^t \frac{c_{2,t}^{(1-1/\tau)}}{1-1/\tau} \quad (19)$$

Subject to the following budget constraints:

$$\begin{aligned} P_t b_t - b_{f,t} &= (1 - f_w)(w_{n,t}L_{n,t} + w_{s,t}S_{t-1}) + \sum_{q=j,n,x} [r_{q,t} - f_{q,t}(r_{q,t} - \delta P_{q,t})]k_{q,t-1} + \\ &(1 - f_h)(1 - \delta)r_{h,t}H + (1 - a_t)T_t - \frac{1+r_f}{1+g}b_{f,t-1} + \frac{1+r_{t-1}}{1+g}P_t b_{f,t-1} - P_{k,t} \sum_{q=j,n,x} (i_{q,t} + \\ AC_{q,t}) - \frac{\eta}{2}(b_{f,t} - \bar{b}_f)^2 - P_{c,t}c_{2,t} - \mu_t Z_{t-1} \end{aligned} \quad (20)$$

where β is the discount factor; τ the intertemporal elasticity of substitution; b is the stock of domestic bonds; $i_{q,t}$ is private investment in sector q , with $q = i, n, x$; δ is the depreciation rate; r_f is the exogenous real interest rate on foreign loans b_f ; r is the real interest rate on domestic bonds; μ is the user fee charged for infrastructure services; η is a positive constants; and $f_q, f_h,$

and f_w are tax rates on capital income (net of depreciation) in sector q , with $q = i; n; x$, land rents, and wage income in the formal sector.

The term $AC_{q,t}$ in the budget constraint captures costs incurred in changing the capital stock in sector q and expressed as $AC_{q,t} = \frac{v}{2} \left(\frac{i_{q,t}}{k_{q,t-1}} - \delta - g \right)^2$, with a positive constant. The term $\frac{\eta}{2} (b_{f,t} - \bar{b}_f)^2$ measures portfolio adjustment costs associated with the deviations of foreign loans from their steady state level \bar{b}_f .

4. Market-Clearing Conditions and External Debt Accumulation

There are three markets in the economy. The market for skilled labor, the market for low-skilled labor and the good markets. Flexible wages equate demand to supply in the market for skilled labor, the market for low-skill labor in sector $x; n; i$ and flexible price equate the demand and supply of goods in the non-traded and informally-produced good the markets.

$$S_t = S_{x,t} + S_{n,t} + S_{i,t}, \bar{L}_t = L_{x,t} + L_{n,t}, q_{n,t} = c_{n,t} + a_{kn} \sum_{q=i,n,x} (i_{q,t} + AC_{q,t}) + a_{zsn} (i_{zs,t} + m_t) + a_{zan} i_{za,t} + a_{sn} i_{s,t} \text{ and}$$

$$q_{i,t} = c_{i,t} + a_{ki} \sum_{q=i,n,x} (i_{q,t} + AC_{q,t}) + a_{zsi} (i_{zs,t} + m_t) + a_{zai} i_{za,t} + a_{si} i_{s,t}.$$

III. Calibration of the model

1. Severity of damage and distribution of natural disaster

The calibration of the model is tailored to a typical African country for which we analyze the response of the economy to a natural disaster shock. To provide a basis for the of the damages and losses we build on natural hazard and disaster data from ifo Geological and Meteorological Event (GAME) database constructed by Felbermayr et al. (2014). The data spans from 1979 to 2010 and provides measures of the physical intensity of the disaster. Moreover, the database integrates some aspects of EM-DAT database, especially, the damage on GDP, the breadth and persistence of the damage as well as the severity of the damage weighted by land area. Building on these data, we calibrate the severity of and duration of the disaster damages and losses.

The aggregate disaster index is an index over the weighted average of types of disaster (flood, storm, drought, high temperature, etc.) which occurred between 1979 and 2010. The index gives a maximum value of 39.3% as a measure of the average severity of disaster between 1979 and 2010. Based on this index, we assume that the aggregate D_j in Eq. (5) which capture the real damage to economic activity (that is, to overall GDP) will fall by the same amount following the disaster shock. The decline in this parameter implies a decline of overall GDP by the same amount. Put differently, the economic damages and losses amount to 39.3% of GDP. Regarding

the distribution of the damage across sectors, we calibrate it according to the size of each sector in overall GDP as discussed next.

Using data on the consumption shares for the formal nontraded good (γ_n), the informal good (γ_j), the imported consumer good (γ_m), and the traded good (γ_x) from the GTAP (Global Trade Analysis Project) Africa social accounting matrix⁴, the GDP shares can be pinned down from the steady solution. According to the GTAP data, formal nontraded goods, imported goods and traded goods account for 40%, 10%, and 30% of total household consumption in Africa, respectively. By deduction we get the consumption share for the informal goods which represent 20%. These consumption shares and the values assigned to other parameters imply GDP shares of 31.8%, 25.5%, and 42.7% for the formal non-tradable sector, the informal sector, and the tradable sector at the steady state. Thus, the damages to output in the tradable sector, in particular damages in tradable, non-tradable, and informal sector, represented 17%, 10% and 13%, respectively (Figure 2).

The distribution of the damage and losses to economic activity (D_j) across public capital (D_{zj}), private capital (D_{kj}), land (D_L) and productivity (D_{aj}) is given by the specification in the earlier section, that is, $(1 - D_{zj}) = \left(1 - \frac{D_j}{(1+\pi_j z_{t-1}^a)^{v_D}}\right)^{\bar{\omega}_z}$, $(1 - D_{kj}) = \left(1 - \frac{D_j}{(1+\pi_j z_{t-1}^a)^{v_D}}\right)^{\bar{\omega}_k}$, $(1 - D_L) = \left(1 - \frac{D_j}{(1+\pi_j z_{t-1}^a)^{v_D}}\right)^{\bar{\omega}_L}$ and $(1 - D_{aj}) = \left(1 - \frac{D_j}{(1+\pi_j z_{t-1}^a)^{v_D}}\right)^{(1-\psi_j \bar{\omega}_z - \alpha_j \bar{\omega}_k - \chi \bar{\omega}_L)}$ where $\bar{\omega}_z$, $\bar{\omega}_k$ and $\bar{\omega}_L$ are measures of the severity of the damages. By definition, the distribution depends on output elasticities with respect to public capital (ψ_j), private capital shares in value added (α_j), skilled labor shares in value added (θ_j), share of land in value added (χ , which is specific to agricultural sector) and low-skilled labor shares in value added, with $j = x, n, i$ (see Eq 1-3). Moreover, it depends on the severity of damages to public and private capital as captured by $\bar{\omega}_z$, $\bar{\omega}_k$ and $\bar{\omega}_L$. Therefore, the calibration of these parameters, discussed next, allow us to pin down the distribution.

2. Calibration of the remaining parameters

The output elasticities with respect to public capital (ψ_x, ψ_n, ψ_i) are pinned down from the initial return on public capital (see Eq. 7). Estimates of the gross return on infrastructure (R^z) are many in the empirical literature, but most of micro and macro evidence points to a high average return. In the World Bank's study of infrastructure in Africa, estimated returns for electricity, irrigation, and roads range from 17% to 24% (Briceno-Garmendia and Foster, 2010, chapter 2);⁵ in developing Asia, the average returns for roads, electricity transmission and distribution, and power generation are 23%, 20%, and 33%, respectively (Asian Development Bank, 2017). Similarly, the macro-based estimates in Dalgaard and Hansen (2005) point to returns between 15% and 30% using a wide range of estimators. Hulten et al. (2006) and Escribano et al. (2008), supply additional evidence of high returns. Some growth regressions suggest low or insignificant returns, but these are dominated by studies that use cumulative

⁴ See this link for more details: <https://www.gtap.agecon.purdue.edu/databases/Africa/v2/default.asp>

⁵ The estimated return for road maintenance is 139 percent.

public investment instead of physical indicators to measure the stock of infrastructure. All of this adds up to a presumption of high returns on infrastructure in developing countries. Therefore, we assume low-median and high-return scenarios assume therefore initial returns of 10%, 20%, and 30%, respectively. The implied value for the elasticity of output with respect to infrastructure (when $\psi_x = \psi_n = \psi_i$) is 0.304 for the high-returns scenario.

We now turn to the calibration of the remaining parameters, that is, the factor shares in valued added (α_j , θ_j and χ_j), with $j = x, n, i$. Data on these parameters are found in World Bank Enterprise Surveys and in social accounting matrices assembled by GTAP and IFPRI (International Food Policy Research Institute).

In the non-tradable sector ($j = n$), the above sources suggest a capital share of 40 – 60% of the non-tradable value added. The data in Thurlow and Wobst (2004) and Perrault et al (2010) suggest similar numbers. Accordingly, we set $\alpha_n = 0.50$. However, data on factor shares by skill or education level are scant. Therefore, we set the cost share for high-skill labor to be consistent with data on the share of high-education (secondary+) workers in the formal sector. The values assigned to θ_n (0.30) and the wage rates $w_s = 3$ and $w_n = 1$ give an employment share of 33.3% for high-skill labor. By way of comparison, the employment share for high-skill labor is 35.6% in Cote d'Ivoire (Gunther and Launov, 2012) and 32.9% in Egypt (Harati, 2013).

Turning to the informal sector ($j = i$), good, sensible data are not readily available for factor shares in the informal sector. We chose cost shares to match data on the share of high-education workers in the informal sector and the share of the informal sector in total non-agricultural employment. High-education workers account for 6.2% of informal sector employment in Cote d'Ivoire (Gunther and Launov, 2012) and 7% in Egypt (Harati, 2013). The informal sector share in non-agricultural employment equals 75% in Sub-Saharan Africa and 70% in South Asia and Southeast Asia (OECD, 2009). For the base case values $\alpha_i = 0.20$ and $\theta_i = 0.20$, the high-skill employment share in the informal sector is 6.3% and the sector's share in non-agricultural employment is 74.1%.

Finally in the tradable sector, the GTAP database gives cost shares for land in less-developed countries ranges from 12% to 51%, while Fuglie (2010) cites studies that place the cost share between 22% and 29% in India, Indonesia, China, Mexico, and Sub-Saharan Africa; the common 50-50 split in sharecropping contracts (Otsuka, 2007) suggests a cost share of 50% for labor and 30 – 35% for land (the landowner usually provides equipment and structures in addition to land). Therefore, we set the cost shares for land, capital, and high-skill $\chi = 0.30$, $\alpha_x = 0.20$ and $\theta_x = 0.05$, respectively. We calibrate $\varpi_z = 0.5$, $\varpi_k = 0.4$ and $\varpi_L = 0.3$ which gives slightly more weight to the destruction of public capital.

The implied damages for input factors are of about 15.1% for public infrastructure, 14.8% for private capital and 11.1% for land, relative to steady state. The productivity losses are commensurate, with deviations from the steady state of 10.9% in the non-tradable sector, 14.2% in the agriculture sector and 12.6% in the informal sector.

3. Recovery time horizon

The recovery time horizon is taken from the EM-DAT database. According to this database, the average count of natural disasters that happened between 1979 and 2010 is 40, which gives a frequency of 1.3 natural disaster per year. This entails that in a five-year-time horizon, the recovery time after natural disasters hit the economy will be 6.4 years. This is also the time required for reconstruction investment to restore the destroyed public capital, with investment in adaptation infrastructure acting as a shock absorber meant to mitigate the size of the effects of the shocks. Meanwhile, the reconstruction time can be shorter but there is a risk of overwhelming the government and reducing efficiency.

4. Reconstruction and Recovery

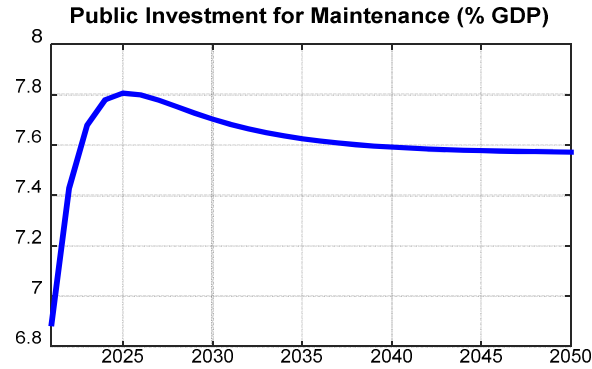
The objective of governments after damages caused to infrastructure is to recover smoothly and start the maintenance phase as soon as possibly feasible. Economic activity depends largely on infrastructure provided by the government (roads, ports, and airports) and therefore the political will to have infrastructure running is high. To capture the impetus for a swift recovery, we assume that the government intends to rehabilitate its damaged infrastructure to its pre-disaster level in about 5 years instead of 6.4 years as indicated earlier.⁶ Public investment efficiency, sectoral TFPs and depreciation of public capital linked to the disaster are all expected to gradually recover to their pre-disaster levels with the maintenance spending. The recovery follows a second-order delayed function of the type in Melina et al. (2016), which depicts smooth transition from the value of a variable x at the time of the disaster x^{disast} to its pre-disaster or steady-state level x^{pre_disast} , such that

$$\frac{x}{x^{disast}} = 1 + [1 + \exp(-k_1 t) - 2 \exp(-k_2 t)]x^{pre_disast} \quad (15)$$

where $x = \{m, a_x, a_j, a_n, s, \delta_{zs}, \delta_{za}\}$, $k_1 > 0$ represents the speed of maintenance spending and recovery to the pre-disaster level, and $k_2 \leq k_1$ represents the degree of frontloading of the maintenance spending and recovery. In particular, if $k_1 = k_2 = 0$, there is no maintenance spending and therefore no recovery, i.e., $x = x^{disast}, \forall t$. If instead $k_1 \rightarrow \infty$, the recovery is faster and x jumps to the pre-disaster level immediately. Lastly, if $k_2 = k_1$, the maintenance spending and recovery follow gradual paths to the pre-disaster level. The mechanics of this functional form are illustrated in Figure 1.

Figure 1: Time path for reconstruction investment

⁶ According to Borensztein et al. (2017), the probability of a large disaster to catch up to pre-disaster trend is between 2 and 5 percent per year for the most exposed countries. Nonetheless, the political will for swift recovery after disaster shocks can stumble over low government capacity, especially when the disaster takes a toll on institutions and human resources. As a result, there can be important delays in reconstruction investment.



IV. Simulation Results

A. The long run outcome

Table 1 shows how a program that increases public investment for reconstruction of infrastructure by 4% of initial GDP affect real output, the aggregate private capital stock, sectoral output and employment, the unemployment rate, real wages, and the relative prices of the formal and informal goods. CIC refers to the crowding-in coefficient, the ratio of the increase in real private investment to the increase in real public investment. The VAT and all other taxes are held constant, so the change in transfers (divided by initial GDP) measures the net fiscal impact of the investment program. We contrast with alternative programs that invest in resilient infrastructure and in standard infrastructure. We also explore programs that combine types of investments to study eventual complementarities.

The impacts on the economy—real GDP, the unemployment rate, real wages, sectoral employment, etc.—differ substantially with the composition of public investment. Six results stand out.

The first and second investment programs quantify the cost of insufficient expenditure for reconstruction of the infrastructure stock. The first program assumes the government does not invest in reconstruction to recover the damage and losses to standard infrastructure stock. The second program, the government increases reconstruction spending *pari passu* with new investment in standard infrastructure. This keeps the depreciation rate at 7% and the return on reconstruction equal to the return on new investment. Results show that underfunding of reconstruction investment can be costly. In fact, this program starts from an equilibrium with gross underfunding of maintenance: *zero-maintenance spending* ($m=0$) which reduce the service life of infrastructure (with the depreciation rate increasing from 7% to 8.13%) and raises the return on reconstruction investment 63% above the return on new investment at the initial steady state ($Rm = 0.325$ vs. $Rz = 0.27$). The efficiency loss reduces GDP 2.6 - 3.1 percentage points and aggregate consumption 3 - 3.5 percentage points.

The third investment program which involves investing in resilient infrastructure is superior compared to program 1 and 2. For this investment program, the crowding-in of the private sector shows a strong sensitivity with the crowding-in coefficient reaching greater than one (Table 1). As a result, there is prominent increase in private capital growth in GDP as well as in private consumption. Macroeconomic returns are always higher when the stock of capital is sustained; the positive effects on the private sector can be stronger as shown by the greater additional gains on the crowding-in coefficient.

Finally, the mixed investment program (Program 4) is highly attractive. Mixed investment programs reduce the large gaps in partial equilibrium returns that emerge when investment is directed solely to one type of public capital. The resulting efficiency gains are important. In this program, GDP increases 7-9 percentage points more than the gains in GDP for investment in reconstruction, in standard infrastructure, in upper-level education, and basic education alone.

Table 1: Base case: Long run effects of different public investment programs.

	Program 1	Program 2	Program 3	Program 4
Real GDP	4.2	7.8	12.3	19.4
CIC: $\Delta(k_n + k_x + k_j)/\Delta z^e$	0.83	0.70	3.54	9.36
Private capital: $k_n + k_x + k_j$	7.6	14.2	21.5	47.8
Traded output : q_x	2.2	4.1	6.7	10.9
Formal output : q_n	1.5	2.7	3.9	9.9
Informal output : q_j	1.4	2.7	4.5	7.4
Private consumption : c_{total}	3.6	7.4	12.1	23.9
Relative price, nontradable: P_n	-3.2	-5.8	-9.2	-16.0
Relative price, informal : P_j	-0.2	-0.4	-0.7	-11.1
Low-skill emplymt traded : L_x	-0.1	-0.1	-0.3	-0.2
Low-skill emplymt formal : L_n	0.0	0.0	-0.1	0.4
Low-skill emplymt informal : L_j	0.1	0.1	0.3	-1.9
Unemployment rate: u	12.14	12.15	12.2	11.76
Real wage, formal : w_n/P	2.06	3.85	6.12	8.25
Real wage, informal : w_j/P	5.10	9.68	15.86	25.22
Real wage, skilled : w_s/P	3.54	6.60	9.97	-19.92
Unproductive spending: $\Delta T/GDP_0$	-0.6	-1.3	-2.8	-0.2

Note: The effects are measured as the percentage change between the steady states, except for taxes, the crowding-in coefficient (CIC) and unemployment rate. Fiscal adjustment is assumed to fall exclusively on unproductive spending, so taxes are kept constant.

Program 1: Investment in infrastructure increases 4% of initial GDP with no change in reconstruction spending

Program 2: Investment in infrastructure and in reconstruction each increases 2% of initial GDP

Program 3: Resilient infrastructure investment increases 4% of initial GDP

Program 4: Investment in resilient infrastructure, upper-level education, and basic education increase 1%, 1% and 2% of initial GDP

B. Medium-term outcomes

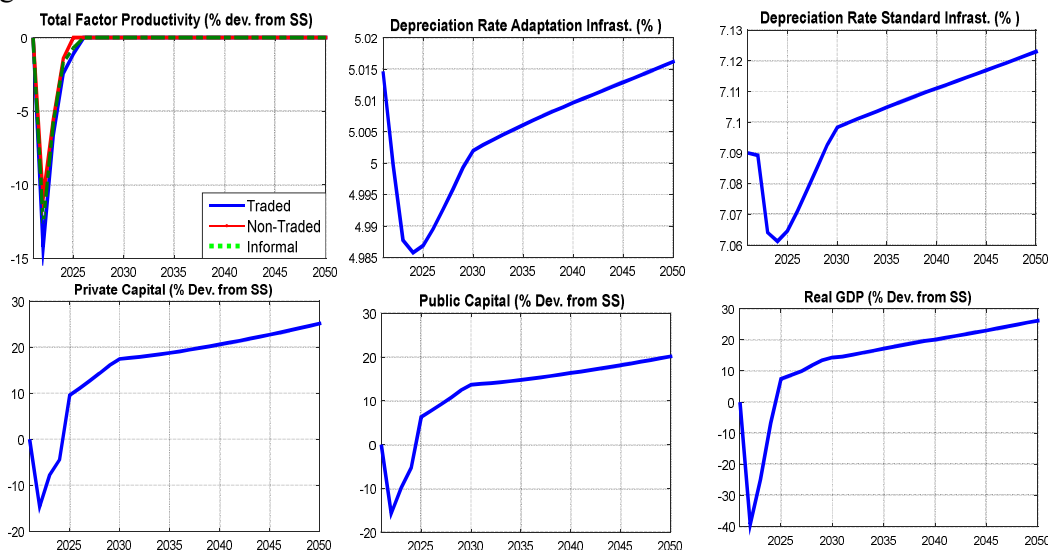
• Natural disaster shocks: No resilience

We analyze the response of the economy to a known natural disaster shock as discussed earlier. through assumptions on the resulting sectoral productivity losses. In this baseline scenario, we assume no resilience in the form of adaptation public infrastructure; as a result, the depreciation rates of the two types of infrastructure (highly substitutable) decline instantaneously during the disaster shock (Figure 2). Based on these assumptions, the disaster shock causes a damage of

about 39.3% on GDP. The implied damages for input factors are of about 15.1% for public infrastructure, 14.8% for private capital and 11.1% for land, relative to steady state. The productivity losses are commensurate, with deviations from the steady state of 10.9% in the non-tradable sector, 14.2% in the agriculture sector and 12.6% in the informal sector.

The recovery is assumed to take about 5 years, in line with ifo-GAME data on persistence of disaster, with reconstruction investment meant to restore the destroyed public capital while investment in adaptation infrastructure acts as a shock absorber to mitigate the size of the effects of the shocks.

Figure 2: Natural disaster shock



Note: These are implied damages from the disaster shock equivalent to GDP losses of 39.3%. The size of the given by EM-DAT database.

- **Reconstruction investment**

In this section we study how the government would have to respond to the natural disaster if it had to finance the entire reconstruction activities by either raising consumption taxes, reprioritizing spending or resorting to external borrowing. We also study the role of building fiscal buffer in the form of contingency fund parked in an external account which the government can draw down to finance reconstruction.

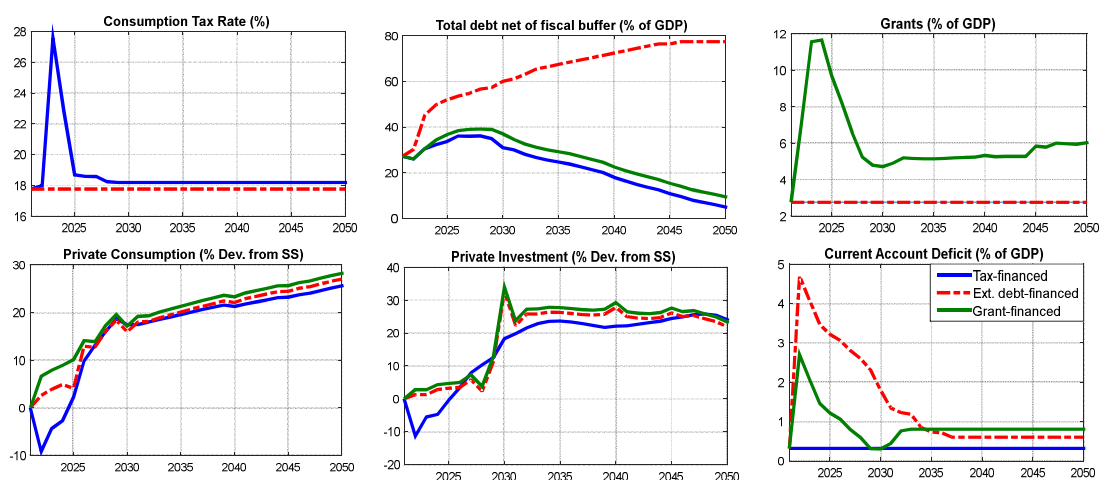
Fiscal and alternative financing mechanisms for reconstruction investment

- ***Grants and external commercial debt financing***

The time path for reconstruction investment is given in Figure 1. We assume that the fiscal financing involves raising consumption tax (Figure 3). By way of comparison, we explore alternative financing whereby the government relies on international solidarity when the shock occurs, as is seen many similar crises where international philanthropy increases. This is

achieved through instantaneous increase of grants following the shock. Moreover, we simulate an increase in external commercial debt to finance the fiscal deficit. We find that the social cost of fiscal financing of reconstruction through tax increases is high in time of natural disaster. Private consumption and private investment both take a hit from higher consumption tax, suggesting that governments should explore other sources of finance for reconstruction. Grant-financing is superior if the government succeeds in securing such funding source; we find that it eases the fiscal adjustment in the short term and as a result the social cost is lower. In fact, private consumption is 7 percentage point higher under this debt-financed reconstruction compared to tax-financed. External-debt financing yields an intermediate outcome. It turns out to be better than tax-financing and less viable compared to grant-financing.

Figure 3: Fiscal and external debt financing



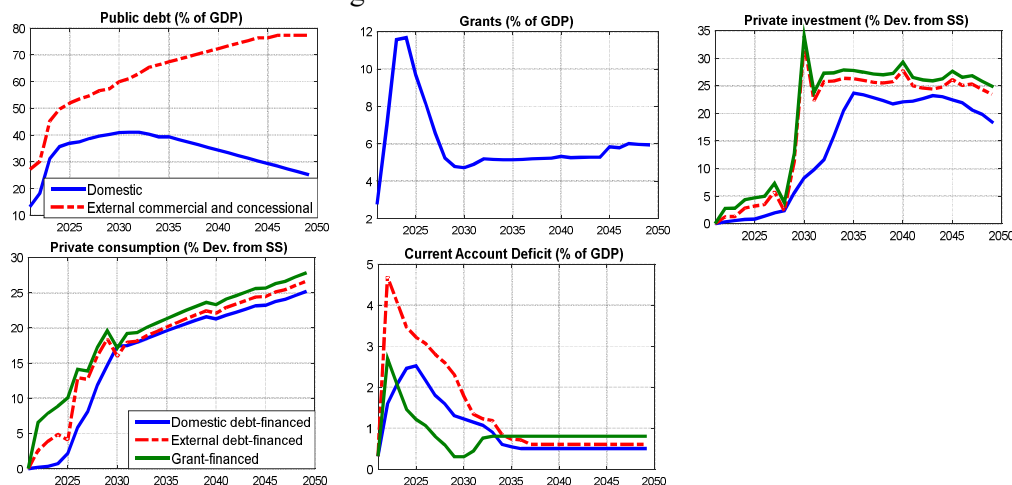
- ***Domestic debt financing***

An alternative option in time of disaster shock is for the government to secure domestic debt in order to close the financing gap. We simulate this alternative financing source and compare it with the previous grant-financing and external debt-financing (Figure 4). The results confirm the viability of grant-financing over the domestic debt-financing. Moreover, we find that external debt-financing is superior to domestically financing the reconstruction. The merits of grant-financing make it the most viable source of financing in time of emergency.

In fact, the benefits of a grant-financed reconstruction program are clear: because of its high concessionality (no interest bearing) the country enjoys the benefits of a recovery without running the risk of debt distress. Another important consideration to have in mind with regards to the grant contribution of donors is that these encompass far more than financial support. In fact, the donors have an eye on how efficiently their money will be utilized. External grants often come with substantial technical assistance, enforcing stricter rules regarding procurement—ensuring public investment is well spent and thus investment efficiency is

sustained—as well as enhancing the functioning of institutions to help cope with the disaster's consequences—allowing households to recover their work and hence boosting a productivity recovery. Adding these features to our simulations show a stronger recovery of private consumption and investment. However, prolonged donor support may lower the government's incentives to efficiently collect tax revenues.

Figure 4: Domestic debt financing



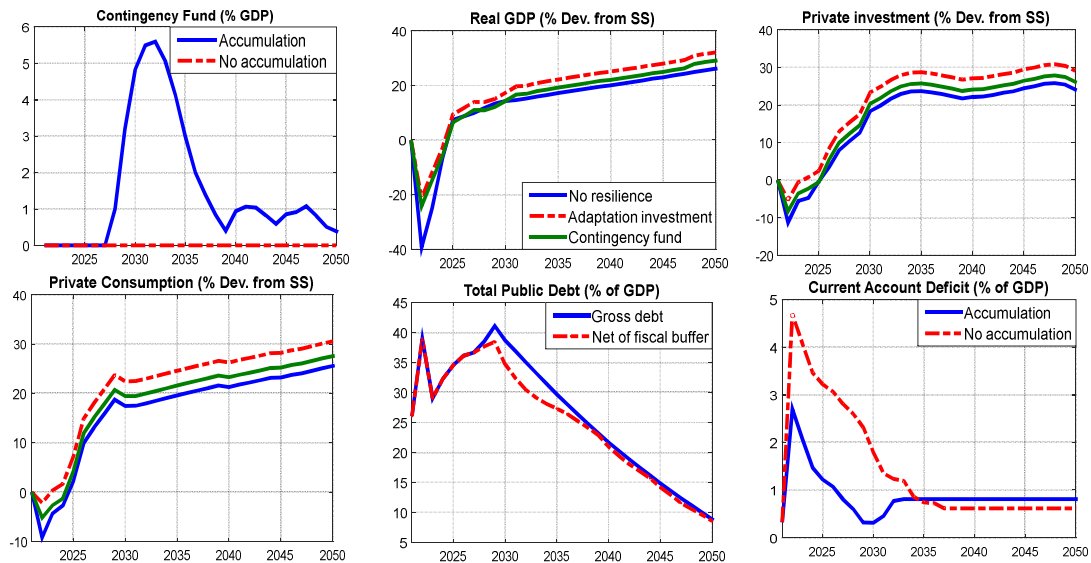
Building fiscal buffers: Role of contingency fund

One of the policy options to shield against the likelihood of future liquidity crunch that may occur when a natural disaster hit—especially in countries that are more prone to those shocks—is to accumulate money in a contingency fund. The justification for a contingency fund is that when a natural disaster hits and disrupts everything including economic activity, access to financing (particularly external private financing) might be difficult or become expensive exactly when the government urgently needs money to deal with the shock. However, the accumulation of the contingency fund comes with a high opportunity cost. In fact, the government is facing a tradeoff between investing upfront on resilient infrastructure to shield against future occurrence of disaster on the one hand and accumulating external financial assets to shield against future liquidity shortages on the other. Therefore, the accumulation of the fund is a diversion of resources away from investment on resilient infrastructure.

With that in mind, this subsection answers the following: what if the government decides to divert resources for the accumulation of the contingency fund abroad? Figure 5 contrasts this scenario (in red) with the case in which the government does not accumulate an external fund. The alternative of not accumulation a fund frees up financial resources allows the government to start reconstruction without the need for additional borrowing in the short term. Alternatively, the financial resource freed up would serve in the construction of the resilient infrastructure, in which case the damage and losses from the disaster shock are mitigated, with no need for reconstruction.

Building fiscal buffers allows the government to live with lower debt-to-GDP levels than otherwise. Diverting part of the investment in adaptation to the contingency fund has both a direct and an indirect effect on GDP. First, it reduces the stock of resilient infrastructure that helps withstand the impact of the storm and thus there is more destruction of public and private capital. On the other hand, the scarcity of adaptation capital raises its marginal benefit, which sustains the crowding in of private investment prior to the disaster. Therefore, the accumulation of the contingency fund acts as a shock absorber, with the contraction of real GDP attenuated (red dotted line) as compared to the no-accumulation case (green dashed line).

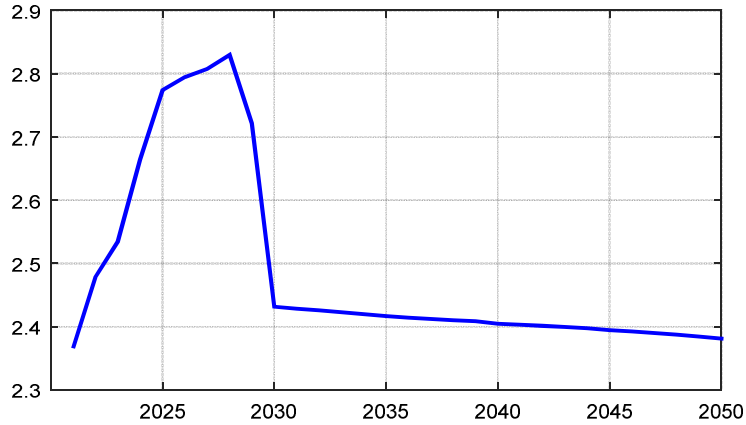
Figure 5: Building contingency fund



Building resilience: Role of adaptation infrastructure

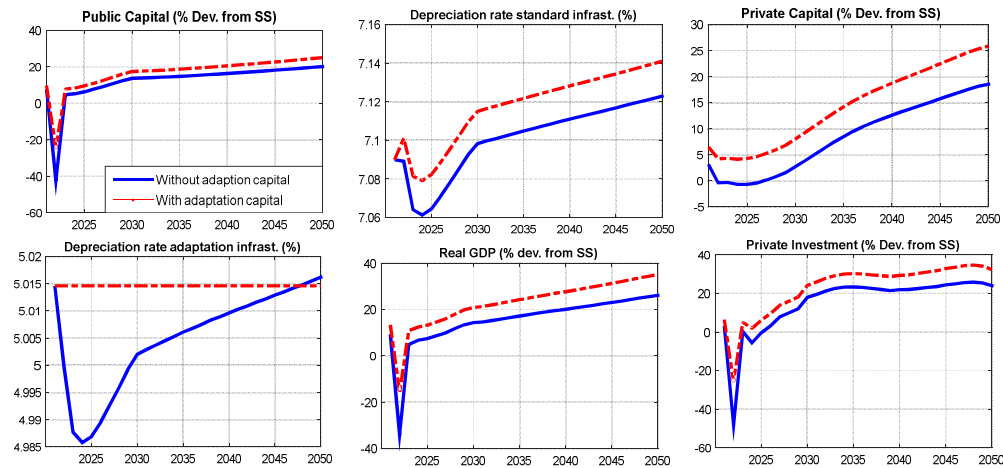
This subsection performs the experiment of scaling up adaption investment—frontloaded during the first 10 years coinciding with the disaster shock (Figure 6). We assume strong substitutability between adaptation infrastructure and standard infrastructure (that is, $\xi \rightarrow \infty$). On the fiscal adjustment, we assume the government finances the investment through accumulation of commercial debt.

Figure 6: Time path for investment spending in adaptation infrastructure (% GDP)



Thanks to the investment in resilient infrastructure, the magnitude of the damages caused by the disaster shock to public and private infrastructure, as well as on sectoral TFP is reduced. Figure 7 shows the magnitude of the damages with adaptation infrastructure and contrasts with the case where the government does not build resilience (discussed in previous section). We find that the adaptation capital lowers the damages caused to public capital and raises productivity. Private capital is on higher path and ultimately the contraction of real GDP is reduced.

Figure 7: Role of resilient infrastructure



V. Conclusion

Natural disasters such as storms, floods and drought are common and increasing shocks in Africa. In addition to deaths toll they inflict, natural disasters destroy public and private infrastructure needed for the economy to function, disrupting economic and social activities with long-lasting effects. They also put considerable strains on government finances, frequently

demanding a swift reconstruction of damaged infrastructure. However, there may be a limited room to raise additional revenues or cut transfers and other expenditures.

This paper assesses two main policy issues: (i) if the government were to fully rebuild the public infrastructure destroyed by the disaster shock within 5 years, what additional resources would be required and what are the policy options and their implication for fiscal and debt sustainability over the medium term? and (ii) if the government were to invest in resilient infrastructure and save financial resources in a contingency fund, how fiscal and debt sustainability would be improved after the disaster?

The results reveal the following. First, the government cannot face damages alone: grant-financing is key for debt sustainability and reducing the social cost of abrupt adjustment. Thought there are principal-agent issues linked with such a strategy, the donor community would need to significantly scale up its financial contributions following the disaster shock. Second, the government can invest in resilient infrastructure and build fiscal buffers that would attenuate the impact of the disaster. However, these initiatives imply that the government would need to create fiscal space (raising taxes) or resort to borrowing. Finally, and more importantly, donors can help support these investments. This would help reduce the need for their financial contributions post-disaster.

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