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The Macroeconomic and Welfare Benefits of Building Resilience in Disaster-Prone Developing Countries

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WORKING PAPERS

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The Macroeconomic and Welfare Benefits of Building Resilience in Disaster-Prone Developing Countries*

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Abstract

Natural disasters often have high economic costs, setting back years of investment in developing countries. This paper develops a multi-sector DSGE model to study the macroeconomic and welfare implications of financing resilience-building using different fiscal instruments. The model includes developing countries' macroeconomic and distributional features, such as a large unproductive rural sector, an incomplete credit market, and an informal sector. The results indicate that investing in resilience capital in a disaster-prone country improves welfare despite its high economic cost, but the financial instrument used to mobilize revenue matters.

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1 Introduction

Global warming is provoking an increase in the frequency and severity of natural disasters, leading policymakers in countries prone to natural disasters to consider significant investments in adaptation. Investment in adaptation aims to reduce risks from and vulnerability to climate change, strengthen resilience, and enhance well-being and the capacity to anticipate and respond successfully to climate change. It includes strengthening early warning systems, building new climate-resilient infrastructure, retrofitting existing infrastructure such as raising the height of bridges or enhancing natural drainage systems, and making water resources more resilient (see OECD (2018)). The United Nations Environmental Programme (UNEP) estimates the annual adaptation costs in developing countries at USD 70 billion in 2020. This figure is expected to reach USD 140-300 billion in 2030 and USD 280-500 billion in 2050 (UNEP (2021)). While acknowledging uncertainties when estimating adaptation costs, these costs are particularly worrisome in developing countries where resources are scarce while investment needs are high.

The distributional implication of natural disasters can also be dramatic. Poor households have less access to credit markets and limited ability to ensure against natural disaster risk, while wealthier households have more access to insurance mechanisms. In addition, wealthy households are more likely to work in the formal sector of the economy. In contrast, poor households are more likely to work on subsistence farms in rural areas or in the informal sector in urban areas. To correctly measure the welfare benefits and costs associated with building resilience, it is essential to consider critical differences in the potential impact of natural disasters across different households and their ability to insure against natural disaster risks.

Against this backdrop, this paper seeks to answer three key questions. First, what are the welfare benefits of investing in climate-resilient infrastructure in developing countries? Second, which households are more likely to benefit from it? Third, how does the choice of financing for these investments impact the cost-benefit analysis?

To address these questions, we build a multi-sector DSGE model with disaster risk along the lines of Gourio (2012). In this model, the government invests in infrastructure that can be resilient to natural disasters or not. Resilient investment is more expensive but it is not impacted by natural disaster, which reduces the effective damage caused by natural disasters. In this model, the stochastic steady-state depends on the distribution of natural disaster shocks and their damages.

We calibrate our model to Mozambique, one of the countries most vulnerable to climate shocks in the world. Located on the southeast coast of Africa with a coastline of about 2500km, Mozambique regularly suffers from tropical cyclones causing widespread devastation. In addition to storms, the country's population and infrastructure are regularly hit by an array of other natural disasters, from droughts, to floods, epidemics, insect infestations, wildfires, and landslides.

To replicate the possible consequences of a natural disaster in Mozambique, we consider stylized firms' and households' heterogeneity in the model. Firms' heterogeneity captures the economy's most important sectors: agriculture, manufacturing, and services, primarily informal, and how these sectors benefit from the resilient capital. Households' heterogeneity captures households' ability to insure against natural disaster shocks, and the sector where they work. These two margins are essential to capture the different impacts of natural disasters and resilience building across workers.

Our main findings are the following. Increasing the stock of resilient capital in the economy brings substantial benefits, both in the steady state and transition dynamics following a natural disaster shock. Resilient capital is beneficial because it reduces the damage caused by a natural disaster. This reduction in damage increases the return of private investment, leading to higher private investment in the economy with a more extensive stock of resilient capital. When comparing economies with different level of resilient capital, the economy with more resilient capital has all macroeconomic aggregates, along with sectors' and households' outcomes, increased relative to a baseline scenario with low investment in resilient capital. As expected, sectors and households involved in capital-intensive activities benefit the most from building resilience. The same conclusions emerge when we compare the impulse responses of aggregate and distributional macroeconomic outcomes to a natural disaster shock for two economies with different levels of investment in resilient capital.

While maintaining a substantial stock of resilient capital offers significant benefits, the associated costs are non-trivial, as resilient capital typically incurs higher expenses than its non-resilient counterpart. To rigorously evaluate the net benefits of resilient capital, it is crucial to account not only for the direct economic advantages but also the welfare implications of the fiscal measures required to finance its accumulation, such as the distortionary effects of increased taxation. To this end, we consider three instruments: i) personal income tax (PIT), ii) consumption tax (VAT), ii) corporate revenue tax (similar to a CIT), and we also consider the possibility that donors finance the investment. As expected, We find that the gains from resilience building are the largest when it is funded by donor grants since donors grants are not distortionary. Concretely, a 1% of GDP increase in climate-resilient investment funded by donor grants induces a rise in steady-state national output, consumption and private investment of 0.6%, 0.4% and 0.1%, respectively, relative to our baseline scenario. Income inequality, measured by the Gini index, increases slightly with the building of resilient capital, given the positive correlation between income and exposure to capital-intensive activities. Raising the CIT rate is the least effective way to back resilience building according to the model, because the tax rate must increase substantially to raise 1% of GDP in revenues, leading to sizable distortions in firms' employment and investment decisions. However, even in this policy scenario, investment in resilient infrastructure proves to be beneficial, with steady-state national output, consumption and private investment of 0.4%, 0.2% and 0.04%, respectively, above our baseline scenario. In sum, we find that investing in resilient capital is beneficial despite its high economic cost, but the financial instrument used to mobilize revenue matters. More important, we find that building resilience leads to a substantial increase in welfare. The welfare gains are highest when resilience building is financed with donors and lowest when financed with CIT, but positive in all cases.

As a robustness check, we also consider the benefits of investing in resilience in an economy where disaster risks are more prominent than in the benchmark economy. We find that the benefits of investing in resilience are larger for economies that face higher natural disaster risks, with larger welfare gains. We also run an additional robustness check regarding the cost of building resilience, and find that the benefit declines when the cost of resilient capital is higher. However, even when the cost is high, 50 percent larger than in our baseline, the benefits of investing in resilience building are still positive. Lastly, we compare the benefit of investing in resilient capital vs. investing in other valuable government services like education. The return on resilience building is larger in the short run than investing in education, while investing in education can generate a more significant return in the long run.

Related literature. Our paper is related to a growing literature that introduces climate risk into macroeconomic models (see IMF (2017) for a comprehensive literature review). Among those studies, Guerson et al. (2021) focus on the reconstruction of public capital in the aftermath of a natural disaster and on forms of insurance at the government level, and Marto et al. (2018) focus on the trade-offs of investment in resilient capital versus post-disaster donor support. Both papers, however, use specific deterministic disaster shocks and perfect-foresight simulations. In this sense, our paper is most closely related to Cantelmo et al. (2023), which also employs a DSGE model with disaster shocks to study the macroeconomic effects of extreme climate events and policies to respond to them. Our main contribution is to introduce stylized firm and household heterogeneity into this setting. Doing so allows us to evaluate the welfare and distributional effects of natural disasters and policies to mitigate the impact of those shocks in a stochastic general equilibrium framework. In particular, we uncover how differences in ownership of capital across segments of the population fundamentally alter the implications of climate disasters, as well as resilience investments, on inequality. Our model is solved using Taylor projection, a solution method developed by Fernández-Villaverde and Levintal (2018) to compute the equilibrium of DSGE models with disaster risk. Compared to the model of Fernández-Villaverde and Levintal (2018), our setting abstracts from nominal rigidities, given our long-run perspective, and is extended to capture aspects that are crucial to the analysis of the effects of natural disasters and policies to cope with them, in particular different types of capital and public investment. By evaluating the distortionary impact of different fiscal instruments, our paper also links to the literature on optimal fiscal instruments for public infrastructure investment (see, for example, Bom and Ligthart (2014)).

The remainder of the paper is organized as follows. Section 2 gives a background about Mozambique's exposure to natural disasters. Section 3 presents our model. Section 4 discusses the calibration and the solution method. Section 5 presents our main results and some robustness checks.

2 Mozambique Country Background

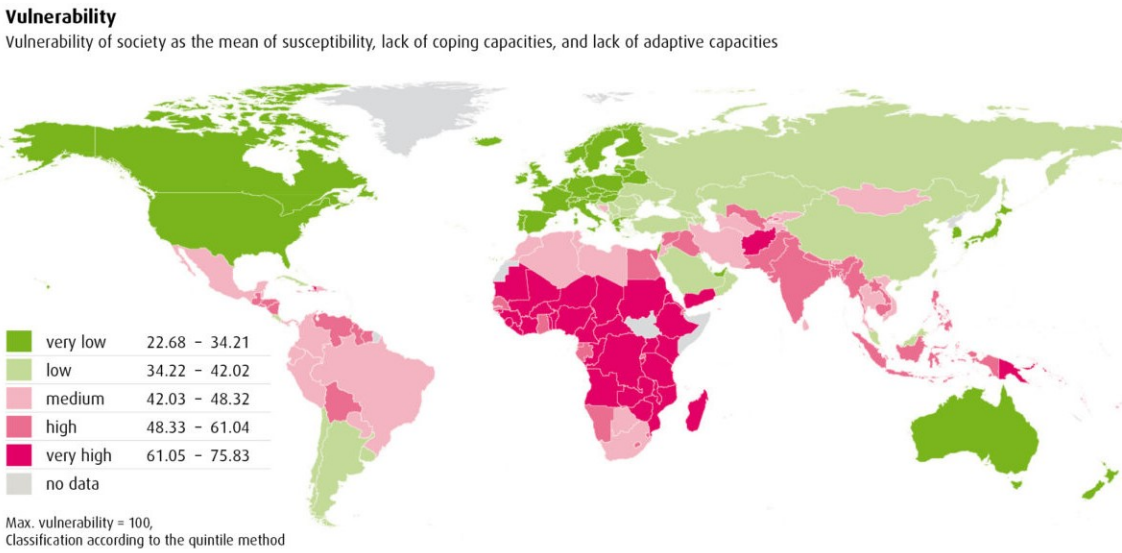
Mozambique is one of the countries most vulnerable to climate shocks in the world. The Long-Term Global Climate Risk Index by Eckstein et al. (2021) puts Mozambique among the 5 countries worldwide that suffer the most from extreme weather events. Similarly, the World Risk Index in World Risk Report (2021), which estimates the risk of disaster following extreme natural events, lists Mozambique as the 11th most vulnerable[1] country out of 181 countries in the 2021 database (Figure 1).

A multitude of factors explain Mozambique's precarious situation, not least the country's geography, with its location bordering a cyclone-prone area of the Indian Ocean, and low-lying topography. Socioeconomic factors such as high poverty and inequality, limited access to insurance, heavy dependence on rain-fed agriculture and rapid urbanization all amplify the negative effects of climatic shocks. Limited preparedness and lack of adequate resources further inhibit the country's crisis adaptation and response capacity.

Climate change is further worsening Mozambique's situation. Between 1960 and 2006, annual temperatures in Mozambique have increased at an average rate of 0.13°C per decade, while mean annual rainfall has decreased at a rate of 2.5mm per month over the same timespan (McSweeney et al.; 2021). With 60 percent of the country's population living in low-lying coastal areas, increasing

[1] In order to measure societal vulnerability, the World Risk Index measures susceptibility, coping capacities, and adaptive capacities of countries. Out of the 22 indicators used to calculate vulnerability, the majority are related to social protection.

Figure 1: Societal vulnerability to disasters as measured by the World Risk Index 2021.



sea levels pose a particular threat to the country. Consequently, the frequency and severity of natural disasters have increased significantly over past years. According to the International Disaster Database EM-DAT (CRED; 2022), the frequency of disasters afflicting Mozambique increased from 8-16 per decade between 1970 and 1999, to 45 in the decade 2000-2009, and 38 from 2010 until March 2022 (Figure 2).[2] While the damage incurred by disasters is more difficult to capture, estimates from EM-DAT point to significant increases in both the number of affected people, as well as the value of damages in USD since the turn of the millennium (Figure 2).

Government policies are being adopted on several fronts to enhance resilience and response capacity, such as the recently approved Law to Manage and Reduce the Risk of Disasters,[3] the National Climate Change Strategy 2013-2025[4] and the Master Plan for Risk and Disaster Reduction 2017-2030.[5] In addition, with support from the World Bank the government has prepared a National Resilience Strategy[6] in 2017 and updated it in 2020, and is mapping the most risk-prone areas and

[2] In the context of this paper, we look at the trends in disaster frequency and severity primarily for motivational purposes. It is nonetheless useful to bear in mind that incomplete data collection for EM-DAT in the past may bias the trends in the database.

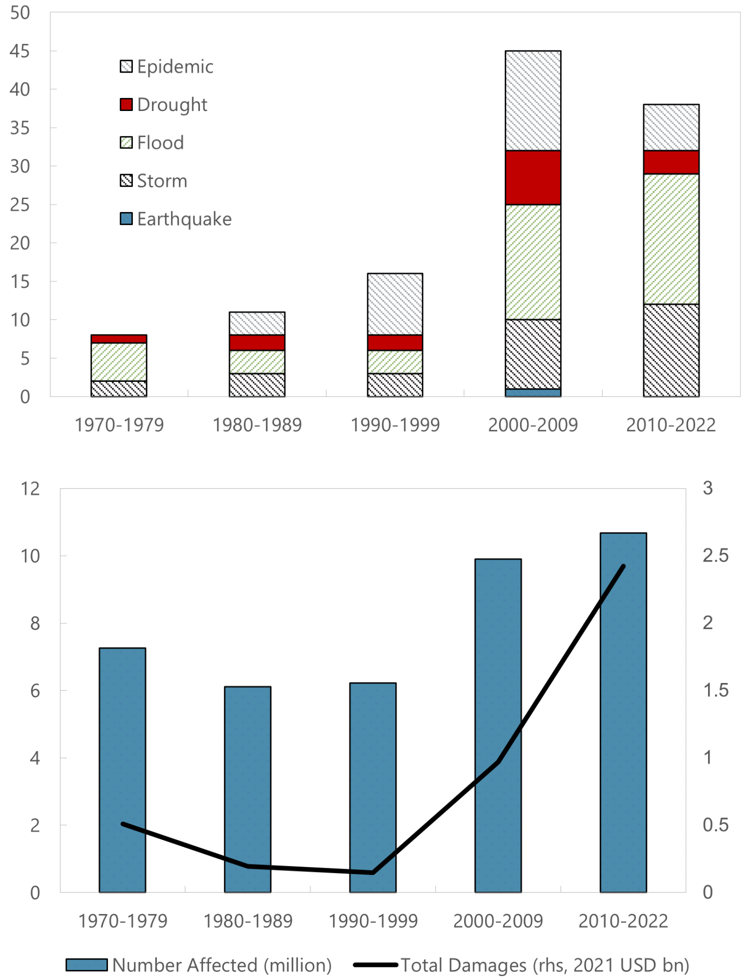
[3] Law 10/2020 - Gestão e Redução do Risco de Desastres

[4] Estratégia Nacional de Adaptação e Mitigação de Mudanças Climáticas 2013-2025 (ENAMMC)

[5] Plano Director para Redução do Risco e Desastres 2017-2030

[6] Estratégia de Redução do Risco de Desastres (ERRD)

Figure 2: Disaster frequency 1970-2022.



respective types of disasters. The World Bank has also conducted a new core diagnostic tool, the Country Climate and Development Report (CCDR) on Mozambique, which helps the country to align climate action and development efforts, as well as absorb new climate-related technologies as they emerge.

A Disaster Management Fund[7] supported by a regular budget allocation and supplemented by development partners is intended to become the main vehicle to channel financing for preparedness, response, recovery, and post-disaster reconstruction activities, as well as risk insurance. Moreover, the government is in the process of preparing a financial plan to protect against disasters. At

[7]Fundo de Gestão de Calamidades (FGC), created by Decree 53/2017

the level of institutions, the National Disasters Management Institute has evolved to cover the management and reduction of disaster risk.

Existing climate-resilient infrastructure in Mozambique has already shown the ability to mitigate disaster damages during cyclones Idai and Kenneth in 2019. The resilience of the infrastructure in the port of Beira, for example, has been critical to prevent further loss of life and allow for a quick resumption of operations. This included an upgraded primary drainage system to reduce flooding risk, and contingency planning by the port's firms. At the same time, solar-powered street lights that withstood the cyclones were among the city's few sources of post-disaster lighting, while emergency restoration of transport and logistic services proved critical to distributing aid.

For the purpose of the analysis to follow, it is important to note a number of features of the Mozambican economy that are critical for how the country is affected by disasters, as well as how resilient infrastructure is likely to affect welfare and economic outcomes. Overall, the Mozambican economy is dominated by agriculture, which makes up roughly a quarter of GDP, with a large share of the population active in small-scale subsistence agriculture. As highlighted by the World Bank (2018), Mozambique is among the most unequal countries in sub-Saharan Africa. While urban provinces tend to be more affluent on average, inequalities within urban areas are high. But even within rural areas inequality remains high, with the Gini coefficient for rural areas consistently above 0.4. Capturing these defining features is one of the principal aims of the model to follow.

3 Model

This paper presents a multi-sector Dynamic Stochastic General Equilibrium (DSGE) model. The model includes four sectors: agriculture, manufacturing, services, and energy, each characterized by distinct input structures to reflect the diversity of production processes. The manufacturing and energy sectors rely on private and public capital, labor, and energy inputs. The service sector uses both labor and energy, while the agriculture sector operates solely with labor as an input. There are two types of labor skilled and unskilled.

Natural disaster shocks affect the economy through two primary channels: (i) a temporary reduction in total factor productivity (TFP) across all sectors, and (ii) the destruction of a fraction of the public sector capital stock. These shocks provide insight into the role of public infrastructure in post-disaster recovery and highlight the differential impacts across sectors.

The model also features three types of households, reflecting sectoral employment and access to credit markets: rural workers (small farmers), urban low-skilled workers, and urban high-skilled workers. Rural and urban low-skilled workers are hand-to-mouth, reflecting limited access to the financial sector, which is a typical feature of low-income economies. In contrast, urban high-skilled workers can save through a risk-free bond. The government collects taxes on consumption, labor income, and profits, using the revenue to finance public capital investment (resilient and non-resilient), household transfers, and debt repayments. Figure 3) summarizes the model structure.

3.1 Environment

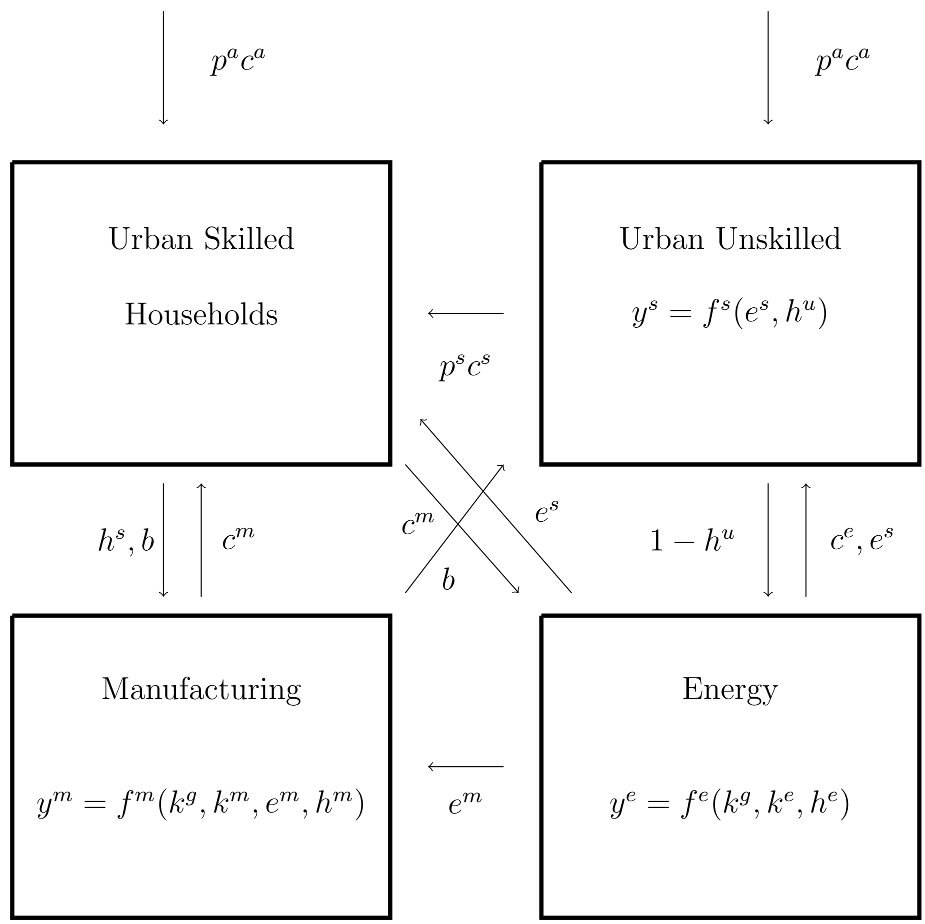
Time is discrete and indexed by t. We start by describing the agriculture sector.

Agriculture. Agriculture goods are produced using rural unskilled labor h_t^a and land l^a in a Cobb-Douglas production function. The production function is given by

$$y_t^a = A_t z^a (H h_t^a)^{1-\alpha^a} (l^a)^{\alpha^a},$$

where A_t denotes aggregate productivity, z^a is the sector-specific productivity of the agriculture industry, and H denotes the total human capital stock. In our baseline, human capital is constant and normalized to one ($H = 1$), but in subsection 6 we model human capital accumulation more carefully to study the tradeoffs between investing in physical capital and human capital. Aggregate productivity A_t follows a random walk process with drift Λ_a and is subject both to a normally

Figure 3: Schematic depiction of model components



distributed shock, $z_{A,t}$, and the disaster shock, $d_t\theta_t$:

$$\log A_t = \log A_{t-1} + \Lambda_A + z_{A,t} - d_t\theta_t,$$

where $z_{A,t}$ follows an AR(1) process with persistence ρ_{za}, standard deviation σ_{za} and $\varepsilon_{a,t} \sim \mathcal{N}(0,1)$:

$$\log\left(\frac{z_{A,t}}{z_A}\right) = \rho_{za}\log\left(\frac{z_{A,t-1}}{z_A}\right) + \sigma_{za}\varepsilon_{a,t}.$$

.

Manufacturing. Manufacturing goods are produced using public capital k_t^g, private capital k_t^m, labor h_t^m and energy e_t^m in a CES production function:

$$y_t^m = A_t z^m (k_t^g)^{\alpha^g}(k_t^m)^{\alpha^m}(e_t^m)^{\phi^m}(Hh_t^m)^{(1-\alpha^g-\alpha^m-\phi^m)},$$

where z^m is the sector-specific productivity of manufacturing, α^g and α^m are public and private capital shares, respectively, and ϕ^m is the share of energy input in the manufacturing production.

Services. Service goods are produced by an informal sector which uses labor and energy as inputs with constant returns to scale:

$$y_t^s = A_t z^s (e_t^s)^{\phi^s}(Hh_t^s)^{(1-\phi^s)},$$

where z^s is the sector-productivity in services, α is the labor share in this sector, and ϕ^s is the share of energy in the services production.

Energy. The energy good is produced using labor, private and public capital, with Cobb-Douglas technology:

$$y_t^e = A_t z^e (k_t^g)^{\alpha^g}(k_t^e)^{\alpha^e}(Hh_t^e)^{(1-\alpha^g-\alpha^e)}$$

where z_t^e is the sector-specific productivity in the energy industry. Energy is used as an input in the services and manufacturing sectors and as a consumption good for local households and foreign markets.

Capital and disaster shock. Households choose the optimal private capital stock, k_t^*, which depreciates at a rate δ, and the investment x_t needed to achieve it. Thus, the law of motion for optimal private capital is

$$k_t^* = (1-\delta)k_t + x_t,$$

with

$$\log k_t = \log k_{t-1}^* - d_t\theta_t.$$

k_t is defined as the actual capital stock at the beginning of period t, which equals the optimal stock of capital chosen in the previous period net of the natural disaster shock. Specifically, d_t is an i.i.d. binary variable that takes a value of 1 with probability p_d in case of disaster, and takes a value of 0 with probability $1-p_d$ in case of no disaster. If a natural disaster hits ($d_t = 1$), the actual capital stock k_t is permanently reduced by an amount θ_t. In particular, θ_t evolves according to

$$\log\theta_t = (1-\rho_\theta)\log\bar{\theta} + \rho_\theta \log\theta_{t-1} + \sigma_\theta\varepsilon_{\theta,t}, \quad \varepsilon_{\theta,t} \sim iid\,\mathcal{N}(0,1). \tag{1}$$

As in Fernández-Villaverde and Levintal (2018), the autoregressive structure captures the time-varying dimension of disaster risk, with $\bar{\theta}$ governing the expected output loss caused by the disaster shock. The term $\varepsilon_{\theta,t}$ is an i.i.d. normally distributed shock with mean zero and standard deviation 1, while σ_θ scales volatility and ρ_θ is the persistence of the shock.

Total public capital $k_{g,t}$ includes resilient $k_{r,t}$ and non-resilient public capital $k_{n,t}$:

$$k_{g,t} = k_{n,t} + k_{r,t}. \tag{2}$$

Similarly to private capital, the actual non-resilient public capital stock $k_{n,t}$ is the previous period's stock $k^*_{n,t-1}$ minus the potential natural disaster shock, with a depreciation rate of δ_g:

$$k^*_{n,t} = (1-\delta_g)k_{n,t} + x_{n,t}, \tag{3}$$

$$\log k_{n,t} = \log k^*_{n,t-1} - d_t\theta_t, \tag{4}$$

where $x_{n,t}$ is investment in non-resilient capital.

On the other hand, resilient capital is not damaged by natural disasters[8] and hence follows a more familiar law of motion, with the same depreciation rate δ_g:

$$k_{r,t} = (1-\delta_g)k_{r,t-1} + x_{r,t}, \tag{5}$$

where $x_{r,t}$ is investment in resilient capital.

Households. Three types of households, with total mass equal to one, populate the economy: rural unskilled workers, urban unskilled workers and urban skilled workers. All households i consume agriculture goods $c^a_{i,t}$, manufacturing goods $c^m_{i,t}$, services $c^s_{i,t}$ and energy $c^e_{i,t}$, and exhibit recursive (Epstein-Zin) preferences

$$V^{1-\psi}_{i,t} = U^{1-\psi}_{i,t} + \beta E_t(V^{1-\gamma}_{i,t+1})^{\frac{1-\psi}{1-\gamma}},$$

where the period-t utility $U_{i,t}$ is defined as:

$$U_{i,t} = \log(c^s_{i,t}) + \varphi\log(c^m_{i,t}) + \psi\log(c^m_{i,t}) + \omega\log(c^e_{i,t}),$$

while $V_{i,t+1}$ is the continuation utility. As discussed by Epstein and Zin (1989), the adoption of recursive preferences has two useful implications. First, they allow us to distinguish between the parameter controlling risk aversion, γ, and the parameter governing the intertemporal elasticity of substitution $1/\hat{\psi}$, where $\hat{\psi}$ is a function of ψ. Second, they offer the intuitive appeal of having

[8] It is important to note that the relative impact of the shock on resilient and non-resilient capital is necessary for the results, but not the assumption that resilient capital is not impacted by natural disaster shocks.

preferences for early (if $\gamma > \hat{\psi}$) or later (if $\gamma < \hat{\psi}$) resolution of uncertainty (see Epstein and Zin (1989) for further details). These features are particularly important in our context where agents face the risk of natural disasters, which induces additional precautionary savings captured by the recursive structure of preferences. Crucially, natural disasters, by increasing the risk faced by agents, generate further need for precautionary savings.

Skilled urban households decide how much labor h_t to supply to the manufacturing sector, and how much to save in public debt b_t and private capital k_t by investing an amount x_t. Unskilled urban households decide how much labor to supply to the energy sector h_t^u and to self-employment in the informal services sector $1 - h_t^u$. They do not participate in credit and capital markets. Rural workers are self-employed in the agriculture sector and do not participate in credit markets either.

Government. The government sector includes a granular menu of fiscal policy instruments. The government collects i) value-added taxes with rate τ^c on agriculture, manufacturing, services and energy goods consumption, ii) corporate taxes with rate τ^k on the revenues of formal sectors, iii) labor income tax with rate τ^w, iv) and nontax-revenue (donor grants GR_t). Government revenues are used to fund government expenditures including public investment in resilient and non-resilient capital ($k_{r,t}$ and $k_{n,t}$, respectively), and human capital H_t, as well as transfers to skilled workers T_t^s, transfers to unskilled workers T_t^u, transfer to rural workers T_t^r and payments to service public debt D_t.

The ratio of investment in non-resilient to resilient capital, λ is exogenous, and defined as $I_{n,t} = \lambda I_{r,t}$. Resilient investment is not destroyed or damaged by natural disasters. It yields the same output as non-resilient investment, but it comes at an extra cost of $p_{r,n} > 1$. For this reason, more units of investment are required to accumulate the same amount of resilient capital compared to non-resilient capital.

Revenue from the consumption tax is defined as

$$R_t^c = \tau^c(p_t^a C_t^a + C_t^m + p_t^s C_t^s + p_t^e C_t^e),$$

where p_t^a, p_t^s and p_t^e are the prices of agriculture, service and energy goods relative to the price of the manufacturing good, respectively.

The formal sectors, namely the manufacturing and energy sectors, must pay the corporate tax, which is constant across sectors. Total revenues from the VAT tax is given by

$$R_t^k = \tau^k(y_t^m + p_t^e y_t^e)$$

and tax revenue from labor income

$$R_t^w = \tau^w \mu^s w_t^s h_t^s,$$

where μ^s is the share of share of skilled workers in the population and w_t^s are their wages.

Total government transfers are the weighted sum of the transfers to all agents in the economy:

$$T_t = \mu^u T_t^u + \mu^s T_t^s + \mu^r T_t^r$$

The government can borrow only from domestic markets at the real interest rate r_t. Public debt is denoted by b_t. The dynamic budget constraint is given by:

$$R_t^c + R_t^k + R_t^w + GR_t + b_{t+1} = p_{r,n} x_{r,t} + x_{n,t} + T_t + (1 + r_t) b_t \quad (6)$$

3.2 Optimization problems

All workers in the model maximize expected lifetime utility by solving an intertemporal optimization problem. They choose consumption of each good in each period. Workers also choose the labor supplied in the different markets available to each.

Rural workers. Rural workers are set as a share μ^r of total population. They choose consumption levels of each good and how much to work in the agriculture sector h_t^a, receiving the income y_t^a. They solve:

$$\max_{\{c_t^{r,a}, c_t^{r,m}, c_t^{r,s}, c_t^{r,e}, h_t^a\}} E\left[\sum_{t=0}^{\infty} \beta^t \left(\log(c_t^{r,a}) + \varphi \log(c_t^{r,m}) + \psi \log(c_t^{r,s}) + \omega \log(c_t^{r,e})\right)\right] \tag{7}$$

subject to

$$(1+\tau^a)p_t^a c_t^{r,a} + (1+\tau^m)c_t^{r,m} + p_t^s(1+\tau^s)c_t^{r,s} + p_t^e(1+\tau^e)c_t^{r,e} = y_t^a + T_t^s,$$

$$y_t^a = A_t z^a (H h_t^a)^{1-\alpha^a},$$

$$h_t^a \in [0,1].$$

Urban skilled workers. Urban skilled workers are set at a population share μ^s. They choose consumption levels of each good, how much to work $h_t^{s,m}$, earning a skill labor wage w_t^m in the formal sector (manufacturing), and how much to save by accumulating public debt b_t, which pays a real interest r_t. They solve:

$$\max_{\{c_t^{s,a}, c_t^{s,m}, c_t^{s,s}, c_t^{s,e}, h_t^s, b_{t+1}\}} E\left[\sum_{t=0}^{\infty} \beta^t \left(\log(c_t^{s,a}) + \varphi \log(c_t^{s,m}) + \psi \log(c_t^{s,s}) + \omega \log(c_t^{s,e})\right)\right] \tag{8}$$

subject to

$$(1+\tau^a)p_t^a c_t^{s,a} + (1+\tau^m)c_t^{s,m} + p_t^s(1+\tau^s)c_t^{s,s} + p_t^e(1+\tau^e)c_t^{s,e} + b_{t+1} = (1-\tau_t^w)w_t^m h_t^{s,m} + T_t^s + (1+r_t)b_t,$$

$$h_t^{s,m} \in [0,1].$$

Urban unskilled workers. A μ^u share of the population is set as urban unskilled workers. They choose consumption levels of each good, how much to work in the energy sector h_t^u, receiving the wage w_t^e, and how much to work in the informal services sector $1 - h_t^u$. Once they work in the informal service sector, they will earn the profit π_t^s. T_t^s is the government transfer to unskilled service sector workers. The optimization problem of an unskilled worker is given by

$$\max_{\{c_t^{u,a}, c_t^{u,m}, c_t^{u,s}, c_t^{u,e}, h_t^u\}} E\left[\sum_{t=0}^{\infty} \beta^t \left(\log(c_t^{u,a}) + \varphi \log(c_t^{u,m}) + \psi \log(c_t^{u,s}) + \omega \log(c_t^{u,e})\right)\right] \tag{9}$$

subject to

$$(1+\tau^a)p^a c_t^{u,a} + (1+\tau^m)c_t^{u,m} + p_t^s(1+\tau^s)c_t^{u,s} + p_t^e(1+\tau^e)c_t^{u,e} = w_t^e h_t^u + \pi_t^{u,s} + T_t^u,$$
$$\pi_t^{u,s} = p_t^s A_t z^s (e_t^s)^{\phi^s}(h_t)^{1-\phi^s} - p_t^e e_t^s,$$
$$h_t^u \in [0,1].$$

Manufacturing sector. The manufacturing sector solves a profit maximization problem by choosing the total amount of labor, capital and energy inputs:

$$\max A_t z^m (k_t^g)^{\alpha^g} (k_t^m)^{\alpha^m} (e_t^m)^{\phi^m} (H h_t^m)^{(1-\alpha^g-\alpha^m-\phi^m)} - w_t h_t^m - r_t^k k_t^m - p_t^e e_t^m \tag{10}$$

Energy sector. The energy sector solves a profit maximization problem by choosing the total amount of labor and capital inputs:

$$\max A_t z^e (k_t^g)^{\alpha^g} (k_t^e)^{\alpha^e} (H h_t^e)^{(1-\alpha^g-\alpha^e)} - w_t h_t^e - r_t^k k_t^e \tag{11}$$

3.3 Equilibrium

A recursive competitive equilibrium is characterized by sequences of decision rules $\{c_t^{i,a}, c_t^{i,m}, c_t^{i,s}, c_t^{i,e}, h_t^i\}_{t=0}^{\infty}$ for each type of household $i \in \{u, s, r\}$, capital choices $\{k_t^j\}_{t=0}^{\infty}$ for $j \in \{m, e\}$, goods prices $\{p_t^a, p_t^s, p_t^e\}_{t=0}^{\infty}$,wages $\{w_t^m, w_t^e\}_{t=0}^{\infty}$ and real interest rate $\{r_t\}_{t=0}^{\infty}$, such that given government policies $\{\tau^c, \tau^k, \tau^w, GR_t, T_t, I_t^h, x_{r,t}, x_{n,t}\}_{t=0}^{\infty}$:

1. Households solve their optimization problem for rural workers, urban unskilled workers (9), and urban skilled workers (8), respectively.

2. Market clearing of skilled workers is satisfied

$$\mu^s h_t^s = h_t^m. \tag{12}$$

3. The capital market clears:

$$k_{n,t} = k_t^m + k_t^e. \tag{13}$$

4. The agriculture goods market clears:

$$\mu^u c_t^{u,a} + \mu^r c_t^{r,a} + \mu^s c_t^{s,a} = \mu^r y_t^a \tag{14}$$

5. Manufacturing goods market clears:

$$\mu^u c_t^{u,m} + \mu^r c_t^{r,m} + \mu^r c_t^{r,m} + x_{n,t} + x_{r,t} = y_t^m. \tag{15}$$

6. Services and energy goods markets clear:

$$\mu^u c_t^{u,j} + \mu^r c_t^{r,j} + \mu^r c_t^{r,j} = y_t^j, \quad \text{for } j \in \{s, e\}. \tag{16}$$

7. Government budget constraint (6) is satisfied.

4 Calibration

The model is calibrated to the Mozambican economy, with the aim of analyzing different fiscal instruments to finance the building of resilient public capital. The calibration matches sector sizes, use of labor and capital and inter-sector linkages.

Preferences. Households' preferences over manufacturing goods (ω_m), services (ω_s) and agriculture goods (ω_a) are calibrated so that consumption shares in the model match those in the data. The discount factor is calibrated at 0.97 according to estimates by Peiris and Saxegaard (2007) based on a DSGE model. The inverse of the intertemporal elasticity of substitution is set to 0.5, a standard value used in the literature on both advanced and developing economies.[9] We set the risk aversion parameter to 3.8, as in Gourio (2012), Fernández-Villaverde and Levintal (2018) and Cantelmo et al. (2023). Note, however, that there are scarce estimates for risk aversion within Epstein-Zin preferences for emerging economies.

Technology. Trend TFP growth (Λ_A) is set to 0.0035, as suggested by Araujo et al. (2016) with reference to countries in the Economic and Monetary Community of Central Africa. Private and public capital depreciation rates (δ and δ_g, respectively) are borrowed from Shen et al. (2018) who assume that the latter is half of the former, at 0.025 and 0.0125, respectively.

Fiscal policy. Government revenue and expenditure parameters are set to fit central government data. In the steady state, government transfers are positive. Transfers are distributed equally across households.

Natural disaster shock. In accordance with the evidence by Cantelmo et al. (2023), we set the annual disaster probability to 16.2% and the average loss to 6.6% of GDP. The standard deviation

[9] See, e.g. Uribe and Yue (2006), Gourio (2012), Uribe and Schmitt-Grohé (2017), Schmitt-Grohé and Uribe (2018) and Fernández-Villaverde and Levintal (2018).

(σ_θ) matches the quarterly dispersion of damages to GDP in disaster-prone countries of 28%. Given lack of evidence for emerging economies, we calibrate the persistence of the disaster risk shock (ρ_θ) to 0.50, in line with Gourio (2012) and Fernández-Villaverde and Levintal (2018).

Table 1 summarizes our calibration choices and highlights the parameters that must be calibrated based on the features of the Mozambican economy.

Solution Method. To solve and simulate the model, we employ the Taylor projection method developed by Fernández-Villaverde and Levintal (2018) to solve DSGE models featuring rare disasters. This paper indicates that a third-order Taylor projection is more accurate than perturbation methods up to a fifth order of approximation and projection methods up to a third order to solve a class of DSGE models with rare disasters. The method yields a solution that, although not global, is possible to approximate at many points of the state-space, making it accurate in dealing with large non-linearities triggered by low-probability, high-impact events such as natural disasters. This solution method was also used by Cantelmo et al. (2023) to study the impact of natural disasters on macroeconomic outcomes and welfare in disaster-prone countries.

5 Results

We next simulate the model to investigate the effects of natural disasters and the importance of resilience building to mitigate those shocks. First, we compare steady-state results depending on the level of public investment in resilient capital. Then, we present the dynamic responses of aggregate and distributional variables to a one-off natural disaster (ND) shock. Finally, we study the results of different policy strategies to finance resilience building on macroeconomic outcomes.

5.1 Steady-state differences

We first compare steady-state macroeconomic outcomes for two different levels of investment in resilient capital. Specifically, we compare results for $\lambda \in \{0, 0.2\}$, where λ is the ratio of public

Table 1: Calibration

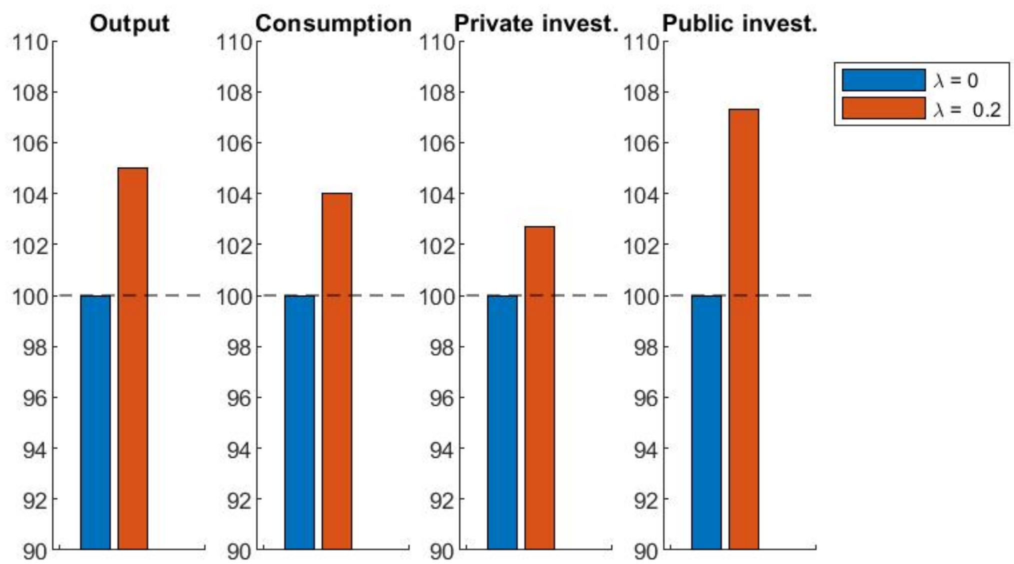
Symbol	Parameter	Value	Source
Parameters to be calibrated based on Mozambican data			
μ^u	Share of unskilled workers[1]	42.6%	Census 2017
μ^r	Share of rural workers	38.9%	Census 2017
μ^s	Share of skilled workers[2]	18.5%	Census 2017
α^g	Public capital share	42.7%	IMF Staff calculation 2022
τ^c	Consumption tax (VAT) rate	17%	Mozambique official rate 2022
τ^w	Personal income tax (PIT) rate	15%	IMF Staff calculation 2022
τ^k	Corporate income tax (PIT) rate	12%	IMF Staff calculation 2022
α^m	Capital share in manufacturing sector	57.4%	Cruz et al. (2018)
α^e	Capital share in energy sector	68.9%	Cruz et al. (2018)
ω_m	Share of manufacturing in total consumption	9.7%	INE Mozambique 2022
ω_e	Share of manufacturing in energy consumption	9.5%	INE Mozambique 2022
ω_s	Share of energy in total consumption	53.5%	INE Mozambique 2022
ϕ^m	Energy share in manufacturing sector	4.4%	Cruz et al. (2018)
p_d	Annual disaster probability	20%	EM-DAT
Standard parameters			
β	Discount factor	0.973	Peiris and Saxegaard (2007)
δ	Private capital depreciation rate	0.025	Shen et al. (2018)
δ_g	Public capital depreciation rate	0.0125	Shen et al. (2018)
γ	Risk aversion	3.8	Cantelmo et al. (2023)
ρ_A	Persistence of TFP shock	0.5	Cantelmo et al. (2023)
σ_A	Standard deviation of TFP shock	0.025	Cantelmo et al. (2023)
ρ_θ	Persistence of disaster risk	0.9	Gourio (2012)
$\bar{\theta}$	Mean disaster size	0.066	Cantelmo et al. (2023)
σ_θ	Standard deviation of disaster risk shocks	0.127	Cantelmo et al. (2023)
ψ	Intertemporal elasticity of substitution	0.5	Gourio (2012)
$p_{r,n}$	Price of resilient capital	1.25	Guerson et al. (2021)
λ	Ratio public investment in resilient to non-resilient capital	0.2	Guerson et al. (2021)

1. Unskilled workers supply labor for the energy sector or the informal services sector.
2. Skilled workers supply labor only for the manufacturing sector.

investment in resilient capital to non-resilient capital.

Figure 4 compares the values of aggregate variables in the steady-state for different levels of investment in resilience building. Contrasting to the scenario with no investment in resilience building ($\lambda = 0$), national output is 5% higher when there is a baseline level of investment in resilient capital ($\lambda = 0.2$), while aggregate consumption increases by 4%. Private investment is 2% higher in an economy with strong investment in resilience infrastructure, due to the crowding-in effect of public investment on private investment. Public investment is 7% greater, reflecting higher spending in resilient infrastructure.

Figure 4: Steady state - aggregate variables

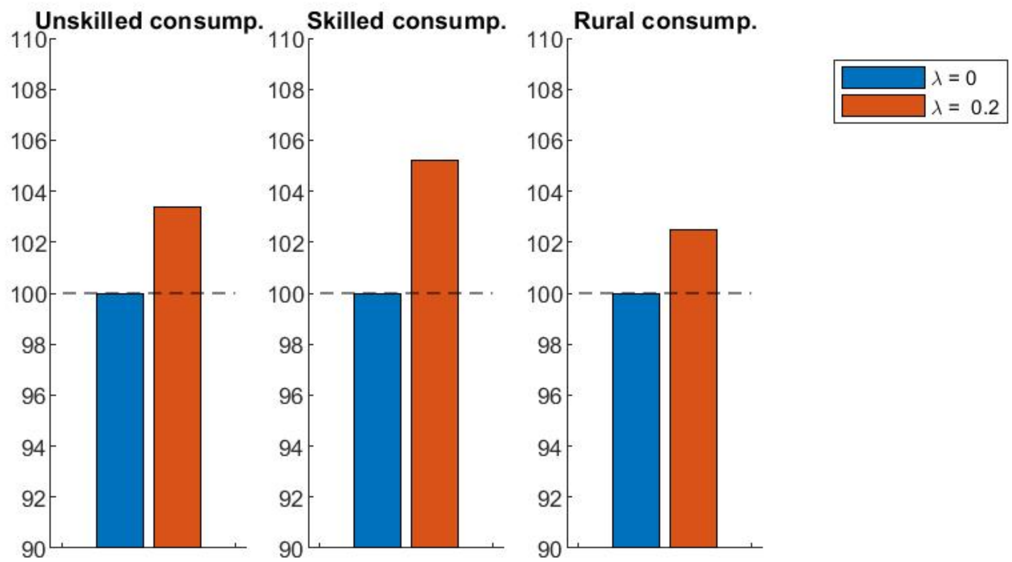


Note: Outcomes under the baseline scenario have been normalized to 100.

We now compare the level of consumption for each type of household in the steady-state given different levels of resilience building in Figure 5. Skilled urban workers benefit the most from stronger build-up of resilient capital, with their consumption rising by 5% compared to the case with no public investment in resilient capital. This occurs because these households are employed in the capital-intensive manufacturing sector, which benefits the most from the increase in public capital.

Consumption of unskilled workers increases by 3%, due to the positive effects of resilience building on the production of the energy sector, which employs this type of workers. Finally, consumption of rural workers increases by 2%. This effect is driven by higher demand for agriculture goods from other households, since capital is not employed in agricultural production.

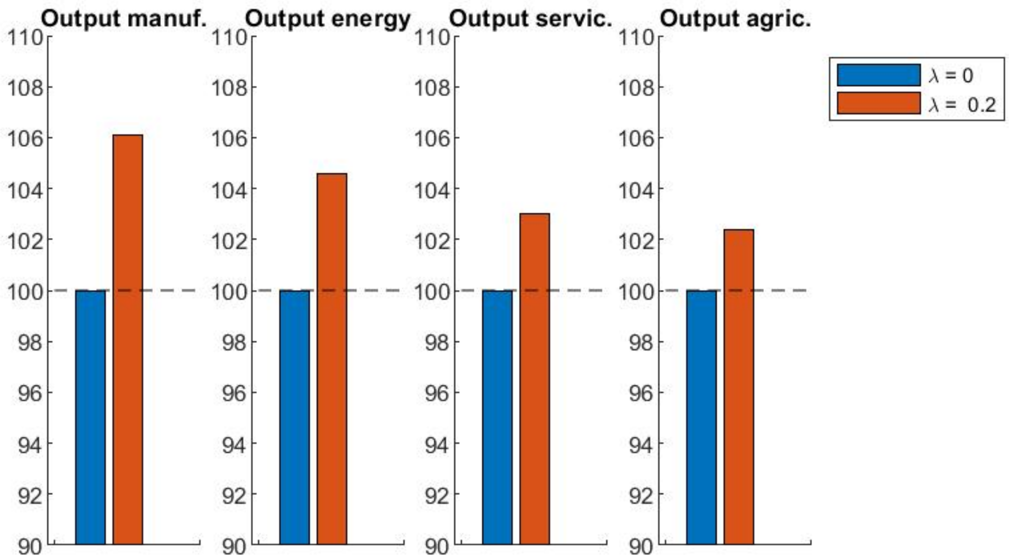
Figure 5: Steady state - household variables



Note: Outcomes under the baseline scenario have been normalized to 100.

Figure 6 compares output levels for each sector in the steady-state given different levels of resilience building. As previously discussed, the manufacturing sector benefits the most from higher investment in resilient capital, since it is the most capital-intensive sector. Its steady-state output rises by 6% in the economy with a higher level of investment in resilient capital. Energy output is 4% higher, also mostly due to positive effects of higher public capital in sectors that employ capital. Services output increases by 3%. Finally, consumption of rural workers increases by 2% driven by higher demand for the agriculture good.

Figure 6: Steady state - sector variables



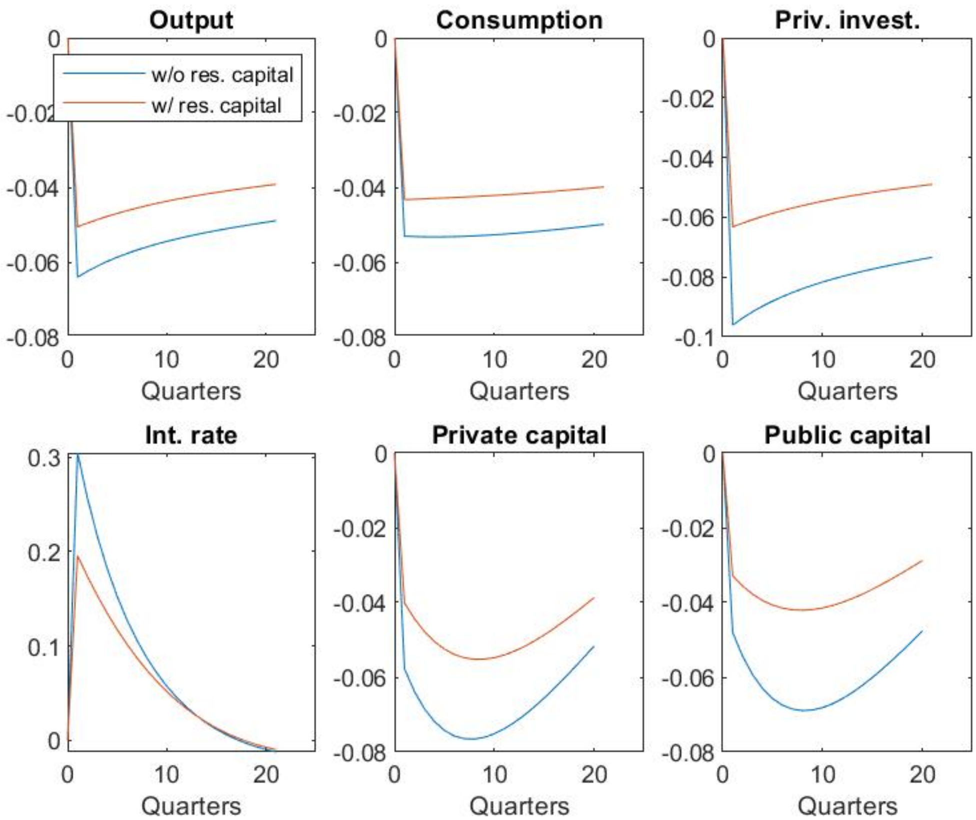
Note: Outcomes under the baseline scenario have been normalized to 100.

5.2 Impulse Responses

We now compare the dynamic responses of macroeconomic outcomes following an average-sized natural disaster (ND) shock in two different economies: one with a baseline level of investment in resilient capital ($\lambda = 0.2$) and another with no investment in resilient capital ($\lambda = 0$).

We start by analyzing the impulse responses of aggregate variables to an average-sized ND shock in Figure 7. Output falls by 6.2% in an economy without resilient capital, compared to a 4.8% fall when the government invests in resilient capital. The model predicts that output takes several years to return to pre-disaster levels, given the highly persistent negative effect of the ND shock on aggregate productivity. National consumption is also severely hit by the natural disaster shock, declining by 5.7% in the scenario with no resilient capital and 4.1% in the scenario with baseline investment in resilient infrastructure. However, the impact of a natural disaster on aggregate consumption is smaller than on aggregate output, since skilled workers, who can accumulate assets and represent an important share of total consumption, are able to partially cushion the impact of the ND shock by withdrawing some of their savings. Private investment falls by 9.8% and 6.1% in an economy without versus an economy with resilience building, respectively. The real interest rate increases by 0.3pp when there is no public investment in resilient capital and 0.2pp when the government invests in resilient capital. The interest rate increases because the marginal productivity of capital rises sharply as a natural disaster partially destroys the capital stock.

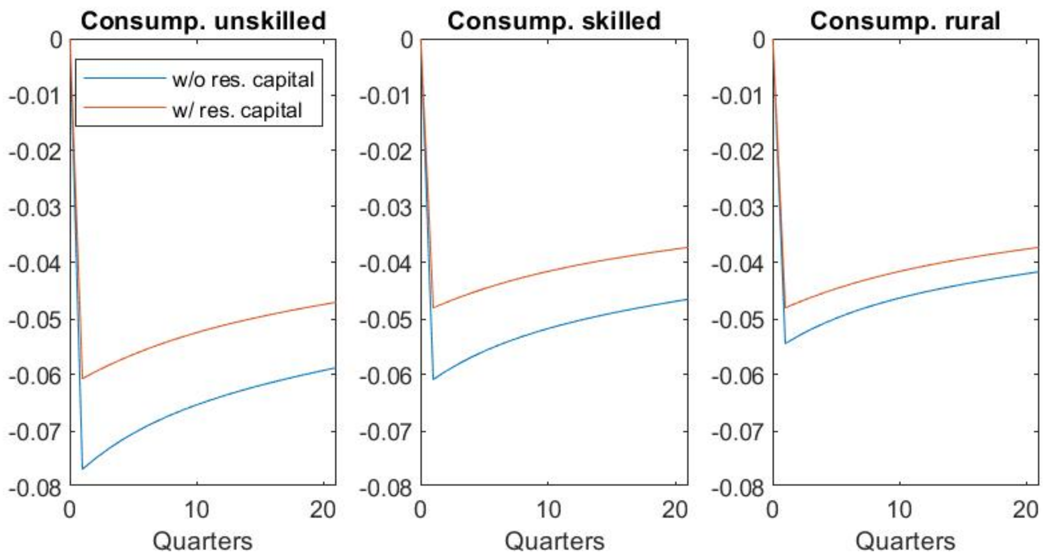
Figure 7: Impact of natural disasters - aggregate variables



Note: Y-axis denotes the change relative to the steady state.

Figure 8 plots the impulse responses of consumption of each type of household after a natural disaster shock. Unskilled workers suffer the largest reduction in consumption given their work in the capital-intensive energy sector and inability to smooth consumption by accumulating assets. Their consumption levels reduce by 7.7% in an economy with no resilient infrastructure and by 6.0% when the government invests in resilient capital. Consumption by skilled workers, who are employed in the manufacturing sectors but can accumulate assets, decreases by 6.0% in an economy without resilient capital, compared to a 4.8% reduction in an economy with resilient infrastructure. Consumption by rural workers declines as well, driven only by lower aggregate TFP and demand, since they do not use capital to produce the agriculture good and are self-employed.

Figure 8: Impact of natural disasters - distribution variables



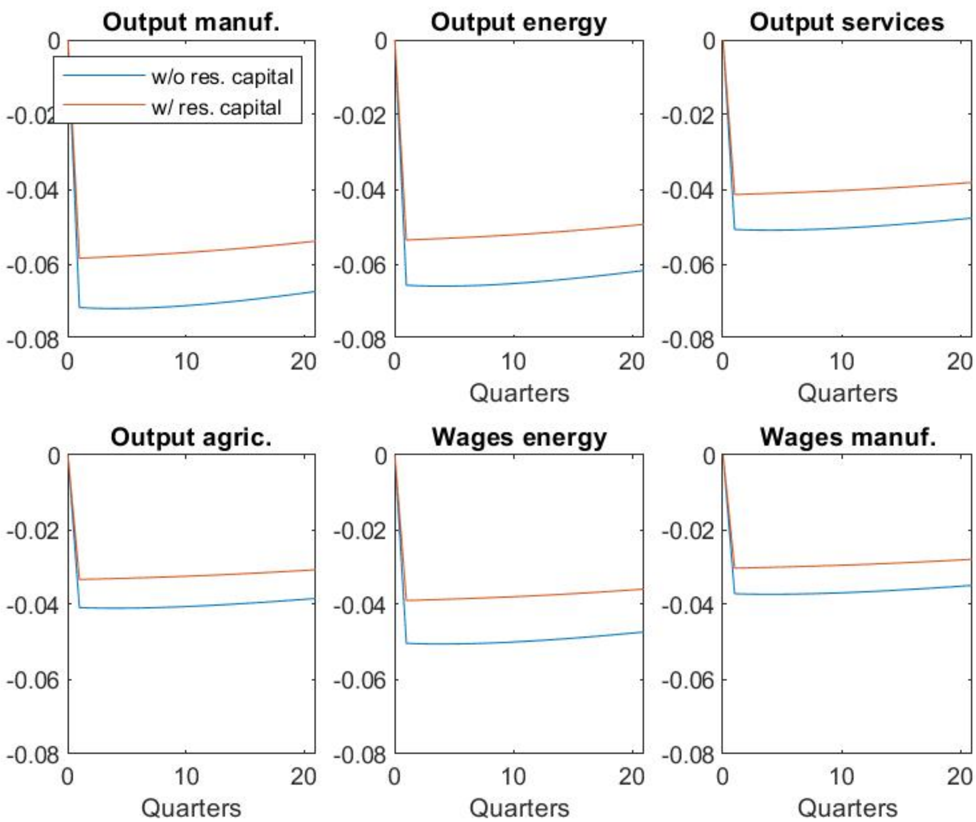
Note: Y-axis denotes the change relative to the steady state.

Figure 9 shows the impulse responses of output for each sector. Manufacturing output declines by 7.1% and 5.9% in the economy with and without resilient capital, respectively. Energy output declines 6.2% and 5.6% in an economy with resilient capital versus an economy without resilient capital. Services output declines 5.1% and 4.0% in an economy with resilient capital versus an economy without resilient capital, respectively. Agriculture output declines by 4.0% and 3.6% in an economy with resilient capital versus an economy without resilient capital, respectively.

5.3 Revenue mobilization schemes

We now study the effects of different revenue mobilization schemes to finance higher investment in resilient capital on macroeconomic outcomes in the steady-state, departing from the baseline case where $\lambda = 0.2$. Four strategies that raise 1% of GDP to finance resilience building are evaluated: i) increasing donor grants; ii) raising the consumption tax (VAT) rate by 1.2pp to 18.2%; iii) raising

Figure 9: Impact of natural disasters - sector variables



Note: Y-axis denotes the change relative to the steady state.

the corporate revenue tax rate (similar to a CIT[10]) by 2.5pp to 14.5%; and iv) raising the labor income tax (PIT) rate by 3.1pp to 18.1%.

Let $\{c_{it}^H\}_{t=0}^\infty$ and $\{c_{it}^L\}_{t=0}^\infty$ denote the consumption path of household i in an economy with higher investment in resilient capital backed by one of the fiscal instruments mentioned above, and in an economy with a baseline (low) level of investment in climate-resilient infrastructure, respectively. Welfare gains from resilience building for each household i are defined by:

$$\sum_{t=0}^{T} \beta^t u\left(c_{it}^H\right) = \sum_{t=0}^{T} \beta^t u\left(\left[1+\omega_i\right] c_{it}^L\right),$$

[10]In the model, firms have zero profits, because they operate in competitive markets using a Cobb-Douglas production function with constant returns to scale. Therefore, we assume that firms' revenues, rather than profits, are taxed.

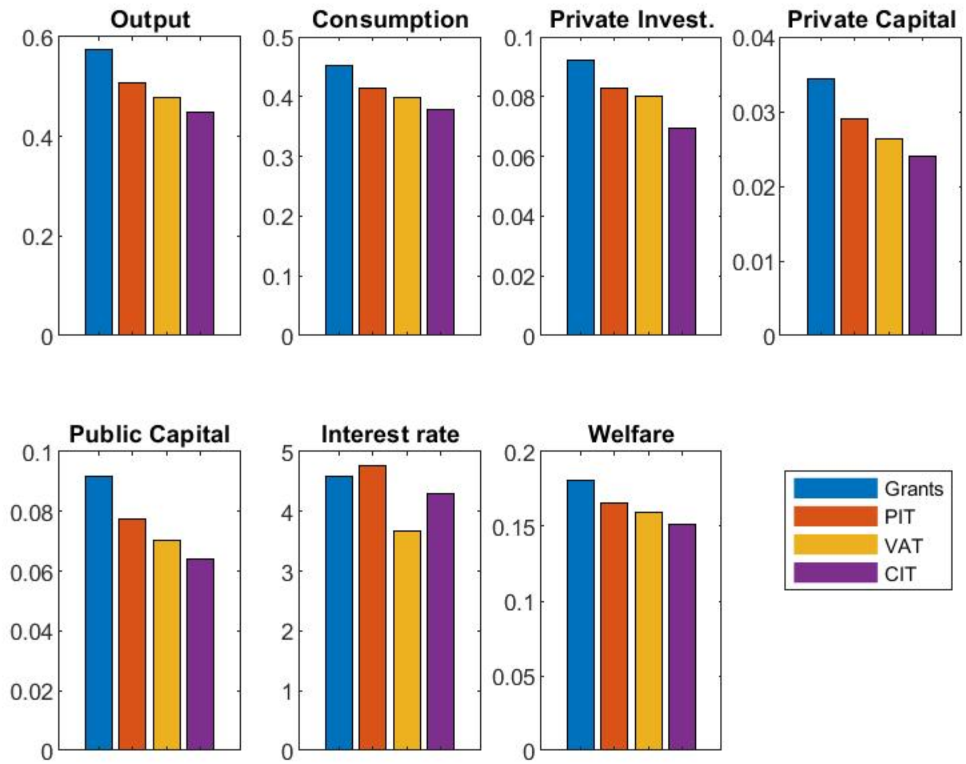
where $\omega_i \times 100$ represents the percent increase in consumption that should occur in an economy with low investment in resilient capital in order for household i to be as well off as in the scenario with higher investment in resilient capital. We set $T = 400$ (100 years) to account for welfare effects of resilience building along the transition and in the steady state.

All financing strategies produce positive impacts on macroeconomic variables compared to the baseline scenario with lower investment in resilient capital. However, the magnitude of positive effects varies across revenue mobilization schemes. Naturally, financing resilience via grants generates the greatest positive macroeconomic effects among the financing alternatives, since it does not involve any tax hikes. Increasing the labor income tax rate is the second best strategy to finance resilient infrastructure, since it does not generate any inefficiency in the model, but reduces disposable incomes. This is because our model assumes that labor is supplied inelastically, and thereby households do not alter their labor decisions following changes in labor income tax. Increasing the consumption tax rate is the third best financing strategy in terms of positive effects on macroeconomic results. Raising the VAT rate is less effective than the previous two revenue mobilization schemes discussed, because it distorts consumption decisions, generating a deadweight loss. Finally, raising the corporate revenue tax rate is the least effective strategy to finance investment in resilient infrastructure, because it distorts firms' production choices, including investment decisions.

Figure 10 compares the effects of the different strategies to raise 1% of GDP in revenues for resilience building on the steady-state values of aggregate variables. Aggregate output increases by 0.58% in the best scenario, where resilience building is financed with donor grants, while it increases by 0.43% in the worst scenario, where investment in resilient capital is financed by an increase in the CIT rate. Private investment rises by 0.09% when resilient capital is financed by donor grants, reflecting the crowding-in effect of resilience building.

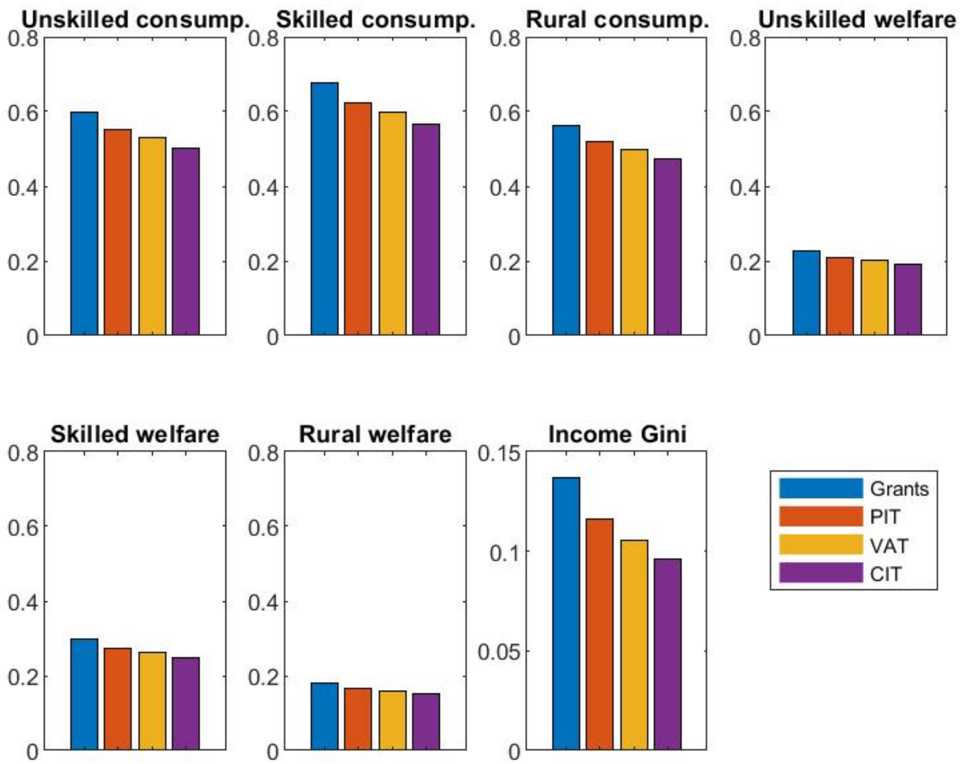
Figure 11 compares the effects on the steady-state consumption levels for each type of household. For all revenue mobilization schemes, skilled workers are those who benefit the most from the build-up of resilient infrastructure, since they are employed in the manufacturing sector, which is the most

Figure 10: Revenue mobilization schemes - aggregate variables



Note: Y-axis denotes the change relative to the steady state.

Figure 11: Revenue mobilization schemes - household variables

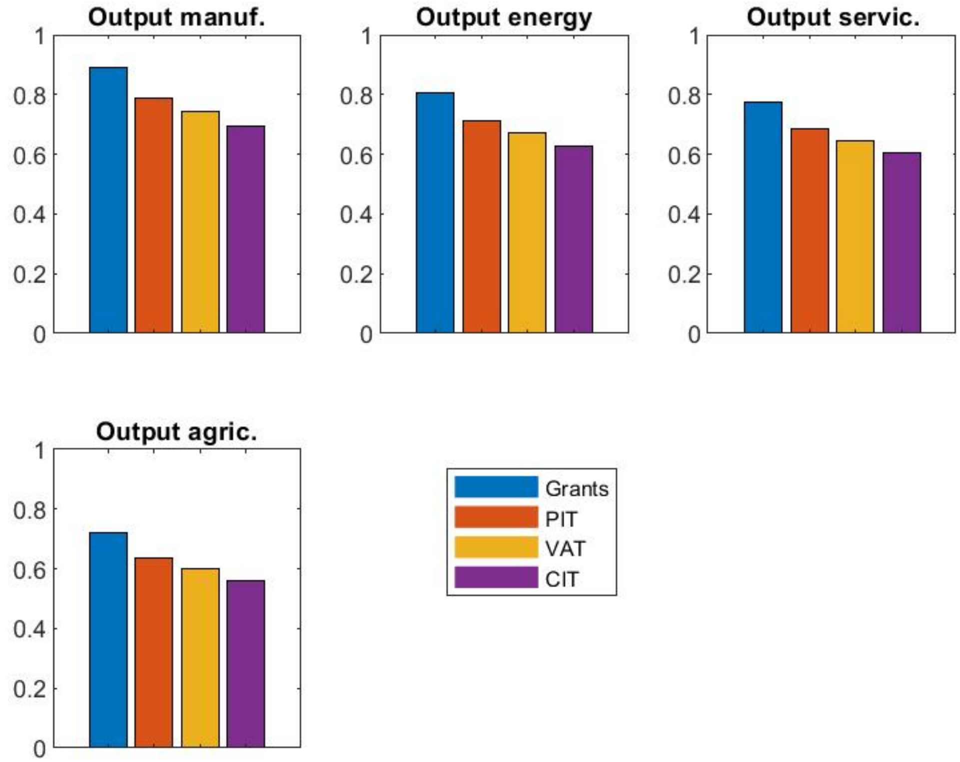


Note: Y-axis denotes the change relative to the steady state.

capital-intensive industry. Rural workers, on the other hand, only benefit due to the increase in total demand for the agriculture good they produce. The conclusion is that gains from resilience building in terms of consumption are precisely highest for the wealthiest households. This implies that inequality increases with stronger investment in resilient capital, as the last graph of Figure 11 reveals. The Gini index for income increases by 1.3 p.p. when resilience building is financed by donor grants, while it increases by 1 p.p. when the government raises the CIT rate to finance resilience building.

Figure 12 compares the effects on the steady-state values of production of each sector. As previously discussed, the manufacturing sector benefits the most from higher investment in resilient capital, since it is the most capital-intensive industry in the economy. Steady-state manufacturing output

Figure 12: Revenue mobilization schemes - sector variables



Note: Y-axis denotes the change relative to the steady state.

rises by 0.83% compared to the baseline scenario when investment in resilient infrastructure is financed by donor grants, while it increases by 0.65% when resilient capital is financed with higher CIT. Again, the rural sector benefits the least from resilience building, increasing by 0.73% in the case where donor grants finance public investment in resilient infrastructure and 0.58% when a hike in the CIT rate finances the investment.

5.4 Robustness checks

In this subsection, we check the sensitivity of our policy results to changes in the value of key parameters controlling the cost-benefit trade-off of fostering resilience infrastructure. We focus on two revenue mobilization schemes: financial resilience building via grants, and increasing the

CIT rate for the energy sector. On the benefit side of resilient infrastructure, we test different parametrizations for $\bar{\theta}$, which represents the average size of natural disaster, and p_d, the probability of a natural disaster hitting the economy every quarter. Higher (lower) values for these parameters imply that the expected damage of natural disasters is greater (smaller), and thereby the insurance benefit provided by resilient capital is higher (lower). On the cost side of building resilience, we change the values of $p_{r,n}$, which measures the higher price of resilient capital relative to non-resilient capital. Naturally, the macroeconomic consequences of resilience building are decreasing in $p_{r,n}$.

Table 2 repeats the policy analysis results developed in subsection 5.3 for $\bar{\theta} \in \{0.0052, 0.066, 0.083\}$. The case $\bar{\theta} = 0.066$ refers to our baseline policy results. We evaluate how the results change when we reduce $\bar{\theta}$ to 0.0052, the average damage to GDP from natural disasters in non-disaster prone countries reported by Cantelmo et al. (2023). When $\bar{\theta}$ is low, the benefit of increasing resilient capital declines substantially for all policy scenarios, and becomes smaller than its costs in the case where investment is financed by an increase in the CIT on the energy sector. Finally, for $\bar{\theta} = 0.083$, the positive effects of resilience building on macroeconomic variables in the steady state rises.

Table 2: Policy results for different sizes of disaster shock ($\bar{\theta}$)

	CIT			Grants		
	$\bar{\theta} = 0.0053$	$\bar{\theta} = 0.066$	$\bar{\theta} = 0.083$	$\bar{\theta} = 0.052$	$\bar{\theta} = 0.066$	$\bar{\theta} = 0.083$
Output	-0.184	0.532	0.765	0.195	0.575	0.792
Consumption	-0.171	0.451	0.568	0.189	0.451	0.589
Private investment	-0.02	0.09	0.125	0.035	0.103	0.132

Values in the table refer to the percentage variation in the steady-state values of variables.

Table 3 shows the robustness analysis for $p_d \in \{5\%, 20\%, 30\%\}$. Our baseline results correspond to the case $p_d = 20\%$. For $p_d = 5\%$, investment in resilient capital brings smaller benefits, and can negatively impact steady-state macroeconomic outcomes when investment is financed with a raise in the CIT rate on the energy sector. For $p_d = 30\%$, a higher probability of natural disasters hitting the economy increases the gains brought by resilient capital, with higher steady-state levels of macroeconomic variables, independent of the fiscal instrument used to finance resilient investment.

Table 3: Policy results for different probabilities of natural disaster (p_d)

	CIT			Grants		
	$p_d = 5\%$	$p_d = 20\%$	$p_d = 30\%$	$p_d = 5\%$	$p_d = 20\%$	$p_d = 30\%$
Output	-0.157	0.532	0.673	0.195	0.574	0.712
Consumption	-0.145	0.450	0.522	0.189	0.492	0.565
Private investment	-0.016	0.093	0.117	0.035	0.103	0.143

Values in the table refer to the percentage variation in the steady-state values of variables.

Table 4 shows the robustness analysis for $p_{r,n} \in \{1, 1.25, 1.5\}$. Our baseline results refer to the case where $p_{r,n} = 1.25$, implying that resilient capital costs 25% more than standard non-resilient capital. When $p_{r,n} = 1$, which means that building resilient capital costs the same as building non-resilient capital, public investment in climate-resilient capital brings large positive effects on all macroeconomic aggregates. Contrarily, for $p_{r,n} = 1.5$, the benefit of increasing resilient capital declines substantially for all policy scenarios.

Table 4: Policy results for different prices of resilient capital ($p_{r,n}$)

	CIT			Grants		
	$p_{r,n} = 1$	$p_{r,n} = 1.25$	$p_{r,n} = 1.5$	$p_{r,n} = 1$	$p_{r,n} = 1.25$	$p_{r,n} = 1.5$
Output	0.698	0.532	0.271	0.736	0.576	0.293
Consumption	0.48	0.450	0.252	0.52	0.4519	0.289
Private investment	0.121	0.092	0.034	0.185	0.138	0.073

Values in the table refer to the percentage variation in the steady-state values of variables.

6 Tradeoff between physical and human capital

In this section, we compare the benefits of investing in human capital, compared to those of building resilient physical capital as studied in previous sections of the paper.

Similarly to resilient physical infrastructure, human capital is not destroyed by natural disasters. However, a key difference between the two types of capital is that upgrading physical infrastructure increases the productivity of private firms relatively quickly, whereas the expansion of "human" infrastructure (consider for instance the scaling-up of schools) takes time to translate into higher labor productivity. Moreover, building resilient physical capital brings direct gains only to the sectors which employ capital in their production function (manufacturing and energy sectors), while increasing the stock of human capital benefits all sectors, since all of them employ labor in their production process.[11]

Model. We model the human capital accumulation process along the lines of Atolia et al. (2021), which studies the optimal public investment in physical capital and human capital. Let H_t denote the stock of human capital in period t and I_t^h denote public investment in human capital. The inertia in human capital accumulation is captured in the model by adding, in the first stage, the investment in human capital to an intermediate stock of human capital, ξ_t, that is currently trapped in schools. This stock evolves according to:

$$\xi_t = (1-\chi)\xi_{t-1} + I_t^h,$$

of which, in a second stage, a fraction χ moves from schools to labor. On average, newly accumulated human capital becomes productive with a delay of $1/\chi$ periods. Therefore, the productive human capital in the economy—i.e., the share that has completed schooling— evolves according to:

$$H_t = (1-\delta_h)H_{t-1} + \chi\xi_{t-1},$$

where δ_h is the depreciation rate of human capital.

The government budget balance (6) when we include human capital accumulated becomes

$$0 = R_t^c + R_t^k + R_t^w + GR_t - p_{r,n}I_{r,t} - I_{n,t} - p_h I_t^h - T_t - (1+r_t)b_t + b_{t+1}, \tag{17}$$

[11] This discussion also links to the literature on optimal investment in the face of climate uncertainty, such as Guthrie (2023), who points out that optimal investment decisions depend not only on beliefs about the severity of future climate change, but also how quickly these beliefs will change in the future.

where p_h is the price of investment in human capital.

Calibration. We follow Atolia et al. (2021) to calibrate the parameters describing the human capital accumulation process. Specifically, we set $\chi = 1/48$, under the assumption that education infrastructure in the model refers to schools from K-12 (12 years, or 48 quarters, of schooling). We calibrate the human capital depreciation rate at the same value as the public capital depreciation rate, that is $\delta_h = 0.0125$. Finally, we assume that investing in human capital costs the same as investing in resilient capital, which implies $p_h = 1.25$.

Policy results. We study the short-, medium- and long-run consequences of investing in resilient capital versus human capital on macroeconomic aggregates. We focus on the case where the government raises 1% of GDP in public revenues with donor grants, which can now be entirely spent in expanding aggregate human capital or resilient capital. For each investment strategy, we simulate the model for 10 years (40 quarters), 40 years (160 quarters) and 100 years (400 quarters), and then compute the average macroeconomic outcomes during these periods.

Table 5 summarizes our results about the tradeoffs between physical capital and human capital. In the first ten years of the public investment policy, the benefits of building resilient capital are much larger than those of building human capital. This is because the accumulation of human capital increases labor productivity slowly, as different cohorts of schooled agents become part of the labor force gradually over time. Indeed, the effect of increasing the total stock of human capital on macroeconomic outcomes is economically negligible in the first ten years. Over 40 years, the gains from investing in both forms of capital build up, but at a faster pace for human capital. Thus, differences in the macroeconomic effects of investment in each type of capital become smaller. After 100 years, the benefits of human capital investment surpass those of resilient physical capital.

The distributional and sectoral implications of public investment in each type of capital are closely related, as the consequences for household consumption and welfare are mainly driven by the effects on the sectors in which they are employed. This explains our result that human capital benefits

Table 5: Dynamic effects: human capital versus resilient physical capital

	10 years		**40 years**		**100 years**	
	Resilient capital	Human capital	Resilient capital	Human capital	Resilient capital	Human capital
Aggregate outcomes						
Output	0.038	0.005	0.354	0.312	0.576	0.598
Consumption	0.026	0.003	0.289	0.252	0.459	0.492
Private investment	0.011	0.001	0.084	0.051	0.138	0.173
Welfare	0.024	0.003	0.286	0.248	0.451	0.485
Households' outcomes						
Skilled w. consumption	0.032	0.001	0.324	0.183	0.506	0.436
Unskilled w. consumption	0.023	0.004	0.269	0.312	0.423	0.531
Rural w. consumption	0.021	0.004	0.221	0.292	0.404	0.522
Sectors' outcomes						
Manufacturing output	0.049	0.003	0.419	0.267	0.624	0.567
Energy output	0.042	0.004	0.398	0.292	0.591	0.583
Services output	0.031	0.007	0.251	0.353	0.543	0.641
Agriculture output	0.028	0.006	0.234	0.338	0.526	0.612

Simulation averages are obtained by simulating the model for the corresponding number of years (10, 40 or 100 years). Values in the table refer to the percentage change of average outcomes relative to the initial steady-state.

unskilled and rural workers the most, since they work in the most labor-intensive sectors, such as the services and agriculture sectors. These sectors are exactly the ones which experience the highest increase in output from public investment in human capital over time. As discussed in previous sections, increasing the stock of resilient capital brings more gains for households employed in more capital-intensive sectors, namely the manufacturing and energy sectors.

7 Conclusion

Natural disasters often have high economic costs, setting back years of investment in developing countries. In this paper, we develop a multi-sector DSGE model to study the macroeconomic and welfare implications of financing resilience-building using different fiscal instruments in Mozambique. The model includes essential features of Mozambique and many developing countries, including a large unproductive rural sector, an incomplete credit market, and a large informal sector.

Our main findings are that investing in resilience capital in a disaster-prone country improves welfare despite its high economic cost, but the financial instrument used to mobilize revenue matters.

Among the fiscal instruments, the worst is the corporate income tax, which reduces the return of private capital, leading to lower investment and output, while financing via value-added and labor income tax is less damaging to the economy. We find that even though all households benefit from resilience building, the investment in resilient capital increases income inequality because wealthy households that own capital benefit the most. In addition, compared to other government investments like human capital, resilience building can have a higher return in the short run because it leads to more considerable private investment. While this paper advances the understanding of the benefits of investment in resilient capital, more research is still needed to be able to account for the impact of resilience building on sovereign risk, brain drain, and entrepreneurship, which can lead to more long-term benefits.

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