

Building Resilience to Natural Disasters: An Application to Small Developing States*

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Abstract

We present a dynamic small open economy model to explore the macroeconomic impact of a major natural disaster. In addition to permanent damages to public and private capital, the disaster causes temporary losses of productivity, inefficiencies during the reconstruction process, and damages to the sovereign's creditworthiness. We use the model to study the debt sustainability concerns that arise from the need to fully rebuild public infrastructure over the medium term and analyze the feasibility of *ex ante* policies, such as building adaptation infrastructure and fiscal buffers, and contrast these policies with the post-disaster support provided by donors. Investing in resilient infrastructure may prove useful, in particular if it is viewed as complementary to standard infrastructure, because it raises the marginal product of private capital, crowding in private investment, while helping withstand the impact of the natural disaster. In an application to Vanuatu, we find that donors should provide an additional 50% of pre-cyclone GDP in grants to be spent over the following 15 years to ensure public debt remains sustainable following Cyclone Pam. Helping the government build resilience on the other hand, reduces the risk of debt distress and at lower cost for donors.

Keywords: Natural Disasters, Resilience, Adaptation, Debt Sustainability, Small States

JEL Classifications: E22, E62, F34, F35, H54, H63, H84, O23, Q54.

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1. Introduction

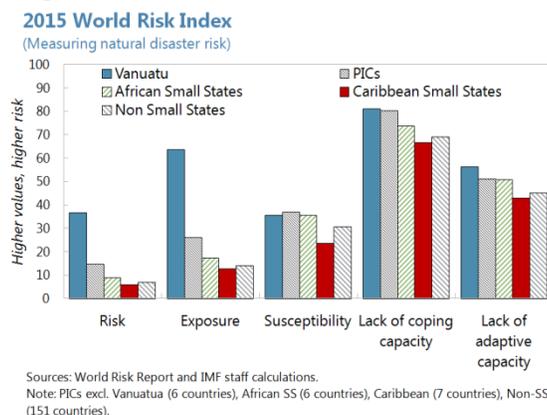
Small developing states are among the most vulnerable countries in the world to natural disasters and climate change. The UN World Risk Index, which measures exposure to natural hazards and the capacity to cope with these events across 171 countries, places small developing states at the top of its ranking. In addition to the limited capacity to respond to natural disasters, these countries are more frequently hit by extreme weather events than larger countries and their economic costs are on average much larger (IMF, 2016a). Climate change will only worsen the reach of natural disasters, by increasing their intensity and frequency (IPCC, 2014). This vulnerability to natural disasters exacerbates the challenging tradeoff policymakers face domestically—allocating spending for growth-promoting infrastructure or vulnerability-reducing resilience—and externally by the donor community—allocating financial support pre or post-disaster.

Boosting infrastructure investment has gained renewed attention as an imperative for economic development. It encourages private investment and increases productivity, and fosters inclusion by improving connectivity and allowing people to spend their time on more productive activities. Improving infrastructure is indispensable for attaining the Sustainable Development Goals and it is regularly included as a key pillar of countries' national development strategies. 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 may manifest itself in an increased frequency and severity of extreme weather events, building resilient infrastructure—capable of withstanding such events—becomes paramount. 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.

One of the most devastating natural disasters in the Pacific region's history, the category five cyclone—Cyclone Pam—ravaged Vanuatu in March 2015 and inflicted damages and losses of about 60 percent of the archipelago's GDP and affected more than 188,000 inhabitants (more than 70 percent of the population). The main productive sectors were highly affected, with damages to tourism and transport infrastructure estimated at 11 percent of GDP, and production losses in agriculture and tourism equivalent to 14 percent of GDP. Vanuatu's limited landmass, aggravated by the double insularity of outer islands, and high population and infrastructure densities in coastal areas make it particularly prone to natural disasters—ranking as the country with the highest disaster risk among the 171 covered by the UN World Risk Index (Figure 1)—and provides therefore a suitable background for this analysis. The probability of a natural disaster happening in Vanuatu in any given year is 65 percent and more than 99 percent in a five-year period. According to EM-DAT, which provides estimates of human and economic costs by type of disaster, natural disasters caused annual damages equivalent to 2.4 percent of GDP over the 1950-2014 period and affected more than 3 percent of the population. In addition to natural disasters, the cumulative impact of non-extreme but prolonged weather events, such as the El Niño's droughts and La Niña's heavy rainfall, has put the country further at risk. On the other hand, the effects of climate change, including sea-level rise, coastal

erosion, overstressed water resources, unstable rainfall, floods, and droughts, pose a severe challenge to the development process of most small states—and Vanuatu in particular. According to Burke et al. (2015), GDP per capita is expected to drop by 75 percent by 2100 relative to a world without climate change (with a 97 percent probability that climate change will reduce GDP per capita by more than 50 percent), making Vanuatu’s population poorer and incomes diverging from—rather than converging to—other developing economies.

Figure 1: One of the most at risk countries



With that background in mind, this paper introduces a small open economy model to analyze how small developing states could build resilience to and recover from major natural disasters. Calibrated to a small, low-income economy like Vanuatu, we use the model to assess the impact of the government’s plan to swiftly rebuild the damaged public infrastructure after Cyclone Pam and study what set of policies could have been put in place to smoothen the response to the cyclone, including the role of developing partners in supporting the recovery. In particular, the paper addresses the following questions: (i) considering the government’s intent of fully rebuilding the damaged public infrastructure in a relatively short time span (about 6 years), how much funding would donors have to provide to ensure debt remains sustainable over the medium term without further fiscal consolidation?; and (ii) if donors had supported investments in resilient infrastructure and helped build up the contingency fund in advance of the disaster, what would Vanuatu’s public debt profile look like?

In this model, the government can invest in standard infrastructure (e.g., roads) as well as in adaptation capital (e.g., seawalls). 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 CES function, which permits exploring the implications of different degrees of complementarity between standard and adaptation capital—departing from the roads vs. seawalls distinction to a closer resemblance between the two, such as climate-proofing roads to withstand stronger natural disasters. In addition to investing in resilient infrastructure, the government can save resources in an external contingency fund that can then be used to finance reconstruction activities. The contingency fund sits in a major financial center and pays the risk-free interest rate.

The model thus allows to analyze the following issues. First, adaptation vs. reconstruction; 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. Second, financial buffers vs. physical resilience; with limited access to financial markets, financing a post-disaster recovery presents a challenge for a small developing state and therefore policymakers may want to prepare *ex ante*. As an alternative to building more resilient infrastructure, the government could accumulate assets in a contingency fund to be used after a natural disaster. Finally, it also allows to contrast alternative paths of post-disaster reconstruction; the model 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 (tax increases, domestic borrowing, and external concessional and non-concessional borrowing).

Our results suggest that in order for these small developing states to recover smoothly and ensure a steady convergence process to their peers, bilateral and multilateral donors would have to pitch in significant amounts of financial resources post-disaster—even if reasonable resources are dedicated to building resilience prior to the disaster. That is not particular to Vanuatu, though we are considering an extreme natural disaster. Investing in resilient infrastructure and building a contingency fund are complementary measures to smooth the impact of the disaster and ensure a swift recovery once infrastructure starts being rebuilt. However, without a strong support from development partners, rebuilding public capital in a short time horizon demands either a strong fiscal adjustment or the availability of (domestic or external) borrowing. In most cases, these instruments are not available or politically feasible.¹ For instance, in the aftermath of the disaster, the government of Vanuatu suspended VAT and import duties on construction materials for two months after the cyclone, deferred the payments of vehicle registration fees and VAT payments to the next quarter, and provided subsidies for agricultural seedlings to affected households. Reversing these policies and increasing taxes over the board would have been infeasible. Although domestic banks delayed loan repayments for 6 to 12 months to some corporate customers pending an insurance payout and provided additional lending to commence repair work, the availability of credit for the government was small. Alternatively, resorting to external borrowing (commercial or otherwise) was either not available or would require more months to negotiate and materialize. We thus argue that in those situations post-disaster grant financing is essential in order to ensure that the reconstruction of the damaged public infrastructure would not put at risk the country's debt sustainability.

This paper relates to two strands of literature. The first is on the macroeconomic effects of public investment and in particular with what relates to fiscal and debt sustainability. Earlier work by Barro (1990), Barro and Sala-i-Martin (1992), Futagami et al. (1993) quantify the growth benefits of public investment, while Turnovsky (1999), among others, adds government debt to similar frameworks. Adam and Bevan (2006) study the relationship between aid and public investment and Buffie et al. (2012), which our model draws on, analyze the debt sustainability concerns that arise with alternative public investment programs.

¹Note that pooled sovereign insurance mechanisms have been established in the Pacific (the Pacific Catastrophe Risk and Financial Insurance, PCRFI) and the Caribbean (Caribbean Catastrophe Risk Insurance Facility) and have proved useful in some occasions. In the case of Vanuatu, the insurance scheme has had limited reach despite its rapid deployment, with the payout from the PCRFI covering less than 1% of Cyclone Pam's damages.

The other strand of literature is on the macroeconomic effects of natural disasters. Cavallo and Noy (2011) summarize the state of the literature examining the aggregate impact of disasters, while Noy (2009) provides an empirical investigation of the macroeconomic costs of natural disasters. The latter finds that small economies face larger indirect economic impacts than larger ones; however, it does not assess the effects of natural disasters on the government budget and its indebtedness. Bevan and Cook (2015) focus on the impact of disasters on public expenditures and the challenges disasters pose for financial public management. Cavallo et al. (2013) provide case studies of countries that had recently endured a natural disaster, using the synthetic control method to construct the counterfactual economic growth. Strobl (2011 and 2012) develop hurricane destruction indices for U.S. counties as well as Central American and Caribbean countries to explore the economic growth impact of hurricanes and finds that these events caused output to fall by 0.5 percentage points in the U.S. and 0.8 in Central America. Becerra et al. (2014) conduct an event study of foreign aid inflows after natural disasters and find that aid surges cover about 3 percent of the estimated damages. Felbermayr and Grschl (2014) show that natural disasters reduce growth when they strike, but financial access, trade openness, and democratic institutions matter for disaster recovery. Similarly, Kahn (2005) shows that richer economies suffer fewer deaths from natural disasters than poorer countries despite facing similar disasters. Other papers have used structural models to look at these issues as well. Bakkensen and Barrage (2017) use an endogenous growth model to quantify the impacts of natural disasters on growth and welfare, drawing on the literature on incomplete markets. In a calibrated model, Borensztein et al. (2017) assess the welfare gains from insuring against natural disasters with catastrophe bonds. Bevan and Adam (2016) use a similar framework to ours and study disaster risk insurance as a means to fund reconstruction. Ikefuji and Horii (2012) associate natural disasters with the use of pollutant inputs and argue that growth is sustainable if the tax rate on those inputs increases over time.

The remainder of the paper is organized as follows. Section II discusses the model and Section III presents the data used to calibrate the model and the scenarios considered. Section IV analyzes the macroeconomic impact of the natural disaster and Section V explores policies that could have been implemented prior to the disaster. The conclusions and policy implications are presented in Section VI.

2. The Model

We introduce a two-sector small open economy model featuring a traded and nontraded goods sectors that are disparately affected by a natural disaster and a government that decides how to prepare for, and how to recover from, a natural disaster with alternative public financing instruments (domestic and external debt, grants, and consumption taxes) along the lines of Bevan and Adam (2016). There are five channels through which the economy is impacted by the natural disaster: (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 (e.g., people are not able to work and have to spend time removing debris); (iv) increased inefficiencies in public investment during the reconstruction period; and (v) damages to the sovereign’s creditworthiness. The framework accounts for all the apparatus 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.

Firms

Firms produce tradable and nontradable goods (y_x and y_n , respectively) according to a Cobb-Douglas production technology combining public infrastructure—a constant elasticity of substitution (CES) function of standard infrastructure z^i and adaptation capital z^a with productivity ν_a —with private capital k_j and labor l_j . Firms operate in one single sector and benefit from a sector-specific total factor productivity (TFP) A_j . The natural disaster affects both sectors, but causes disparate damages $D_j \in [0, 1]$ to output by permanently destroying public and private capital and resulting in a transitory 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 (with π_j and ν_D being scaling factors).

In each sector j , a firm maximizes profits according to

$$\Phi_{j,t} = P_{j,t} \left(1 - \frac{D_{j,t}}{(1 + \pi_j z_{t-1}^a)^{\nu_D}} \right) y_{j,t} - w_t l_{j,t} - r_{j,t} k_{j,t-1}, \quad (1)$$

where w is the economy-wide wage and r_j is the sectoral return on capital in sector j . Output is defined as

$$y_{j,t} = A_{j,t} z_{t-1}^{\psi_j} k_{j,t-1}^{\alpha_j} l_{j,t}^{1-\alpha_j} \quad \text{for } j = n, x. \quad (2)$$

The tradable sector here is better thought of as the tourism and travel industry, which tends to be the largest tradable sector in small island states. For small states with an important agricultural sector, firms’ technologies could include land as a factor of production. Note that since land is in fixed supply and cannot be permanently destroyed (as opposed to private and public capital, the country cannot “grow” another island, nor one will be wiped out of the map permanently), the transitory losses attributed to TFP can easily incorporate damages to land by rearranging the definition of $(1 - D_{A_j})$ below. Public capital is given by

$$z_t = \left[\rho_z^{\frac{1}{\xi}} (z_t^i)^{\frac{\xi-1}{\xi}} + (1 - \rho_z)^{\frac{1}{\xi}} (\nu_a z_t^a)^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}}, \quad (3)$$

where ρ_z is a weight parameter and ξ is the intratemporal 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 (e.g. seawalls vs. climate-proofing roads; see discussion in the calibration section). Note that damages can be decomposed into damages to public and private capital as well as losses of productivity according to $(1 - D_{z_j}) = \left(1 - \frac{D_j}{(1 + \pi_j z^a)^{\nu_D}} \right)^{\varpi_z}$, $(1 - D_{k_j}) = \left(1 - \frac{D_j}{(1 + \pi_j z^a)^{\nu_D}} \right)^{\varpi_k}$, and $(1 - D_{A_j}) = \left(1 - \frac{D_j}{(1 + \pi_j z^a)^{\nu_D}} \right)^{1 - \varpi_z \psi_j - \varpi_k \alpha_j}$, respectively. The severity of the damages to public and private infrastructures is controlled by ϖ_z and ϖ_k , respectively, such that the larger ϖ_z is, the greater

public infrastructure was destroyed relative to private capital and TFP (with $1 - \varpi_z \psi_j - \varpi_k \alpha_j \geq 0$).² The literature on natural disasters distinguishes damages from economic losses. We thus target the size of D_{A_j} as representing economic losses and D_{z_j} and D_{k_j} as damages to physical infrastructure. The disruption in the functioning of public and private infrastructure has a persistent yet transitory effect on the TFP because infrastructure takes some time to rebuild and workers may have to spend their time cleaning roads, rebuilding their houses or are wounded and thus at the hospital, or else crops have been destroyed and land has become less productive. Hence, aggregate productivity is assumed to recover slowly to its pre-disaster level.³

Profit-maximizing firms demand capital and labor according to

$$P_{j,t} \alpha_j \frac{y_{j,t}}{k_{j,t-1}} = r_{j,t} \quad \text{for } j = n, x, \quad (4)$$

and

$$P_{j,t} (1 - \alpha_j) \frac{y_{j,t}}{l_{j,t}} = w_t. \quad (5)$$

Output elasticities with respect to total public capital can also be derived as

$$P_{j,t} \psi_j \frac{y_{j,t}}{z_{t-1}} = R_t^z \quad (6)$$

where R_t^z is the total return to public infrastructure, which can be expressed in terms of the returns to standard and adaptation infrastructure as $R_t^{zi} \left(\frac{z_{t-1}^i}{\rho_z z_{t-1}} \right)^{1/\xi}$ and $R_t^{za} \left(\frac{\nu_a^{1-\xi} z_{t-1}^a}{(1-\rho_z) z_{t-1}} \right)^{1/\xi}$, respectively. Note that firms do not take into account the added benefit of adaptation (namely the protection against natural disasters) in their optimal decisions and only factor in the benefits of having additional infrastructure as an input in their production processes. Infrastructure prices are a function of the price of the imported machinery needed to produce capital, P_{mm} , and of the price of the a_j ($j = k, zi, za$) nontradable inputs needed to produce capital P_n . The price of private capital is given by $P_{k,t} = P_{mm,t} + a_k P_{n,t}$. We allow public standard and adaptation infrastructures to have different imported and nontradable input contents to reflect the idea that adaptation infrastructure requires more technical inputs provided externally and sold at a premium pr or that they demand more or less construction materials than the standard infrastructure. The prices of standard and adaptation infrastructure are thus given by $P_{zi,t} = P_{mm,t} + a_{zi} P_{n,t}$ and $P_{za,t} = (1 + pr) P_{mm,t} + a_{za} P_{n,t}$, respectively.

²By contrast, Bevan and Adam (2016) are interested in disaster risk and define the probability of a damaging disaster to follow a negative exponential distribution. Instead, we are focusing on a known disaster, for which aggregate damages to GDP are available.

³We could also have considered the death a fraction of labor force as a potential consequence of the natural disaster. In the case of Vanuatu, the death toll was small (11 people in a labor force of 125,000 people) and thus not detrimental.

⁴Labor is assumed to be perfectly mobile across sectors while returns on private capital are sector-specific, except in the steady state.

Government

Government expenditures are directed to investments in standard and adaptation infrastructure i_{zi} and i_{za} , transfers to households \mathcal{T} , and servicing public domestic and external debt. The government also collects revenues from VAT on households' consumption and from fees on Ricardian households' usage of standard public infrastructure (as a fraction f of recurrent costs $\delta_{zi}P_{zi_o}$ involved in the maintenance of the infrastructure (i.e. $\mu = f\delta_{zi}P_{zi_o}$)).⁵

As Dablas-Norris et al. (2012) show, infrastructure stocks vary considerably in low-income countries despite high levels of investment. Therefore, the economy only benefits from effectively produced capital, which depends on public investment efficiency $s \in [0, 1]$. The public investment process is assumed to be equally bureaucratic and inefficient across the two types of capital inputs. To account for the increased inefficiencies that arise post-disaster, s is time-varying and affected by D_s at the time of disaster. In particular, the ability to transform each dollar spent into capital takes some time to recover, with expenses being lost in non-productive activities (e.g., poorly managed projects or other moral hazard issues related to the significant inflows of foreign aid). Public capital therefore evolves according to

$$z_t^i = (1 - \delta_{zi}) z_{t-1}^i + (1 - D_s) s_t i_{zi,t}, \quad (7)$$

$$z_t^a = (1 - \delta_{za}) z_{t-1}^a + (1 - D_s) s_t i_{za,t}. \quad (8)$$

Note that these two types of infrastructure depreciate at different rates in order to account for their different resilience to natural disasters. Adaptation infrastructure is able to better withstand the effects of climate change and natural disasters than standard infrastructure, and therefore $\delta_{zi} > \delta_{za}$. Adam and Bevan (2014), in contrast, consider the case of operations and maintenance expenditures affecting the level of depreciation of public capital to underline the need for accounting these in the government's budget constraint.

Another channel through which natural disasters can affect fiscal policy is through market interest rates. As S&P (2015) points out, natural disasters can, in addition to the physical destruction of infrastructure, damage a sovereign's creditworthiness. While the real interest rate on concessional debt is held constant ($r_{d,t} = r_d$), the natural disaster shock weakens the sovereign's rating by $D_{r,t}$. And as common in the literature, large accumulations of external debt (in deviations from its steady state level) aggravate the country risk premium, in line with Schmitt-Grohe and Uribe (2003). Given the risk-free world interest rate r^f and nominal GDP ($y_t = P_{n,t}y_{n,t} + P_{x,t}y_{x,t}$), the real interest rate on external commercial debt follows

$$r_{dc,t} = (1 + D_{r,t}) \left(r^f + v_g e^{\eta_g \left(\frac{d_t + d_{c,t}}{y_t} - \frac{\bar{d} + \bar{d}_c}{\bar{y}} \right)} \right). \quad (9)$$

In addition to building resilience with adaptation infrastructure, the government can decide to set up a fund to build up its savings against a natural disaster. Let \mathfrak{s}_t be government savings in

⁵Liquidity-constrained households do not have to pay fees for using public infrastructure.

a bank abroad, 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. In addition to this buffer, the government can finance its fiscal deficit with external grants \mathcal{G} and a combination of tax adjustments and borrowing: external concessional debt $\Delta d_t = d_t - d_{t-1}$ as well as domestic $\Delta b_t = b_t - b_{t-1}$ and external commercial $\Delta d_{c,t} = d_{c,t} - d_{c,t-1}$ debt according to the rule $(1 - v) \Delta b_t = v \Delta d_{c,t}$, with v controlling the relative proportion of increase in domestic versus external commercial debt. The government budget constraint is thus given by

$$\begin{aligned} P_{zi,t} i_{zi,t} + P_{za,t} i_{za,t} + \mathcal{T}_t + r_{t-1} P_t b_{t-1} + \\ r_{d,t-1} d_{t-1} + r_{dc,t-1} d_{c,t-1} + \Delta \mathfrak{s}_t \leq P_t \Delta b_t + \Delta d_t + \Delta d_{c,t} + r^f \mathfrak{s}_{t-1} + \\ + \tau_t^c P_t c_t + \mu z_{t-1}^e + \mathcal{G}_t. \end{aligned}$$

We can rewrite the budget constraint above in terms of the fiscal gap ($\mathfrak{G}\text{ap}$) as

$$\mathfrak{G}\text{ap}_t = P_t \Delta b_t + \Delta d_{c,t} + (\tau_t^c - \tau_o^c) P_t c_t - \Delta \mathfrak{s}_t \quad (10)$$

where $\mathfrak{G}\text{ap}_t = \mathfrak{E}\text{xp}_t - \mathfrak{R}\text{ev}_t$, i.e. given by the difference between total expenditures and revenues when the consumption tax is kept at its initial value (τ_o^c) and concessional debt and grants are exogenous, is covered by domestic and external commercial borrowing, VAT adjustments, and/or savings withdrawals, such that

$$\mathfrak{E}\text{xp}_t = P_{zi,t} i_{zi,t} + P_{za,t} i_{za,t} + \mathcal{T}_t + r_{t-1} P_t b_{t-1} + r_{dc,t-1} d_{c,t-1} + (1 + r_d) d_{t-1} - d_t$$

and

$$\mathfrak{R}\text{ev}_t = r^f \mathfrak{s}_{t-1} + \tau_o^c P_t c_t + \mu z_{t-1}^e + \mathcal{G}_t.$$

The fiscal rule for the consumption tax rate allows τ^c to respond to both tax and debt deviations from their target, with λ_1 controlling the response of the tax adjustment to the tax rate that would prevail if all the other financing instruments were not available to close the fiscal gap and λ_2 controlling the response to deviations from the debt target

$$\tau_t^c = \tau_{t-1}^c + \lambda_1 \left((\tau_t^c)^{\text{target}} - \tau_{t-1}^c \right) + \lambda_2 \frac{(P_{t-1} b_{t-1} + d_{c,t-1}) - (P b + d_c)^{\text{target}}}{y_t} \quad \forall \lambda_1, \lambda_2 \geq 0. \quad (11)$$

where the tax target $(\tau_t^c)^{\text{target}} = \tau_o^c + \frac{\mathfrak{G}\text{ap}_t}{P_t c_t}$, ensuring debt sustainability in the long run.⁶ For the scenario analysis that we conduct, $\tau_t^c = \tau_o^c$ for the case in which the government finances its reconstruction entirely with borrowing and $\tau_t^c = (\tau_t^c)^{\text{target}}$ when the reconstruction program is entirely financed with taxes.

⁶Buffie et al. (2012) also allow transfers to adjust and hence can be used as another policy instrument to close the fiscal gap. Alternatively, government transfers could be used to smooth the impact of the disaster on liquidity-constrained households, but additional resources would have to be leveraged to close the fiscal gap.

Households

The economy features two types of households: Ricardian and liquidity-constrained (denoted by \mathbf{r} and \mathbf{c} , respectively), who consume tradable goods produced domestically $c_{x,t}$ and abroad $c_{m,t}$ as well as domestic nontradable goods $c_{n,t}$. The consumption basket is defined as the CES function

$$c_t^i = \left[\rho_x^{\frac{1}{\epsilon}} (c_{x,t}^i)^{\frac{\epsilon-1}{\epsilon}} + \rho_m^{\frac{1}{\epsilon}} (c_{m,t}^i)^{\frac{\epsilon-1}{\epsilon}} + (1 - \rho_x - \rho_m)^{\frac{1}{\epsilon}} (c_{n,t}^i)^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}} \quad \text{for } i = \mathbf{r}, \mathbf{c}, \quad (12)$$

where ρ_m and ρ_x are weights and ϵ is the intratemporal elasticity of substitution between consumption goods. The associated consumer price index is given by⁷

$$P_t = \left[\rho_x P_{x,t}^{1-\epsilon} + \rho_m P_{m,t}^{1-\epsilon} + (1 - \rho_x - \rho_m) P_{n,t}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}. \quad (13)$$

Ricardian households face the intertemporal optimization problem

$$\max \sum_{t=0}^{\infty} \beta^t \frac{(c_t^{\mathbf{r}})^{1-1/\zeta_c}}{1-1/\zeta_c},$$

where β is the discount factor and ζ_c is the intertemporal elasticity of substitution of consumption. In addition to consuming goods, this representative household invests in private tradable and nontradable capital (i_x and i_n , respectively), which encompasses some adjustment costs $AC_{j,t}^{\mathbf{r}} \equiv \frac{v}{2} \left(\frac{i_{j,t}^{\mathbf{r}}}{k_{j,t-1}^{\mathbf{r}}} - \delta \right)^2 k_{j,t-1}^{\mathbf{r}}$; pays levies on standard public infrastructure μz^i ; saves through domestic bonds b ; and buys foreign debt b^* , which carries a real interest rate r^* as well as portfolio adjustment costs $\Theta_t^{\mathbf{r}*} \equiv \frac{\eta}{2} (b_t^{\mathbf{r}*} - \bar{b}^{s*})^2$, where \bar{b}^{s*} is the steady-state value of external private debt. The government levies a value-added tax (VAT) τ^c on consumption, which affects both Ricardian and liquidity-constrained households.

The income side of the household's budget constraint

$$\begin{aligned} (1 + \tau_t^c) P_t c_t^{\mathbf{r}} + \mu z_{t-1}^i + P_t b_t^{\mathbf{r}} + (1 + r_{t-1}^*) b_{t-1}^{\mathbf{r}*} + \\ \Theta_t^{\mathbf{r}*} + P_{k,t} (i_{n,t}^{\mathbf{r}} + i_{x,t}^{\mathbf{r}} + AC_{n,t}^{\mathbf{r}} + AC_{x,t}^{\mathbf{r}}) \leq w_t l_t^{\mathbf{r}} + r_{n,t} k_{n,t-1}^{\mathbf{r}} + r_{x,t} k_{x,t-1}^{\mathbf{r}} + (1 + r_{t-1}) P_t b_{t-1}^{\mathbf{r}} \\ + b_t^{\mathbf{r}*} + \frac{1}{1+a} (\mathcal{R}_t + \mathcal{T}_t) + \Phi_t^{\mathbf{r}}. \end{aligned} \quad (14)$$

is composed of an employment wage w on labor $l^{\mathbf{r}}$ supplied to firms; interest r_x and r_n received from tradable and nontradable capital, respectively; interest r received on domestic bonds; a fraction of remittances \mathcal{R} and government transfers \mathcal{T} corresponding to the share of Ricardian households in the labor market;⁸ as well as profits $\Phi^{\mathbf{r}}$ from owning domestic firms. The accumulation of private capital,

⁷The foreign consumer price index P_t^* is the numeraire.

⁸The fraction of liquidity-constrained households in the economy is given by $a > 0$.

which depreciates annually at rate δ_k , is given by

$$k_{j,t}^{\mathbf{r}} = (1 - \delta_k) k_{j,t-1}^{\mathbf{r}} + i_{j,t}^{\mathbf{r}} \quad \text{for } j = n, x. \quad (15)$$

The solution to the household's constrained maximization problem yields the consumption Euler equation

$$c_t^{\mathbf{r}} = c_{t+1}^{\mathbf{r}} \left[\beta (1 + r_t) \frac{1 + \tau_t^c}{1 + \tau_{t+1}^c} \right]^{-\varsigma_c}, \quad (16)$$

and the non-arbitrage conditions defining that the returns on tradable and nontradable capital equate the return on domestic bonds

$$(1 + v\Upsilon_{j,t}^{\mathbf{r}}) (1 + r_t) \left[\frac{P_{t+1}}{P_t} \frac{P_{k,t}}{P_{k,t+1}} \right] = \frac{r_{j,t+1}}{P_{k,t+1}} - \frac{v}{2} (\Upsilon_{j,t+1}^{\mathbf{r}})^2 + v\Upsilon_{j,t+1}^{\mathbf{r}} \left[\frac{i_{j,t+1}^{\mathbf{r}}}{k_{j,t}^{\mathbf{r}}} + (1 - \delta) \right] + (1 - \delta), \quad (17)$$

where $\Upsilon_{j,t}^{\mathbf{r}} = \left(\frac{i_{j,t}^{\mathbf{r}}}{k_{j,t-1}^{\mathbf{r}}} - \delta \right)$ for $j = n, x$, and that the return on domestic bonds equates the return on external private debt

$$(1 + r_t) \frac{P_{t+1}}{P_t} = \frac{(1 + r_t^*)}{[1 - \eta(b_t^{\mathbf{r}*} - \bar{b}^{\mathbf{r}*})]}, \quad (18)$$

where the real interest rate on external private debt $r_t^* = r_{dc,t} + u$ is a premium u over the sovereign's real interest rate on external commercial debt r_{dc} and η governs the level of integration the private sector has in international capital markets.⁹

Liquidity-constrained households have the same preferences as Ricardian households but are prevented from saving and borrowing in the domestic and external financial market. These households have therefore to consume as much as their income from wages, remittances, government transfers allow, and pay the same consumption taxes as the Ricardian households, i.e.

$$(1 + \tau_t^c) P_t c_t^c = w_t l_t^c + \frac{a}{1 + a} (\mathcal{R}_t + \mathcal{T}_t). \quad (19)$$

Aggregation and Market-Clearing Conditions

Aggregating across both types of households and firms, we have $x_t = \sum_{\substack{i = \mathbf{r}, \mathbf{c} \\ j = n, x}} x_t^{i,j}$ for $x_t^{i,j} =$

$c_{j,t}^i, l_{j,t}^i, i_t^i, k_{j,t}^i, AC_{j,t}^i, b_t^i, b_t^{i,*}, y_{j,t}, \Phi_{j,t}^i$. Labor markets clear with labor demanded in the tradable and nontradable sectors supplied by both types of households, i.e. $l_{x,t} + l_{n,t} = l_t^{\mathbf{r}} + l_t^c = l_t$. Nontradable output produced domestically must match the demand for nontradable goods, public and private

⁹A low η depicts the case in which the country has an open capital account with the private sector easily borrowing from abroad.

investment used in the process of building nontradable public and private capital domestically (with a_k and a_z defining their nontradable content)

$$y_{n,t} = \rho_n \left(\frac{P_{n,t}}{P_t} \right)^{-\epsilon} c_t + a_k (i_{n,t} + i_{x,t} + AC_{n,t} + AC_{x,t}) + a_{zi} i_{zi,t} + a_{za} i_{za,t}. \quad (20)$$

Finally, the balance of payment condition must hold

$$\begin{aligned} \Delta b_t^* + \Delta d_{c,t} + \Delta d_t + \mathcal{G}_t + \mathcal{R}_t - \Delta \mathfrak{s}_t = & - [P_{n,t} y_{n,t} + P_{x,t} y_{x,t} - r_{t-1}^* b_{t-1}^* - \Theta_t^{s^*} - \\ & - r_{dc,t-1} d_{c,t-1} - r_d d_{t-1} + r^f \mathfrak{s}_{t-1} - P_t c_t - \\ & P_{zi,t} i_{zi,t} - P_{za,t} i_{za,t} - P_{k,t} (i_{n,t} - i_{x,t} - AC_{n,t} - AC_{x,t})] \end{aligned} \quad (21)$$

where the right-hand-side of (21) represents the current account deficit and the left-hand-side the capital account, i.e. the current account balance $ca_t = -\Delta b_t^* - \Delta d_{c,t} - \Delta d_t - \mathcal{G}_t - \mathcal{R}_t + \Delta \mathfrak{s}_t$.¹⁰

3. Calibration

The model is tailored to Vanuatu's economy at the time of the natural disaster (2015), calibrating parameters and initial values of endogenous variables using the available literature and data provided by the authorities, the IMF, and other bilateral and multilateral partners when we visited the country in late 2016 in the context of the Article IV consultations (IMF (2016b); Table 1 for initial values and Table 2 for parameters).

Natural Disaster

We analyze the response to a known disaster—2015 Cyclone Pam—for which damages and losses have already been accounted for. We therefore calibrate D_j to match Vanuatu's known damages to infrastructure and economic losses following the cyclone. The authorities' Post-Disaster Needs Assessment (2015) details damages and losses amounting to 60.8% of GDP (36.7% in damages and 24.2% in losses). Damages to the tradable sector, in particular damages and losses in agriculture, industry, and tourism, represented 23.7% of GDP (45% of which in damages and the remainder in losses); and 24.7% to the nontradable sector, which aggregates damages and losses in education and health, communication, energy, environment, transport, and water (57% of which in damages and the remainder in losses). The remaining 12.4% in damages and losses were in private housing.¹¹ Note that when data on damages is not available one could also make D_j as a function of wind speeds, surface temperature, geographic location, or quality of the institutional framework as for instance in Hsiang

¹⁰Under a flexible exchange rate regime $\Delta \text{reserves} = 0$. A framework with more prominent monetary policy features would be more adequate to discuss the effect of natural disasters on international reserves.

¹¹We abstract from additional or other types of disasters since these would not qualitatively change our main argument and conclusions. Additional damages would worsen the recovery of the main macroeconomic aggregates and demand a far greater support from donors and other lenders to finance a larger reconstruction program.

and Narita (2012), Nordhaus (2010), or Strobl (2011) and (2012). That is a particularly interesting avenue to study the impact of climate change, through an increased intensity of natural disasters, on public finances and the feasibility of adaptation investments.

The distribution of damages and losses among public and private capital destruction and productivity losses reflects our field assessment in Vanuatu. The distribution depends on output elasticities with respect to public infrastructure (ψ_n and ψ_x), private capital shares in value added (α_n and α_x) as well as the severity of damages to public and private capital (ϖ_z and ϖ_k , respectively). The former are pinned down by the initial return on public infrastructure with $\psi_n = \psi_x$. Estimates of the rates of return on public infrastructure abound and have been estimated to be between 15% and 30% for low-income countries (e.g., Foster and Briceño-Garmendia (2010)), but could also be greater than 50% depending on the type of infrastructure (Canning and Bennathan (1999)).¹² For the baseline scenario (separable public capital inputs), the initial return on total public infrastructure $R_o^z = 30\%$, which by definition equals the gross return on standard public investment $R_o^{zi} = 30\%$ given our assumption on ξ as discussed below. On the other hand, estimates on the gross return on public adaptation investment R_o^{za} are much less abundant. Our initial value is high (50%) but commensurate with the scarcity of adaptation infrastructure in developing economies or the additional benefit resilient infrastructure provides to the standard infrastructure.¹³ Therefore the implied value of the output elasticities with respect to public infrastructure is 0.0312. Estimates of public capital shares for low-income countries vary substantially across countries and type of public infrastructure, with values for larger low-to-middle-income countries around 0.1. These low elasticities for Vanuatu reflect the high inefficiencies in the public investment process. Indeed, we calibrate the initial efficiency of public investment to be $s_o = 60\%$, which is in line with the relative distance of small developing states from one of the most efficient countries in the IMF's PIMA and PIE-X assessments as done in Ghazanchyan et al. (2017).

Public standard infrastructure investment ($i_{zi,o}$) is set to 2015 levels and taken from the IMF World Economic Outlook. Adaptation infrastructure was practically nonexistent in Vanuatu at the time Cyclone Pam struck the country and we therefore have $i_{za,o} = 0$ as well as $z_o^a = 0$. Standard and adaptation capital depreciate at the different rates, with the former set at $\delta_{zi} = 7.5\%$ and the latter at $\delta_{zi} = 3\%$. This implies an additional lifespan for adaptation infrastructure of about 75 years relative to standard infrastructure, since the former is more resilient to natural deterioration. Private capital shares in value added are computed from the social accounting matrices and input-output tables (taken from the International Food Policy Research Institute (IFPRI) Global Trade Analysis Project (GTAP) database). The literature suggests a capital share of 55-60% in the nontradable sector and 35-40% in the tradable sector for Sub-Saharan African countries. Given the structure of Vanuatu's economy and the limited data availability, we consider the nontradable sector to be more labor-intensive and set $\alpha_n = 30\%$, and for the tradable sector we set it in line with other low income countries $\alpha_x = 40\%$. We calibrate $\varpi_z = 0.4$ and $\varpi_k = 0.3$, which gives slightly more weight to the destruction of public capital.

Thus the cyclone causes damages of about 25.8% of public infrastructure and 25.5% of private

¹²The World Bank requires operations for approval to have internal rates of return of at least 12%.

¹³The seawall or the climate-proofing of a road could extend the average number of days in a year when it is passable, allowing it to operate in less than ideal weather conditions.

capital relative to steady state. Given these and respective factor shares at the sectoral level, the productivity losses are commensurate, with deviations from the steady state of 20.9% in the nontradable sector and 20.5% in the tradable sector. In accordance with accounts of most stakeholders involved in Vanuatu’s recovery, a non-negligible fraction of the financial resources deployed were lost in non-productive activities. Thus the magnitude of the public investment efficiency loss (D_s) is assumed to be 20%, which suggests that following the cyclone for every dollar invested an additional 12 cents was lost as a result of the increased uncertainty and administrative challenges. The natural disaster’s impact on Vanuatu’s credit rating has been contained given its limited exposure to international capital markets (its debt portfolio is mostly concentrated in concessional and semi-concessional borrowing—and thus $\eta_g = 0$). At the same time, S&P (2015) argues that the largest natural disasters for both earthquakes and tropical storms could lead to downgrades of around 1.5 notches for the sovereigns affected, which includes some low-income countries. A 1-notch downgrade may translate into different levels of deterioration of interest rate spreads and the extent of the downgrade may depend, to name a few, on whether the downgrade means the government’s bonds have a speculative grade or not. For that reason, we assume that the country’s real interest rate on external commercial debt is aggravated by 15% (i.e. $D_r = 0.15$) following the natural disaster.

Reconstruction and Recovery

Vanuatu’s major challenge after Cyclone Pam destroyed part of the country’s infrastructure was to recover smoothly and start the reconstruction phase as soon as feasible. Economic activity (mostly tourism and agriculture) depends largely on infrastructure provided by the government (roads, ports, and airports) and therefore the political will to have infrastructure running was high. To capture the impetus for a swift recovery, we assume that the government intends to rebuild its damaged infrastructure to its pre-Pam level in about six years.¹⁴ Public investment efficiency, sectoral TFPs, and the credit risk premium linked to the disaster are all expected to gradually recover to their pre-Pam levels with the economic activity reestablished. The recovery follows a sigmoid function, which depicts the transition from the value of a variable x at the time of the disaster x^{Pam} to its pre-Pam (steady-state) level $x^{\text{pre-Pam}}$, such that

$$x_t = \exp(-\gamma_x t) x^{\text{Pam}} + (1 - \exp(-\gamma_x t)) x^{\text{pre-Pam}}, \quad (22)$$

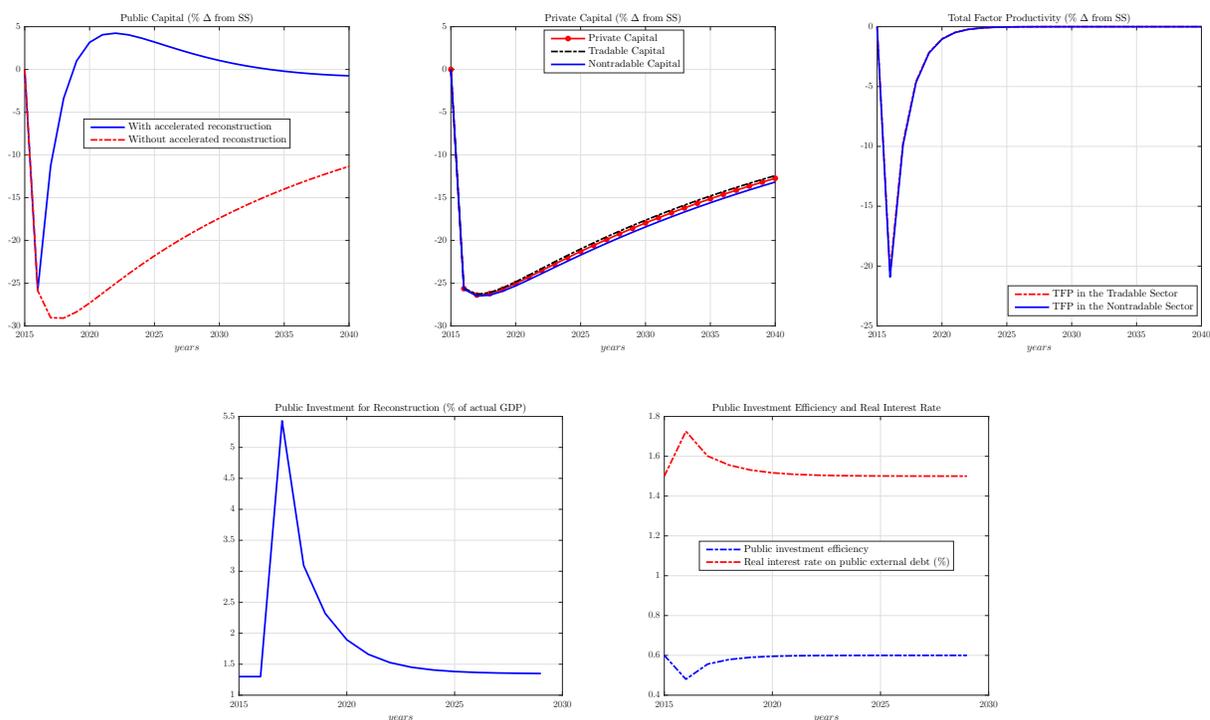
where $x = \{z^i, s, A_j, D_r\}$, γ_x controls the speed of the transition from one state to the other, and t is a vector of time.¹⁵ Given the path for standard public capital z_t^i , we can retrieve the public investment path for the accelerated reconstruction phase, i.e. $i_{z^i,t}^{\text{reconstruction}} = \frac{z_t^i - (1 - \delta_{z^i}) z_{t-1}^i}{s_t}$. Note that in the absence of the accelerated reconstruction program, the government would still be investing ($i_{z^i,o}$) every period to replenish part of the depreciated capital.

¹⁴For simplicity, we are considering the case of rebuilding public standard infrastructure. An alternative could be to consider the reconstruction of total public infrastructure and allocate part of the reconstruction to adaptation investments that would capture the argument of “building back better.” Furthermore, the timeframe was chosen to fit a standard political cycle. Shortening the amount of time needed for reconstruction would further put strains on the government’s fiscal stance and risk the government debt sustainability.

¹⁵Note that $D_r^{\text{pre-Pam}} = 0$.

Figure 2 shows the time path for public capital (with and without the accelerated reconstruction) as well as the impact of Cyclone Pam on private capital and TFP for both the traded and nontraded goods sectors. With the accelerated reconstruction program, public capital recovers to its pre-Pam level in less than five years, with public investment peaking at 5.5% of GDP before gradually declining to its pre-Pam level (1.3% of GDP) in about 10 years. Without the accelerated reconstruction program, public capital would stay well below its pre-Pam level for a long period of time (as is the case for private capital). Sectoral TFPs take about 6 years to regain their pre-Pam levels, while public investment efficiency recovers in less than 4 years. The 25 basis point increase in the government’s real interest rate on external borrowing fades away after about 5 years.

Figure 2: The natural disaster’s transmission channel



Remaining Calibration

Public debt levels (b_o , d_o , and $d_{c,o}$) were taken from the IMF’s 2016 debt sustainability analysis. Vanuatu has little access to international capital markets, so the public external commercial debt corresponds to public semi-concessional debt negotiated with bilateral donors (such as borrowing with the Chinese EXIM bank). Private external debt (b_o^*) is taken from the World Bank’s (WB) long term private nonguaranteed external debt series. Grants and remittances (\mathcal{G}_o and \mathcal{R}_o , respectively) are taken from the IMF and based on estimates from the Reserve Bank of Vanuatu and the Ministry of Finance. Note that the initial value for grants includes the significant inflows that followed Cyclone Pam during the year of 2015. Since we are interested in donor contributions for the reconstruction

phase, we use the 2015 value. Remittances and government transfers are assumed to be constant. Interest rates on debt instruments are set to match recent history. Nominal interest rates tend to be relatively low and thus real interest rates reflect these and relatively low inflation rates in Vanuatu and the world economy. The real interest rate on concessional debt r_d is assumed to be zero, as shows recent lending from the Asian Development Bank and the World Bank. The real interest rate on public external debt ($r_{dc,o}$) matches the real interest on semi-concessional lending provided by bilateral donors and the real interest rate on public domestic debt (r_o) the effective rate from domestic borrowing excluding state-owned enterprises. The initial tax rate on consumption (τ_o^c) is set at its current statutory level.

Table 1: Selected initial values (%)

Definition	Param.	Value
Public standard investment to GDP	$i_{zi,o}$	1.3
Public adaptation investment to GDP	$i_{za,o}$	0.0
Return on public standard infrastructure investment	R_o^{zi}	30.0
Return on public adaptation infrastructure investment	R_o^{za}	50.0
Public domestic debt to GDP	b_o	7.7
Public concessional debt to GDP	d_o	12.9
Public external (commercial) debt to GDP	$d_{c,o}$	5.0
Real interest rate on public domestic debt	r_o	5.0
Real interest rate on public concessional debt	$r_{d,o}$	0.0
Real interest rate on public external debt	$r_{dc,o}$	1.5
Savings to GDP	s_o	0.0
Grants to GDP	\mathcal{G}_o	11.2
Consumption tax (VAT) rate	τ_o^c	12.5
Private external debt to GDP	b_o^*	0.0
Remittances to GDP	\mathcal{R}_o	3.5

The intratemporal elasticity of substitution between public capital inputs ξ is such that $\frac{\xi-1}{\xi} = 1$ (or $\xi = +\infty$) in the baseline case, which makes standard and adaptation infrastructure as perfect substitutes and therefore $z_t = z_t^i + \nu_a z_t^a$. In that case, the marginal rate of technical substitution between the public capital inputs is constant and given by $\frac{R_t^{za}}{R_t^{zi}} = \nu_a$. Although not critical for our experiments, that decision is not without consequences in further model applications. With adaptation and standard public capital being perfect substitutes, a social planner choosing the composition of public investment optimally would prefer to invest entirely in resilient infrastructure since adaptation capital is scarcer, has a lower depreciation rate, and also reduces the impact of natural disasters.

Considering adaptation infrastructure a substitute for standard infrastructure rests on the notion that building seawalls is not the same as building roads or schools. However, adaptation to natural disasters and climate change need not be building seawalls to protect the coastline. There may instead be some complementarity between the two stocks of public capital. One could think of adaptation investments as enhancing bridges to withstand stronger extreme events or climate proofing roads (e.g., by using better materials). Departures from our original assumption regarding the complementarity

between standard and adaptation infrastructure could take the following forms: (i) the two inputs are perfect complements and thus total public capital is given by the Leontief technology $\min\left(\frac{z_t^i}{\rho_z}, \frac{\nu_a z_t^a}{1-\rho_z}\right)$ with $\xi \rightarrow 0$ such that the $\lim\left(\frac{\xi-1}{\xi}\right) \rightarrow -\infty$; and (ii) the two inputs follow a Cobb-Douglas production technology given by $z_t = (z_t^i)^{\rho_z} (\nu_a z_t^a)^{1-\rho_z}$ with $\xi \rightarrow 1$ such that the $\lim\left(\frac{\xi-1}{\xi}\right) \rightarrow 0$. The former would render any increase in one type of investment irrelevant if not done in fixed proportions. The marginal rate of technical substitution between the public capital inputs is such that $\frac{R_t^{z^a}}{R_t^{z^i}} = \frac{z_{t-1}^i}{z_{t-1}^a}$ with $\nu_a = \frac{R_t^{z^a}}{R_t^{z^i}} \frac{1-\rho_z}{\rho_z}$. In the latter case, the ratio of marginal benefits would also be a function of the share parameters, i.e., $\frac{R_t^{z^a}}{R_t^{z^i}} = \frac{\rho_z}{1-\rho_z} \frac{z_{t-1}^i}{z_{t-1}^a}$.

From the remaining parameters, we highlight the following. The share of liquidity-constrained households is calibrated from the latest WB reported poverty headcount ratio at the national poverty lines (as % of population). The fee Ricardian households pay on standard public infrastructure (μ) is a fraction of the recurrent costs. Given the considerable variation in recurrent costs, we assume that the government charges 50% of its costs to households. Imports to GDP, used to pin down the share parameters in the CES consumption basket, are taken from the IMF as imports of goods (54%), while the share parameter in the CES public capital definition is tilted in favor of standard public infrastructure (90%). The value added in nontradable sectors, used to compute the share of output in the nontraded sector, are estimates from the sectoral aggregation of nontradable activities in value added from national accounts (48%).

Table 2: Calibrated parameters

Definition	Param.	Value
Firms		
Capital share in value added in the nontraded goods sector (%)	α_n	40.0
Capital share in value added in the traded goods sector (%)	α_x	30.0
Cost share of nontraded inputs in the production of private and public capital (%)	a_k, a_{zi}, a_{za}	50.0
Households		
Intertemporal elasticity of substitution of consumption	ζ_c	0.34
Intratemporal elasticity of substitution across consumption goods	ϵ	0.50
Share of liquidity-constrained households (%)	$\frac{a}{(1+a)}$	12.7
Portfolio adjustment costs parameter	η	1.0
Depreciation rate of private capital (%)	δ_k	5.0
Government		
Intratemporal elasticity of substitution across public capital inputs	ξ	$+\infty$
Depreciation rate of standard infrastructure (%)	δ_{zi}	3.0
Depreciation rate of adaptation infrastructure (%)	δ_{za}	7.5
User fees fraction of recurrent spending (%)	μ	50.0
Premium on imported machinery for adaptation infrastructure (%)	pr	0.0
Public debt risk premium parameter	η_g	0.0
Risk-free world real interest rate (%)	r^*	2.0

4. Recovering with Fiscal and Debt Sustainability

In this section we study how the government would have had to respond to the natural disaster if it had to finance the entire reconstruction activities by either raising consumption taxes or resorting to external borrowing. Then we assess what aid package should donors have provided the government to ensure fiscal and debt sustainability over the medium term, i.e. allowing the government to maintain similar debt levels without raising taxes.

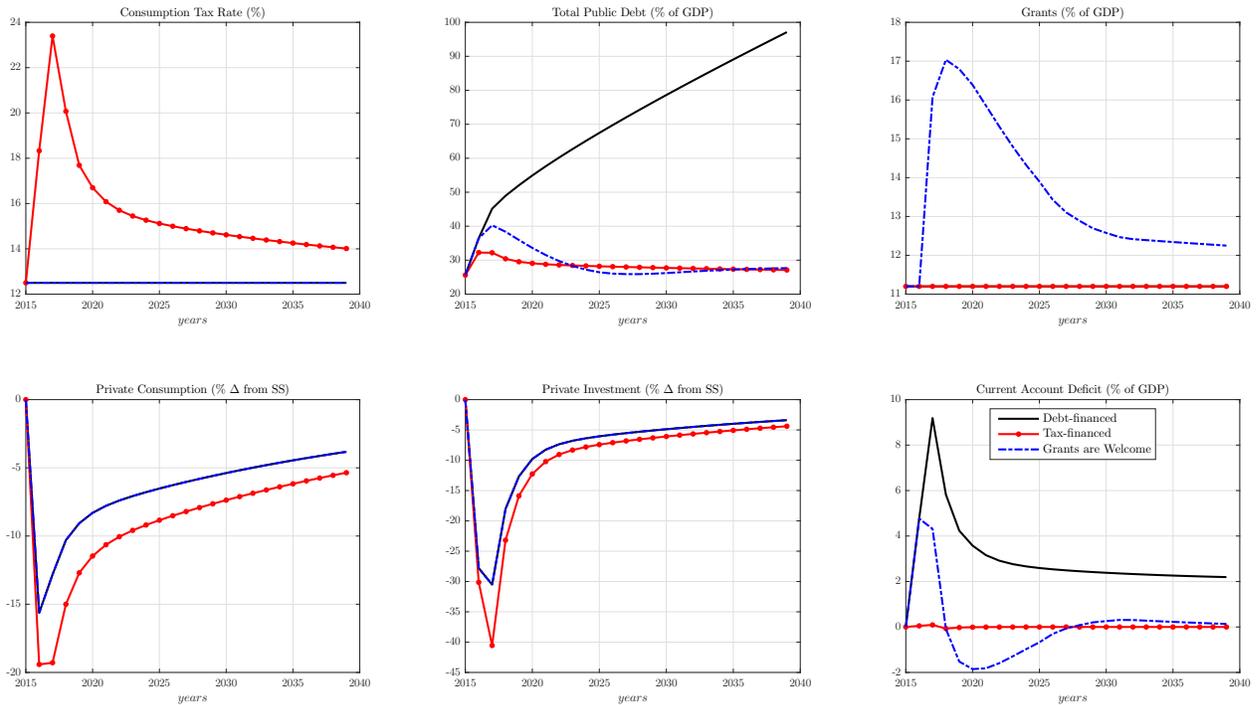
4.1. Alone in the Dark

This subsection examines the fiscal and debt implications of financing the government's accelerated reconstruction without further support from its development partners. Figure 3 presents the time path of selected endogenous variables, illustrating the macroeconomic implications of the two scenarios—one in which the fiscal gap is entirely financed with consumption taxes and the other in which external borrowing adjusts to close the fiscal gap. Although the impact on real GDP of these two financing schemes is similar, increasing taxes is far more damaging to households than the additional debt. The government would have to raise the consumption tax rate from 12.5% to close to 23% in the short term and to about 14% over the medium term. As a result, private consumption would drop 20% relative to its pre-Pam level. Resorting to external borrowing has a smaller effect, with private consumption falling less than with a tax-financed reconstruction. Although Ricardian households base their optimal decisions on the entire profile of government debt and taxes, an increase in taxes affects both types of households. On one hand, liquidity-constrained households have to consume as much as their disposable income allows, thus an increase in taxes has a direct effect on their disposable income. On the other hand, the increase in taxes and domestic real interest rates affect Ricardian households intertemporal consumption decision, with the latter increasing sharply with the spike in taxes (from 5% to 18%).

Increasing taxes would be at odds with the authorities' goal to smooth the impact on households' consumption. In response to the cyclone the government suspended VAT and import duties on construction materials to boost reconstruction of damaged infrastructures and allowed members of the National Provident Fund (mostly civil servants) to withdraw up to 20% of their retirement savings. However, the alternative scenario of resorting entirely to external borrowing poses threats to the government's debt sustainability. The debt-financed accelerated reconstruction phase would push public debt to levels well above 90% of GDP in the medium term—which could reach above 105% of GDP in 30 years—from 25% pre-Pam. The resulting appreciation of the real exchange rate (4%) makes the tradable sector lose some price competitiveness and the current account deficit to worsen to about 9% of GDP.¹⁶ The negative impact on the tradable sector is 5 percentage points stronger relative to its Pre-Pam level when the government resorts to borrowing as opposed to taxes.

¹⁶For instance, Hsiang (2010) finds that tourism-related income is disproportionately impacted by cyclones, driven by persistent and long-lasting reductions in tourist visits. In addition to the extent of the damaged infrastructure, institutional challenges and exchange rate considerations may have help drive tourists away from the affected areas.

Figure 3: Debt and fiscal sustainability implications



It is important to note that the macroeconomic variables are reported in deviations from steady state. Year-on-year growth rates of real private consumption and private investment show a rapid increase after the disaster.

Private investment falls more under the tax-financed reconstruction program, with a very strong decline in investment in both the tradable and nontradable sectors (about 40 and 42%, respectively)—despite similar rates of return on tradable and nontradable capital (2 percentage points above their initial values). The years after the cyclone are marked by rapid year-on-year growth in private investment (and private consumption), but these aggregates are still below pre-Pam levels. Private capital, as a result, trails below the path implied by debt-financed reconstruction. In both cases, the capital stocks are 20% below the pre-Pam level for more than 10 years. All in all, both financing strategies entail significant risks and a challenging recovery over the medium term. Despite the benefits of accelerating the reconstruction process, restoring the level of public infrastructure that prevailed prior to the disaster may require adjustments that are politically infeasible.¹⁷

4.2. Grants for Reconstruction

In this subsection we address the fiscal and debt sustainability concerns discussed previously by considering that the donor community is willing to help the government realize its accelerated reconstruction program, such that it would not need to raise taxes or resort to additional borrowing.

¹⁷The latest January 2018 IMF Article VI mission estimates suggest that public debt to GDP has risen significantly in line with the model predictions, with public debt expected to reach 56% of GDP in 2018 following a strong push in reconstruction after the cyclone.

Depicted in blue, Figure 3 also shows the time path of the endogenous variables for the case with external grants closing the government’s budget constraint. Grants are provided exogenously, mimicking the large inflow of grants needed to sustain the accelerated reconstruction program. In order to finance the accelerated reconstruction program, donors would have to contribute significant resources over the medium term: an additional 50% of pre-Pam GDP in grants for over 15 years after the cyclone. The bulk of grants would be provided in the first five years, peaking at 17% of (actual) GDP and staying above 12% of GDP over the medium term before returning to its 2015 level in the long run—which *per se* was a remarkable increase in grants relative to the years prior to Pam. This financing package far outweighs the large commitments several development partners have made to Vanuatu over the next few years. And with the benefit of hindsight, we indeed confirm that grants (in terms of GDP) have not followed suit, in spite of the initial commitments—yet short in disbursements—of bilateral and multilateral donors following the cyclone. This suggests that the pace of reconstruction activities will have to be slower than expected and that important infrastructure projects may take more time to materialize.

On the other hand, the benefits of a grant-financed reconstruction program are clear: the country enjoys the benefits (or lesser evil) of a debt-financed recovery without the debt distress concerns. Thanks to the lower debt levels, the current account is stabilized in about 15 years after the cyclone. Another important consideration to have in mind with regards to the grant contribution of bilateral and multilateral donors is that these encompass far more than financial support. 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 (by assuming that public investment efficiency recovers faster from the post-disaster dip) show a stronger recovery of private consumption and investment, with real GDP converging to its initial steady state at a faster rate.

5. Building Resilience with Adaptation Infrastructure and Fiscal Buffers

The previous section analyzed how the government could rebuild the damaged infrastructure after the disaster ravaged the country. In contrast, this section focuses on what policies could the government have implemented prior to the natural disaster with the support of donors. We consider two such policies: (i) investing in adaptation infrastructure; and (ii) saving proceeds in an external contingency fund.

5.1. Investing in Resilient Infrastructure

This subsection performs the following thought experiment: suppose the government had spent 3% of GDP per year in adaptation infrastructure in the five years prior to Cyclone Pam—expenditures entirely funded by donors—what would have happened to debt and fiscal sustainability? For comparability purposes, we assume the same accelerated reconstruction path post disaster despite the smaller destruction of public infrastructure. Thanks to the investment in resilient infrastructure, the magnitude of the cyclone’s damages to public and private infrastructure, as well as on sectoral TFP is reduced. Thus, the fiscal gap that needs to be financed provides an upper bound for public debt since post-disaster the government builds more public capital than it would have built under the previous scenario. Figure 4 shows the magnitude of the damages and contrasts the previous section’s paths of public and private capital and TFP in blue with the ones obtained from investing in resilient infrastructure in red. Investing in adaptation would have reduced damages to standard public infrastructure (e.g. roads) by 5.2%, by 9.7% the damages to private capital, and by 3.8% and 3.9% the productivity losses in the tradable and nontradable sectors.

Figure 4: More resilient infrastructure, lower damages

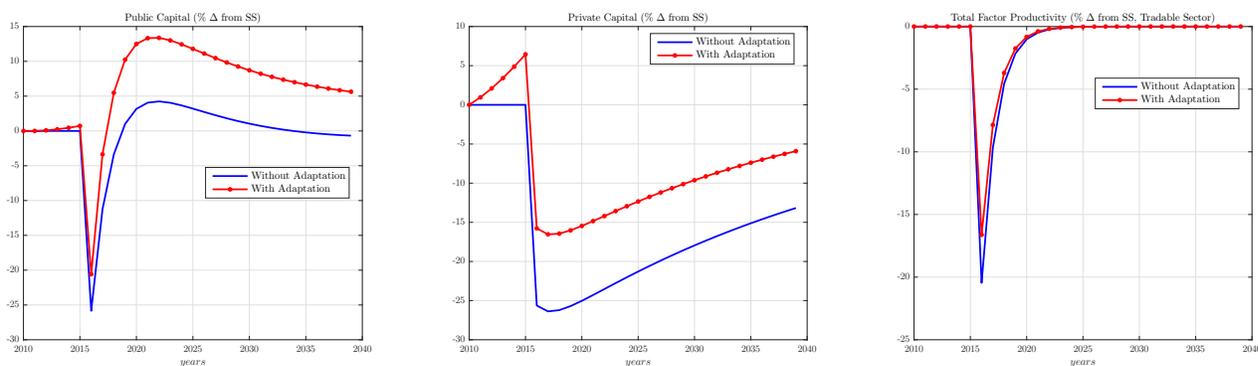
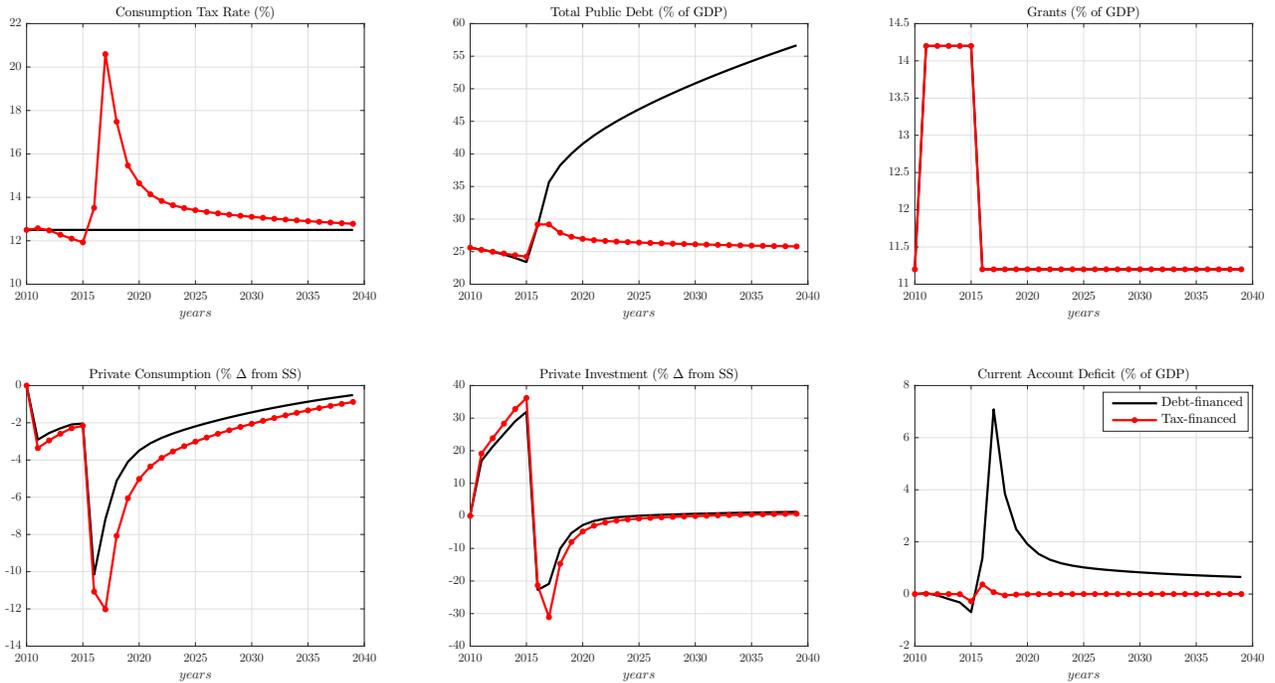


Figure 5 presents the results for both the debt and tax-financed reconstruction programs following public investments in resilient infrastructure. Fiscal and debt sustainability concerns are attenuated thanks to the build up of resilient capital. Investing in adaptation helped reduce the risks of debt distress, with public debt reaching less than 60% of GDP over the medium term (as opposed to 100% of GDP in the previous subsection), while the tax-financed reconstruction program requires a less demanding fiscal adjustment. In that case, the consumption tax rate would have to increase to 21%, yet reverting much faster to its initial value (in about five years as opposed to a prolonged tax increase in the scenario with no adaptation investment). Note that investing in adaptation raises the marginal product of private capital, crowding in private investment prior to the disaster together with the increase in the domestic real interest rate. This gives rise to a contraction of private consumption in the short term—in particular from the savers. Post-disaster, private investment declines by about 23% to 31% relative to the initial steady state—a 10 percentage point difference with the previous scenario—while private consumption decreases by about 10 to 12%.

Figure 5: Resilient infrastructure reduces risk of debt distress



5.2. Building Fiscal Buffers

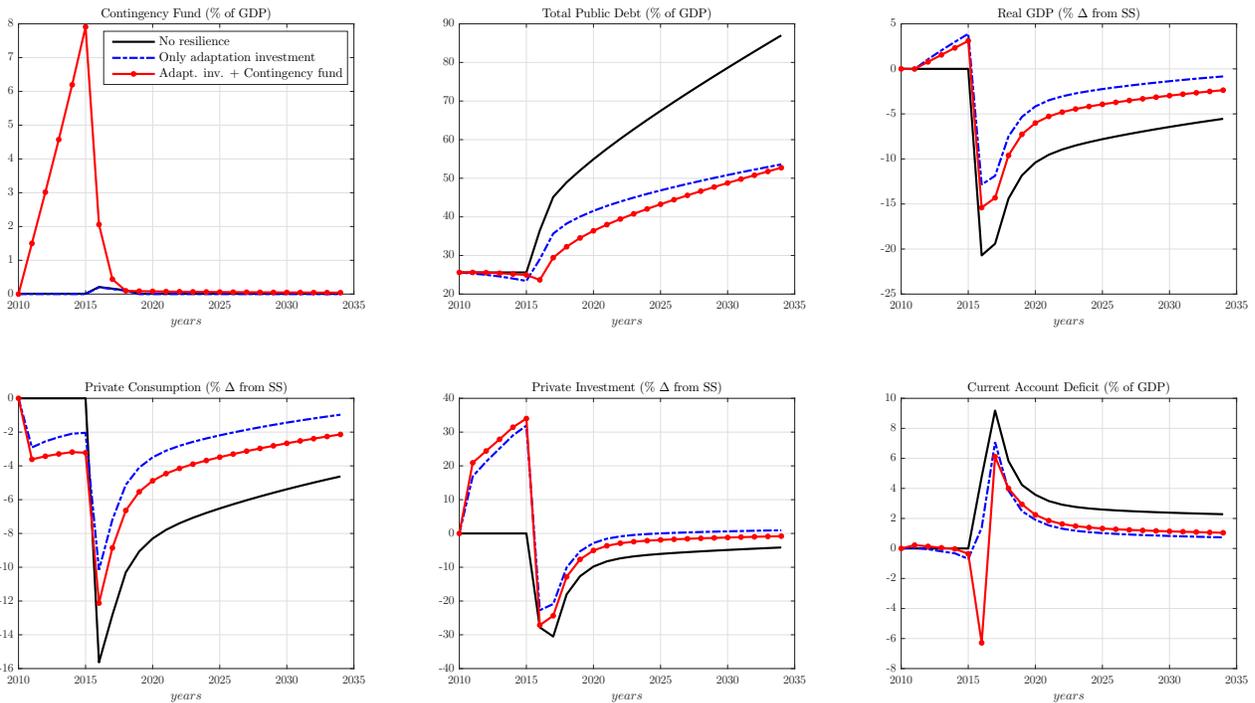
A common advice to countries facing a high probability of a large shock is to accumulate money in a contingency fund. The reason for that is that access to financing (particularly external financing) might be curtailed or become prohibitively expensive exactly when the government needs money to deal with a shock. This is, for example, a rationale for holding international reserves despite their high opportunity cost. With that in mind, this subsection answers the following: what if the government had decided to reallocate part of its intended capital spending on resilient infrastructure into a contingency fund instead? The government and donors decide to allocate annually half of the 3% of GDP to a contingency fund and the other half to adaptation investments. Figure 6 contrasts this scenario (in red) with the case in which the government invests the 3% of GDP only in adaptation (from the previous subsection; in blue) and the case in which the government has no donor support and does not adopt any preemptive measures (from subsection 4.1; in black); in all these scenarios, external borrowing closes the government’s fiscal gap.

With the support of donors, the government accumulates about 8% of GDP in its external contingency fund that is then used to fund reconstruction (withdrawals amount to 75% of the fund’s remaining balance for three years after the disaster). The availability of financial resources allows the government to start reconstruction without the need for additional borrowing in the short term. Thus, building fiscal buffers allows the government to live with lower debt-to-GDP levels compared with only investing in resilient infrastructure over the medium term—despite GDP being more affected in the

former than in the latter. However, the gains disappear by 2035 with total public debt reaching 53% of GDP. On the other hand, both preemptive policies lead to lower debt levels than warranted under the post-disaster reactive policy (about 25 percentage points lower).

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. Relative to its initial value, investing entirely in adaptation saved the economy 3 percentage points of its output relative to the strategy of coupling adaptation investments with savings—and note that adaptation investments are not fully efficient. Although the tax rate is fixed, private consumption still drops 12% below its initial value upon the shock with the domestic real interest rate reaching negative values. With the expectation of the storm coming, households are trading today’s consumption for more consumption in the future. Then, given the low real interest rate, private consumption rebounds immediately but stays below pre-Pam level for several decades. On the other hand, adjusting taxes to finance the reconstruction would have further dampened the contraction of private consumption.

Figure 6: Saving in a contingency fund helps smooth the recovery



So all in all, should a small developing country susceptible to natural disasters invest in a contingency fund? The answer depends on what sort of event it needs to insure itself against—including the size of the shock and the reaction of the international community. Relatively frequent (occurring once every few years) events of manageable proportions (e.g., with damages in the order of 1% of GDP)

are unlikely to elicit a major response from development partners. If the country has to deal with the consequences of such events largely on its own, a permanent income hypothesis argument suggests that accumulating resources in a contingency fund during non-disaster years would allow avoiding costly adjustments in disaster years—which should be welfare-improving.¹⁸ Contributions to the fund could correspond to the average cost of “non-catastrophic” disasters (e.g., if there is one in five chance every year of a shock that costs 1% of GDP, then $\frac{1}{4}\%$ of GDP should be deposited in the contingency fund every non-disaster year).

That same argument does not apply to truly catastrophic events like Cyclone Pam. As discussed above, trying to finance reconstruction on its own would undermine the country’s development. It has to rely on external support and the international community is very likely to come to the rescue. By the same token, the country cannot divert enough resources into a contingency fund to deal with a possible future cataclysmic event without stunting its development. Accumulating some money to cover a fraction of the cost would alleviate the burden on donors, but unless there is a credible mechanism to commit the country to cost-sharing in case of a major natural disaster, it would not be rational for a developing country to try and save money to its development partners. For the same reasons, small states might see purchasing catastrophe insurance as a wasteful transfer to more developed economies, as the latter would likely decrease the amount of their post-disaster aid by the size of the insurance payout.

One could make an argument that it would be useful for the small state to have some money in the contingency fund because even if ultimately the bulk of reconstruction expenses is financed by donors, it takes a while for them to put the package together and in the meantime the government should have some cash on hand to finance immediate needs. That is true to an extent and thus such needs could be served by a small contingency fund advocated in the previous paragraph and other liquid resources the government has (foreign reserves; government deposits). It should be noted, however, that with the disruption that the cyclone caused on Vanuatu and the country’s remoteness, cash alone would have solved very few problems. The shortages of food, potable water, shelter, electricity, and other essential goods and services could not have been resolved simply by purchasing those. Their delivery and help with repairing essential infrastructure had to be largely organized by the donors anyway. Finally, for the donors themselves, pre-funding a response to a possible future natural disaster in a foreign country would not be beneficial as they would not face liquidity constraints post-disaster in any case (unlike the affected country).

A few caveats are worth mentioning. Moral hazard issues and donor fatigue from prolonged foreign aid support may arise. For instance, Raschky and Schwindt (2016) argue that foreign aid may reduce incentives to invest in disaster prevention, particularly significant for poorer and less democratic countries, with policymakers preferring to rely on a bail-out from the international community. While that is indeed possible, the severity of the material cost from major natural disasters coupled with the massive development gaps these countries face make moral hazard considerations less prominent.¹⁹

¹⁸Another way to think about this is that both the cost of borrowing and the opportunity cost of not investing in infrastructure are likely to be higher after a natural disaster than in quiet times, so it makes sense to “pre-fund” the recovery and reconstruction expenditures that the government knows it is going to incur with near certainty over a few years.

¹⁹Although we abstracted from this in the paper, donors may want to behave strategically and may not be willing to

On the other hand, as demonstrated above, investing in building resilience to natural disasters could pay off should one occur. This type of infrastructure reduces the extent of the damages and hence a country's vulnerability to natural disasters and the need for *ex post* relief. Even for the donors, in the long run it would likely be cheaper to finance resilient infrastructure in small developing states than to help them deal with the consequences of unmitigated shocks—although politically it might be easier to mobilize support for a country hit by a highly visible shock than to finance its infrastructure program.

6. Conclusions

Small developing states are frequently hit by natural disasters that tend to leave long-lasting scars on the economy. In addition to tragic loss of life, natural disasters destroy public and private infrastructure needed for the economy to function, disrupting economic and social activities. They also put considerable strains on government finances, frequently demanding a swift reconstruction of infrastructure—yet with limited room to raise additional revenues or curtail transfers and other expenditures. Thus, balancing development needs and addressing vulnerabilities to disasters challenges the economic convergence of these countries. Although these issues are macro-critical and common to most small developing states, they have been little explored in the literature.

This paper assesses two main policy issues related to a major natural disaster: (i) if the government were to fully rebuild the public infrastructure destroyed by the cyclone in less than a decade, what additional resources would the donor community have to pitch in to ensure debt and fiscal 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 would that mitigate the impact of the disaster on debt and fiscal sustainability? In an application to Vanuatu, severely hit by Cyclone Pam in March 2015, we show the following. First, the country cannot face damages alone: grant-financing is key for debt sustainability. Despite the moral hazard considerations linked with such a strategy, bilateral and multilateral partners would have to significantly scale up their financial contributions following the cyclone if the donor community wants to ensure a smooth recovery. Second, the government can, and should, invest in resilient infrastructure and build fiscal buffers (including insurance mechanisms) that would attenuate the impact of the disaster. However, these initiatives involve some difficult policy choices: the government would need to create fiscal space (raising taxes or reducing other expenditures) or resort to borrowing. Finally, and more importantly, donors can help make these investments. Moral hazard issues notwithstanding, this would help reduce the need for their financial contributions post-disaster. Still, recovering from a highly damaging natural disaster would demand significant financial contributions from donors, even with a reasonable level of adaptation infrastructure.

These results show the important role the donor community may play in sustaining a swift recovery in countries severely hit by highly damaging natural disasters. Possible extensions of this model could study the optimal balance between *ex ante* and *ex post* policies for both policymakers and donors, consider different damage functions that could be endogenously given by temperature changes or

compromise on a long-term agenda.

wind speed, or alternatively assess the impact of climate change on growth and debt sustainability. Another avenue for research is to study which generations should bear the costs from adaptation and reconstruction in an overlapping generations framework or allow for more heterogeneity in households and firms to assess distributional consequences of different policies since landholding in coastal areas could impact the poor more disproportionately. On the other hand, the policy dialogue could revolve around the following issues: incorporating disaster costs into budget planning (e.g., average impact on growth, increased infrastructure depreciation rates and maintenance costs); building fiscal buffers and investing in infrastructure able to withstand the impact of a disaster (including urban planning and integrated coastal zone management); and enhancing the framework for coping with natural disasters (national plans, institutions, and responsibilities) to accelerate the recovery process and reduce the impact on productivity and investment efficiency.

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