BinD: A model of growth, climate change, and debt sustainability*

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Abstract

Climate change disproportionately impacts capital and output in low- and middle-income countries (LMICs). Limited fiscal space and high dependence on capital good imports further curtail their ability to make timely climate-resilient investments. In this paper we present a demand-driven model that is supply-side constrained due to insufficient build up of production capacity. Calibrating the model to Fiji, we evaluate growth pathways for three climate futures – 2C, 3C, and 4C global warming by the end of the century. We evaluate the role of a public climate fund to enable partial recovery that is financed through four different schemes - debt-led recovery, higher tax on households, higher taxes on capitalists, and unconditional grants from the rest of the world. Recovery is possible in the 2C scenario, but the 3C and 4C scenarios increasingly face higher investment costs in the face of lower growth and saving rates. In the 4C scenario, even the most generous unconditional grants scheme fails to prevent the downward spiral of hitting capacity constraints despite an initial boost to output. These insights underscore the need for effective and equitable domestic climate policies and affordable finance and compensation to support sustainable development in vulnerable countries.

Keywords: climate change, economic growth, low and middle income countries, sustainable economic development, climate financial resilience

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1 Introduction

Low- and middle-income countries (LMICs) are disproportionately affected by climate change, rising temperatures, and higher frequency of extreme weather events (Burke et al., 2015; Georgieva et al., 2022; IPCC, 2023). Beyond human suffering, climate change drives up capital stock losses, while lowering productivity. Given that temperatures are projected to rise, even in the most optimistic scenarios (IPCC, 2023; CCKP, 2023), climate-induced damages will increase further, potentially putting LMICs on unsustainable low-growth pathways (Dell et al., 2012).

In addition to climate change, LMICs face two key macroeconomic challenges. First, LMICs have a high reliance on imports of capital goods (Mutreja et al., 2018). Capital goods, mostly machinery, cannot be easily replaced with domestic capital and is a necessary investment to achieve domestic production capacity to meet demand. Increasing rates of capital loss through climate damages further exacerbate the problem by forcing LMICs to allocate their scarce financial resources towards expensive capital imports. Second, LMICs have low tax-to-GDP ratios and high debt levels that restricts their fiscal space (Volz, Ulrich, 2022; UNCTAD, 2022; Chamon et al., 2022; TCFD, 2023; Neunuebel, 2023). Additionally, existing climate change impacts are already driving up the cost of capital as international financial markets increasingly price climate risks. Therefore, an increase in the risk premium of LMICs will further limit their capacity to borrow at favorable conditions (Beirne et al., 2021; Volz, Ulrich, 2022).

Despite these constraints, LMICs need to make the necessary investments in climate-resilient development, and therefore require significant financial support given the tight fiscal space coupled with domestic policies to ensure inclusive growth. Additionally, if the right climate policy measures are not implemented at the right time, LMICs face a high likelihood of entering a vicious downward spiral where greater climate vulnerability will escalate investment costs and restrict investment ability (Feyen et al., 2020).

This paper contributes to the ongoing debate by examining macroeconomic transmission channels of climate impacts on LMICs, and proposes a potential policy response through a public climate fund financed through different schemes. In order to capture these various direct and indirect macroeconomic mechanisms, the paper presents the "BinD model" that incorporates supply-side constraints into a demand-driven framework. In summary, aggregate demand drives output that requires a capital stock. Limited financial resources to build up the capital can also limit output by constraining the supply side. Therefore the rate of change of demand, and the rate of change of capital stock drive the model outputs. The financial side is tracked through "gaps" in private savings, public savings, and external balances.

The model is applied to Fiji, a small island country that faces financial and fiscal constraints in the face of strong climate impacts. Fiji's patterns of economic growth are tracked under three climate trajectories that represent 2C, 3C and 4C warming above pre-industrial levels by the end of the century. The baseline simulations of the three climate futures, with no policy intervention, shows a decline in output due to loss of capital stock that lowers demand from reduced consumption and investment. As a policy response, the government sets up a climate fund (CF), to partially finance climate investments in order to rebuild capital stock. Four CF financing scenarios are evaluated; higher debt, a flat increase in taxes, a progressive tax on capitalists, and unconditional grants from the rest of the world similar to a loss and damage mechanism. The CF initially stimulates economic growth through quicker recovery, however, over time the costs associated with financing the CF, such as higher interest payments and taxes and lower external balances, start to dampen demand both in terms of private and public consumption. Even in the most favorable scenario with unconditional grants, the model economy shows more favorable outcomes, but still faces limited growth potential due to climate-induced capital stock losses which eventually constrains the supply due to insufficient investments.

The findings of the paper reveal several policy-relevant insights in the context of climate-vulnerable LMICs such as Fiji. First, economic growth comes to a halt, even under the favorable unconditional grants scheme, under high temperature (3C and 4C) scenarios due to lack of demand and growing supply-side constraints. This implies that the temperature trajectories matter for achieving long-term growth. It is hence crucial for the world to stay within the 2C limit to give highly vulnerable countries an opportunity to achieve sustainable development. Second, a CF could be a potential mitigation strategy under limited temperature increases, but financing options (tax or debt-funded) have different socioeconomic implications and create trade-offs for economic growth, income distribution, external balances, and debt sustainability. Given those insights, there is an urgent need for countries to design effective and equitable policies while the international community needs to enable affordable finance and compensation to allow the climate-vulnerable countries to maintain a sustainable future.

The remainder of the paper is organized as follows. Section 2 provides an overview of the related literature. Section 3 outlines the 'BinD' model. Section 4 provides the macro-financial context for Fiji and describes the applied climate and policy response scenario. Section 5 presents the results, while Section 6 provides conclusions and directions for future work.

2 Relevant literature and context

Several papers highlight the extent of vulnerability of LMICs to climate change. Kahn et al. (2021) use historical climate patterns to conduct cross-country analysis and show a 7% output loss by the end of the century relative to a baseline. Likewise, Acevedo et al. (2020) estimate output losses of about 9% compared to a scenario with no climate impacts by the end of the century while admitting conservative assumptions. On the other side of the spectrum, Burke et al. (2015) find output losses of about 23% by the end of the century under a warming of 4 degrees or higher, with low-income countries facing losses up to 80%. Beyond output losses, climate impacts may also reduce growth rates (Dell et al., 2012), which could further amplify impacts. Likewise, compounding risks, such as the interaction between hurricanes and pandemics, can further exacerbate losses, with implications for economic recovery costs, financial stability, and public debt sustainability (Dunz et al., 2023). Climate change is likely to exacerbate inequality, particularly across countries, and economic development alone may be unlikely to reduce damages (Felbermayr and Gröschl, 2014; Burke and Tanutama, 2019). A growing literature is analyzing the macroeconomic impacts of acute climate-related disasters and evaluating corresponding disaster risk management and adaptation policies (Marto et al., 2018; Hallegatte et al., 2020; Burns et al., 2021; Hallegatte et al., 2022; Yokomatsu et al., 2023) but evaluation of complex macro-financial spillover effects remains relatively understudied in modeling frameworks.

Lower-income countries import a significant share of their capital goods from mostly emerging economies or high-income countries (Eaton and Kortum, 2001; Mutreja et al., 2018).[1] Capital goods, such as machinery,

[1]For instance in Fiji, the export-to-import ratio for different product categories in 2020 was lowest for capital goods (0.22 and 0.12 in 2019) meaning that Fiji is importing way more capital goods than exporting them, compared to consumer goods (0.46 and 0.44 in 2019), intermediate goods (0.5 and 0.37 in 2019), raw materials (0.80 and 0.79

trucks, and ships, are essential for building domestic production capacity but can also become a barrier to economic growth, as the cost of imports go up, especially due to damages caused by climate change.

LMICs are often financially constrained due to factors such as low levels of saving, limited access to credit, high levels of debt, and limited fiscal space. At the same time, financial markets in LMICs countries are often underdeveloped and do not present sufficient opporunity to raise finance to invest in infrastructure and industrial planning that is essential for long-term economic development. Financial constraints can also limit the ability of LMICs to respond to crises such as natural disasters or pandemics further worsening growth trends and socioeconomic vulnerabilities (IMF, 2016). To address these challenges, LMICs may need to explore alternative sources of financing, such as foreign aid, better domestic tax policies, and mobilization of private investment through the right market signals.

The BinD model introduced in this paper builds on a strand of structuralist approaches that led to the development of three-gap models in the beginning of the 1990s (Bacha, 1990; Taylor, 1991, 1994). Three-gap models extend the two-gap model that was originally developed by Chenery and Bruno (1962) and widely used by the World Bank in the 1970s and 80s for estimating required foreign aid based on an assumed linear relationship between investment and output (Easterly, 1999). In contrast, three-gap models view output as an adjustment mechanism (Easterly, 1999), thereby distinguishing between employed capacity representing potential output, and current capacity utilization, representing actual output. The reasoning for separating both the variables is that many transition economies operate at less-than-full capacity, and therefore, can increase output at least in the short-to-medium run, without requiring additional investments (Sepehri and Akram-Lodhi, 2005). The original pool of three-gap models were designed to assess LMICs' financing needs in a data-scarce environment. Given the current state of worsening climate impacts, co-occurring shocks, and broadly lower fiscal space at the national and the global level, structural adjustment models provides a promising starting point for understanding climate shocks and climate policies since they already incorporate several macro-fiscal characteristics that constrain LMICs.

3 The BinD model

The "binary constrained disaster" (BinD) model develops a dynamic framework with the following key innovations; (a) incorporating and capturing emerging consequences of path-dependent stocks of foreign debt, private capital, and public capital, (b) incorporation of climate impacts on the economy on both capital stock an indirectly on labor through wage channels, and (c), discussion of the potential trade-offs of allocation of limited financial resources that are evaluated through the interaction effects of fiscal, private, and foreign savings.

Another key innovation of the model is the introduction of supply-side constraints into a demand-led model, a methodological and conceptual avenue that receives increasing attention in the climate macroeconomic literature, but is still relatively unexplored. In summary, the output is driven by aggregate demand. However, since we assume that access to financial markets in LMICs is limited, and they have only limited unemployed resources, output can also be constrained by the supply side due to insufficient capital stock build up to meet the expected demand. Additionally climate change can lower private and public saving rates, that are necessary for capital formation. Therefore, hitting supply-side capacity constraints can put countries on a

in 2019), and overall exports and imports (0.48 and 0.35 in 2019) (WITS, 2020).

low-growth equilibrium that can further worsen the macroeconomic and distributional impacts.

The model evaluates a country's growth paths under different climate futures. Recent climate literature has shown that 2C, 3C, or 4C degrees of average temperature increases over the baseline by the end of the century results in very different growth pathways (Rezai et al., 2018; Omer and Capaldo, 2022; Gourdel et al., 2022; Omer and Capaldo, 2023). Higher temperatures are likely to cause higher capital stock depreciation, and thus even without climate shocks, the investment costs to maintain and build up capital stock increases, adding additional financial pressure. Therefore, different "baselines" are required to analyze the transmission channels of climate impacts and policy responses to incorporate different climate futures as is now standard in climate literature.

Figure 3.1: Interactions in the BinD model

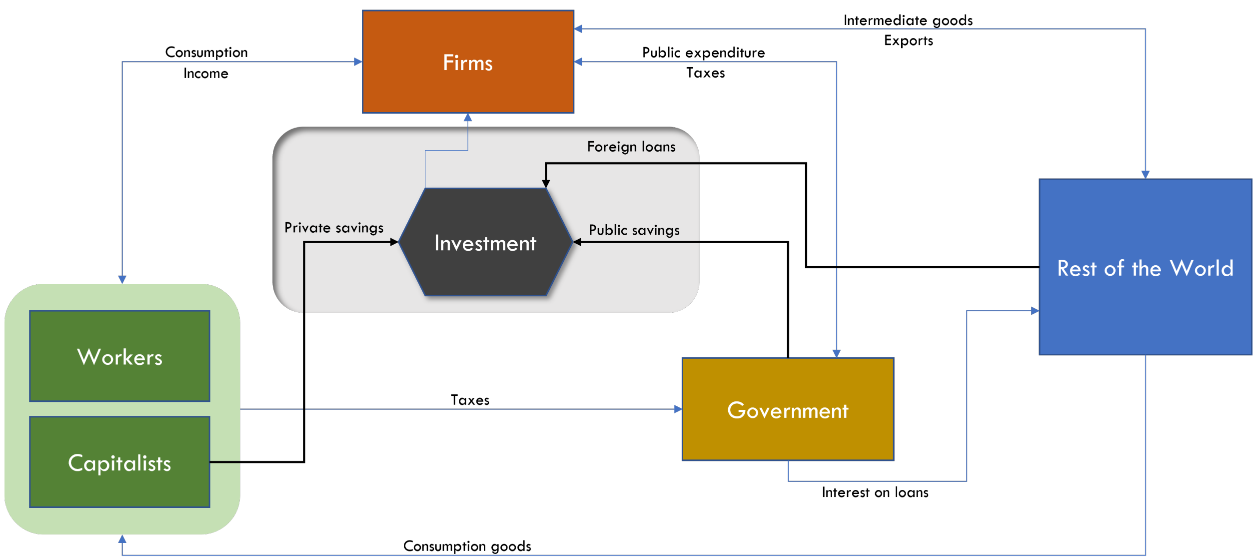


Figure 3.1 summarizes the framework of the model that comprises of four sectors; Firms, Households, Government, and the Rest of the World (RoW). The private firm sector produces consumption and capital goods that have both domestic and foreign demand. To produce the goods, the firm sector requires labor, and capital. For maintaining and building up the necessary productive capital stock, the firm sector must conduct investments. It can produce a certain fraction of capital stock, whereas the rest has to be imported. Since LMICs typically have a narrowly developed domestic banking sector and limited access to international financial markets, private investments must rely on domestic private and public savings, as well as foreign capital inflows financed through loans that add to the debt burden.

In order to assess the distributional aspects, the model introduces two types of households; workers and capitalists. Worker households receive labor income which is fully split into taxes and consumption. Capitalist households own the firm sector and receive profit income, net of interest payments on loans. Capitalist households pay taxes, consume a certain share, and save the rest, that partially finances the domestic investment requirements.

The government collects domestic taxes, which is used for funding general government consumption and public investment, that we assume necessary for crowding in private investments. Both the firm and the government sector have to pay interest on the foreign loans they receive. Rising temperatures driven by climate change impact capital stock that continuously requires increased investment to maintain it at precrisis levels. This requires more capital imports that need to be financed through higher foreign financial flows, for example, loans or grants), or higher domestic savings, for example through higher taxes. Both options have the potential to reduce aggregate demand which can have non-trivial repercussions on the economy. Therefore, this model aims to evaluate the balance between demand and supply constraints, and subsequent fiscal impacts that the BinD model aims to evaluate.

3.1 Macro balances

The demand for output Y^d is determined as:

$$Y_t^d = C_t + I_t + G_t + X_t \tag{1}$$

where C_t is total household consumption, I_t is total domestic investment, G_t is public spending, and X_t is total exports, or demand from the rest of the world.

The demand is fulfilled by the domestic firm sector, that aims to have a supply-side production capacity, Y_t^s determine by two inputs; Labor L_t and Capital K_t:

$$Y_t^s = f(K_t, L_t) \tag{2}$$

Servicing demand implies that $Y_t^s \geq Y_t^d$, a key constraint in the BinD model.

In our small open-economy setting, we assume that labor is available in abundance, but the country faces strong capital constraints. More precisely, domestically-produced capital stock, K_t^D is not sufficient to meet demand, and therefore the remaining, or foreign capital K_t^F, has to be imported. For simplicity, we assume that domestic and foreign capital stocks are complementary and homogeneous with the same level of productivity. Therefore, the total capital stock in the economy equals $K_t = K_t^D + K_t^F$.

Capital stock productivity is defined by the output-to-capital ratio ϵ_K from which the maximum supply-side output can be derived as $Y_t^s = \epsilon_K K_t$, our *binding* constraint. From this, we derive the total output of the economy as:

$$\begin{aligned} Y_t &= Min\left[Y_t^d, Y_t^s\right] & (3) \\ &= Min\left[C_t + I_t + G_t + X_t, \epsilon_K K_t\right] & (4) \end{aligned}$$

We assume that demand is fully met in normal times if $Y_t^d \leq Y_t^s$, but output constraints, driven by climate change or other factors, can push production capacity to below demand levels if $Y_t^d > Y_t^s$. The is a deviation from standard macro models that assume that in the very long run the demand-side adapts to supply-side levels through price and wage adjustments. In contrast, we assume that due to limited financing options, and due to stickiness in the adjustment of capital stock, demand imbalances are created that can result in supply-side constraints.

3.2 Firms

Economic growth requires upkeep and investment in capital stock. Target investment level of the firm sector, I_t is assumed to take the following functional form:

$$I_t = \left(\alpha_0 + \alpha_1(1 - w_t)\frac{Y_t}{\epsilon_K K_t} + \alpha_2 \frac{Y_t}{\epsilon_K K_t}\right)\epsilon_K K_t \tag{5}$$

Here we assume that investment grows at an autonomous rate α_0, representing "animal spirits", and proportional to the profit share $(1 - w_t)$ and to the capacity utilization ratio $Y_t/\epsilon_K K_t$. In equation 5, $\alpha_1 > 0$ and $\alpha_2 > 0$ define the sensitivity of response of macro variables, profits and output, respectively on investment levels.

Investment is further split between domestic and foreign capital stocks such that $I_t = I_t^D + I_t^F$:

$$I_t^D = \frac{\theta\chi}{1 + \theta(\chi - 1)} I_t \tag{6}$$

$$I_t^F = \left(I_t - I_t^D\right)\chi \tag{7}$$

where θ is the exogenous baseline share of domestic capital in total capital stock and χ is the exchange rate.[2] The foreign capital stock investment, I_t^F, is derived as a residual.

The rate of change of the two capital stocks is defined as:

$$\frac{\dot{K_t^D}}{K_t^d} = \frac{I_t^D}{K_t^D} - \delta_0 - \delta_1 Temp_t \tag{8}$$

$$\frac{\dot{K_t^F}}{K_t^f} = \frac{I_t^F}{K_t^F} - \delta_0 - \delta_1 Temp_t$$

where δ_0 is the depreciation rate, and $\delta_1 Temp_t$ is the climate damage caused by rising temperatures, described in detail in Section 3.3.

Rate of change of loans equal investment in domestic and foreign capital, public investment less total domestic savings S_t:

$$\dot{L}_t = I_t^D + I_t^F + I_t^G - S_t \tag{9}$$

Equation 9 implies that a rise in investment demand, or a decline in domestic savings, increases the total debt burden.

[2] In this version of the model, we assume the exchange rate to be exogenously defined to avoid considerably expanding the simulation scenarios and their transmission channels. Potential policy extensions are discussed in the conclusions section.

The economy also has labor productivity growth (τ) which is represented as a "technical progress function" and is proportional to output growth a'la Kaldor (1957). It shows that faster output growth result in increasing returns to scale with decreasing cost and leads to use of more advanced technologies. Growth of labor productivity is formalized as:

$$\frac{\dot{\tau}_t}{\tau_t} = \lambda_0 + \lambda_1 \frac{\dot{Y}_t}{Y_t} \tag{10}$$

where λ_0 is the autonomous productivity growth and λ_1 represents the capital deepening effect driven by output growth.

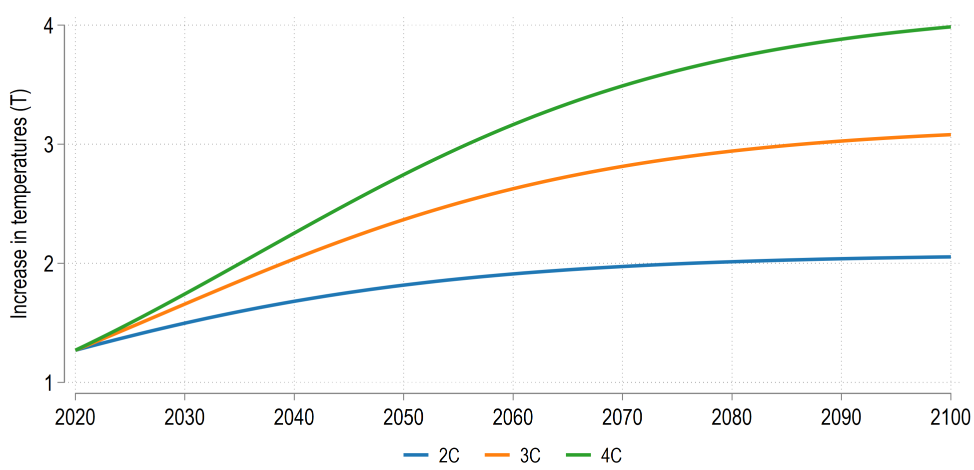
3.3 Climate damages

In the BinD model, an exogenous atmospheric temperature growth equation, $\dot{Temp}_t$, represents the changes in global temperatures using the following functional form:

$$\frac{\dot{Temp}_t}{Temp_t} = a_1 \left(1 - \frac{Temp_t}{\boldsymbol{T}}\right) - a_2(1 - e^{-\iota}) \tag{11}$$

where a_1, a_2, and $e^{-\iota}$ are shape parameters that show the rate of increase in emissions determined by different climate futures $\boldsymbol{T}$. The target $\boldsymbol{T}$ is set to 2C, 3C, and 4C warming by the end of the century, where the increase in temperatures is plotted in Figure 3.2.

Figure 3.2: Increase in temperatures ($Temp_t$) by 2100



The growth rate of exogenous temperature, $Temp_t$ feeds back on the economy through two channels. First, it causes a decline in real wages (Eq. 16) lowering demand, and second, it results in higher capital stock depreciation (Eq. 9) increasing investment requirements.

Climate damages (Ω_t) are introduced as additional capital stock depreciation rate δ_1 driven by temperature increases and the stock of capital:

$$\dot{\Omega}_t = \delta_1 K_t Temp_t \tag{12}$$

3.4 Households

Total income of the economy, or the GDP, equals total output less imports, or:

$$GDP_t = Y_t - M_t \tag{13}$$

This income is fully split into the wage and profit shares that are transferred to worker (W) and capitalist (K) classes respectively. We make a simplifying assumption that the workers fully consume their total income net of taxes, which equals total employment times the wage rate. Hence, their saving rates are zero. In contrast, capitalists consume a fraction of their income:

$$\begin{aligned} C_t^W &= GDP_t(1-\tau_W)w_t \\ C_t^K &= GDP_t(1-\tau_K)(1-w_t)(1-\sigma_1) - \sigma_0 - \rho i_L L_t \end{aligned} \tag{14}$$

where τ_W and τ_K are the tax rates on worker and capitalists households respectively, σ_0 is autonomous consumption, σ_1 is the marginal propensity to consume out of income. The last term in capitalists' consumption is the private sector's share ρ on the interest payment on loans $i_L L_t$. Total household consumption, therefore, equals $C_t = C_t^W + C_t^K$.

When the economy is not labor-supply constrained, labor productivity and wage rate growth have important impacts on the macroeconomic dynamics. Real wage growth is assumed to be determined by productivity growth, climate change effect, and output effect:

$$\frac{\dot{\omega}_t}{\omega_t} = \lambda_0 + \lambda_1 \frac{\dot{Y}_t}{Y_t} + \lambda_2 \left(\frac{GDP_t}{K_t} - \boldsymbol{u} \right) - \lambda_3 (Temp_t - 1.27) \tag{15}$$

where $\boldsymbol{u}$ is the long-term capital utilization rate, usually in the range of 0.3, and 1.27 is the average global temperature increase since 1880 (IPCC, 2023; CCKP, 2023). The first two terms, $\lambda_0 + \lambda_1(\dot{Y}_t/Y_t)$, is the productivity growth, while the third term, $\lambda_2((GDP_t/K_t) - \boldsymbol{u})$ represents the output effect. If the current output-capital ratio (capital utilization rate) increases above its long-term average, it creates a positive impact on real wages through the labor markets where tighter labor market leads to higher real wages. Finally, the last term signifies the cost of climate change to real wage growth. If atmospheric temperature increases above its historic atmospheric temperature, it creates downward pressure on real wages. As a result, the combined impact of output and climate change determines the difference between the growth rates of labor productivity and real wages, which in turn, determines the distributional dynamics in the economy. The wage share (w_t) growth is pegged to growth rates of real wage (ω_t) and productivity (τ_t):

$$\frac{\dot{w}_t}{w_t} = \frac{\dot{\omega}_t}{\omega_t} - \frac{\dot{\tau}_t}{\tau_t} \tag{16}$$

3.5 Government

The public sector's consumption G_t is defined as:

$$G_t = g_0 + g_1 GDP_t + CF_t - (1-\rho) i_L L_t \tag{17}$$

where g_0 is autonomous spending and g_1 is the pro-cyclical spending of the government. The government also contributes to the Climate Fund CF_t, a potential policy instrument to to help recover the capital stock losses at a rate r_Ω of total damages:

$$CF_t = r_\Omega \Omega_t \tag{18}$$

The CF_t is set to zero in the baseline and introduced in policy scenarios. The last term in equation 17 represents the government's share $(1-\rho)$ of interest payments on loans $i_L L_t$.

And finally, public investment is also assumed to be pro-cyclical and proportional to the capital stock buildup:

$$I_t^G = i_G K_t \tag{19}$$

3.6 Rest of the world

The economy interacts with the rest of the world through three channels, exchange rates, exports, and imports.

The real exchange rate channel is an exogenously-determined policy instrument:

$$\frac{\dot{\chi}}{\chi} = r_\chi \left(1 - \frac{\chi}{2}\right) \tag{20}$$

where r_χ is the rate of change of the exchange rate.

Total exports (X_t) are affected positively by the real exchange rate (χ) depreciation and set proportional to the capital stock as:

$$X_t = \chi \lambda_X K_t \tag{21}$$

Total imports are proportional to domestic income and are negatively impacted by real exchange rate depreciation:

$$M_t = \frac{\lambda_M GDP_t}{\chi} \tag{22}$$

Overall, in order to represent the dynamics of the model as discussed above, levels of injections such as government spending, investments, and exports are scaled to capital stocks so that the system can grow.

Leakages such as taxes and imports are scaled to the level of output (Taylor et al., 2015).

3.7 Gaps in savings

Investment is domestically financed by private, public savings, and potential saving gaps by loans from abroad. These gaps represent imbalances in the economy that are tracked as follows:

The net private savings (S_t^P) after investments, or the private saving gap, is derived as:

$$S_t^P = \sigma_0 + \sigma_1(1 - w_t)(1 - \tau_K)GDP_t - I_t^D \tag{23}$$

The foreign savings (S_t^F) gap, or current account balance, equals:

$$S_t^F = I_t^F + M_t + i_L L_t - X_t \tag{24}$$

where I_t^F is foreign investment, M_t is the imports, X_t is the exports, and $i_L L_t$ are interest payments on loans to the rest of the world.

Public savings gap (S_t^G), or fiscal balance equal:

$$S_t^G = \tau_H GDP_t - G_t - I_t^G \tag{25}$$

where $\tau_H GDP_t$ is the total household tax share, and G_t and I_t^G are the government spending and government investment respectively.

From the above equations, the total fiscal gap S_t, or net savings in the economy, can be derived as:

$$S_t = S_t^P + S_t^G - S_t^F \tag{26}$$

4 Application to Fiji

This section describes the macro-financial context of Fiji, an upper middle-income island in the Pacific. It then proceeds with the description of the different climate and climate policy scenarios, that are designed to assess their potential impacts on Fiji's economy.

Fiji is a small island nation in the South Pacific, which heavily depends on imports (imports of goods and services stood at 55% of GDP in 2021), particularly for food, fuel, and capital goods (WITS, 2020). Exports made up 27% of GDP in 2021, where Fiji is heavily reliant on tourism, which alongside remittances, is a major contributor to the country's foreign exchange earnings. Following the pandemic recovery, the current account deficit narrowed down to 15.2% of GDP by end of 2022, while still facing a significant gap (World Bank, 2023).

In recent years, Fiji has struggled with high levels of government debt and fiscal imbalances. The country's debt-to-GDP ratio has been steadily increasing over the past decade, reaching 93% of GDP in 2021, up from 45% in 2010 (World Bank, 2023). The fiscal deficit stood at 11.7% in 2021, while government expenditures was 37.5% of GDP during the same period (World Bank, 2023). The financial sector in Fiji is still relatively underdeveloped, with the IMF's Financial Development Index standing at 0.22 in 2021 (IMF, 2023).

As a small island developing state, Fiji is highly vulnerable to climate change, especially extreme weather events. Climate shocks have already strongly affected Fiji in the past; for instance cyclone Winston in 2016, the most severe storm ever documented in the Southern Hemisphere, had a profound impact on Fiji, affecting 62% of its population and resulting in Fijian $2 billion worth of damage, equivalent to 20% of the country's GDP (World Bank, 2017). Furthermore, sea level rise, changes in rainfall patterns, and the frequency and severity of extreme events such as cyclones and floods are expected to increase in Fiji that will likely puts the economy under further stress (World Bank, 2023). To address those impacts, the Fijian government has taken steps through the development of a National Adaptation Plan (Fiji, 2018) aiming to better use existing and mobilizes new resources for strengthening the country's resilience.

4.1 Policy scenarios

The focus of this analysis is to assess macroeconomic and macro-financial impacts of climate change for Fiji till the end of the century. We use three baselines assuming 2C, 3C, and 4C global average temperature increases by 2100. Climate temperature trajectories and impacts are taken as exogenous in the model, reflecting Fiji's very small contribution to global climate change.

Table 4.1: Model scenarios

Scenario	**Description**
Baseline	Only climate impact is assessed - no climate fund
CF+DebtFin	A CF to finance 10% of climate change (Ω) damages - Financed by issuing additional external sovereign debt.
CF+FlatTax	A CF to finance 10% of climate change (Ω) damages - Partially financed by a 50% increase in taxes for capital owners and workers.
CF+ProgTax	A CF to finance 10% of climate change (Ω) damages - Partially financed by a 50% increase in for capital owners.
CF+Grant	A CF to finance 10% of climate change (Ω) damages - CF is funded by unconditional grants from the rest of the world

In all the policy scenarios, the government is expected to set up a climate fund (CF) that would allow quick access to finance to repair climate damages to capital stock (Eq. 12). The CF is a commonly discussed policy response, especially in smaller economies, which allows access to domestic finance to fund the recovery investment needs after a disaster hits (Toro et al., 2023). We assume the size of the CF to be around 10% of the damages to capital stock evaluated for the three climate futures.

We assess the impact of four CF financing strategies summarized in Table 4.1. Under the *CF+DebtFin* scenario, the CF is funded by the government issuing additional external debt. In this scenario we currently do not assume any fiscal breaks or lending constraints that might limit the ability to borrow. Under the *CF+FlatTax* scenario the tax rates are increased by 50% for all households, capital owners and workers. This also poses an additional burden for worker households, which are assumed to be impacted more by climate change as compared to capitalist households. Under the *CF+ProgTax* scenario, the government increases the tax rates for capital owners by 50% to partially finance the CF, whereas the remainder is still financed by issuing additional external debt. Finally, under the *CF+Grants* scenario, the CF is funded by unconditional grants from the 'benevolent' international community, similar to a Loss and Damage compensation.

5 Results

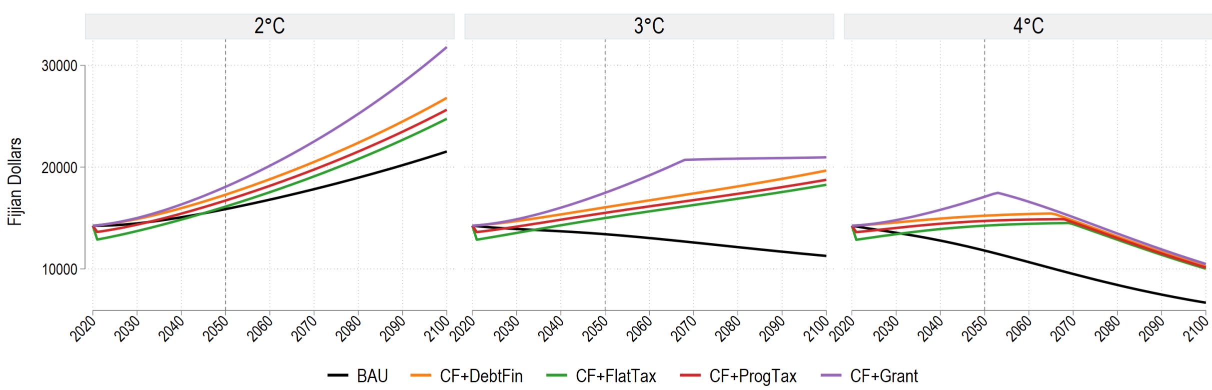
The modeling results for climate damages and a climate fund in Fiji are assessed for the three different climate futures (2C, 3C and 4C) until 2100, together with the four funding scenarios for the CF described in Table 4.1.

The 2C warming scenario shows the least climate-related damages among all the three climate futures, with damages leveling off towards the end of the century. However, in a 3C world, damages keep rising almost linearly, with the baseline scenario showing the highest damage due to a strong decline in GDP and high capital stock losses. In contrast, the 4C scenario shows exponentially rising damages.

5.1 Macroeconomic impacts

Since the CF has to be funded using the different policy instruments, there is relatively little variation in output across the different policy scenarios (Fig. 5.1), but the underlying adjustment mechanisms vary considerably.

Figure 5.1: Output (Y_t)

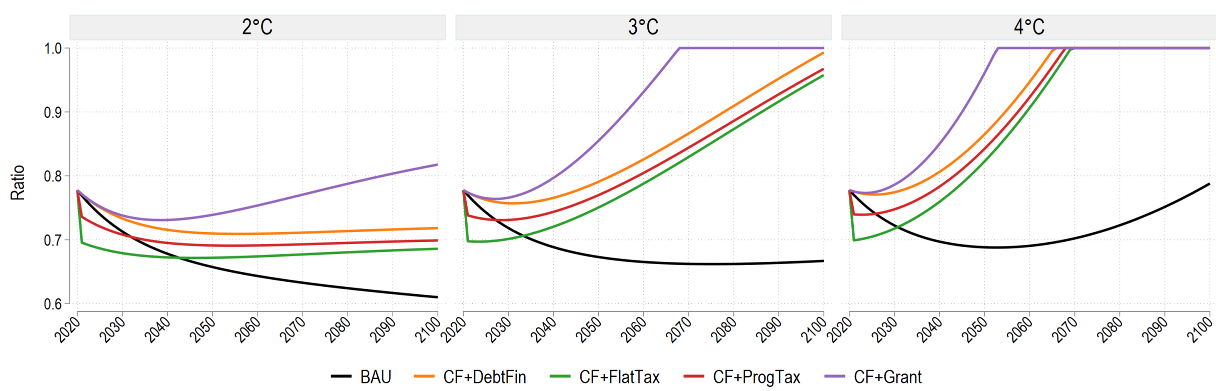


We explain each warming scenario in detail below:

2C scenario: In a 2C scenario, Fiji's economy would still be able to grow until the end of the century, however, continuously occurring climate damages result in a lower growth rates (approximately 5%) than historically observed (6.7% between 1960 and 2022) (Fig. 5.1). However, substantial differences can be observed. The tax policy scenarios (*CF+FlatTax*, *CF+ProgTax*) induce initial repercussions as household spending is curtailed as taxes are raised to fill up the CF. Yet, how taxes are raised also matters. In the progressive tax scenario (*CF+ProgTax*), the benefits of having a climate fund for cheap and quick access to recovery finance pay off eventually, allowing the economy to run on a higher GDP growth path towards the end of the century, close to the historic average. Differently so in the regressive tax scenario (*CF+FlatTax*), where the economy is able to almost catch up with (*CF+ProgTax*) levels of GDP until the end of the century, as worker consumption, an important driver of aggregated demand, is curtailed. The initially lower GDP, makes this scenario overall least favorable in a 2C world.[3] For the scenario, where the climate fund is filled by the government issuing additional debt (*CF+DebtFin*), the economy can avoid the initial repercussions, and ensures a higher growth path than in the baseline and tax-based scenarios. This is true despite higher interest payments that the economy faces (Fig. 5.4c) due to piling deficit, which might not favorable given restrictions set by fiscal rules.[4] Unsurprisingly, the scenario where the fund is financed by external grant money (*CF+Grants*) performs best in a 2C world, allowing the economy to come closer to its original economic growth trajectory.

3C scenario: A 3C world already implies much heavier damages from recurring hurricanes and sea level rise for a small island economy such as Fiji (Fig. 5.1). As a consequence, the economy shrinks until the end of the century in the 3C baseline scenario, compared to the 2020 GDP levels. The policy scenarios allow the economy to slightly grow beyond 2020 GDP levels as the climate fund is able to quickly step in and finance recovery investment after disasters hit. However, even the policy scenarios will face a lower growth path compared to a 2C baseline till the end of the century. Different from the 2C scenario, the regressive tax scenario (*CF+FlatTax*) is beneficial over the 3C baseline scenario when considering the entire century GDP trajectory. Initial negative GDP impacts are lower in the progressive tax scenario (*CF+ProgTax*), strongly out competing the 3C baseline scenario. As in the 2C scenario, a debt-financed climate fund is able to avoid those initial repercussions and performs better than the tax financed scenarios. While the grant-financed climate disaster (*CF+Grants*) fund scenario allows the economy to grow in the beginning of the century, the climate damages to capital stock eventually restrict the economy's ability to replace destroyed capital quick enough, which makes the economy hitting its capacity constraint (Fig. 5.2), despite having sufficient financing at hand. As a consequence, the economy stops growing after around 2070 in the model run.

Figure 5.2: Demand-to-Capacity ratio



4C scenario: Under a 4C scenario, the economy is going to collapse under each policy scenario (Fig. 5.1). In the 4C baseline scenario the economy shrinks strongly, reducing to only half of its size in 2100 due to

[3] It should be noted that from a policymaker perspective, it is uncertain at the time of the introduction of the policy in which temperature path the world will end up by the end of the century. For instance, all policy scenarios, including *CF+FlatTax*, are favorable in a 3C and 4C scenario over the baseline scenario.

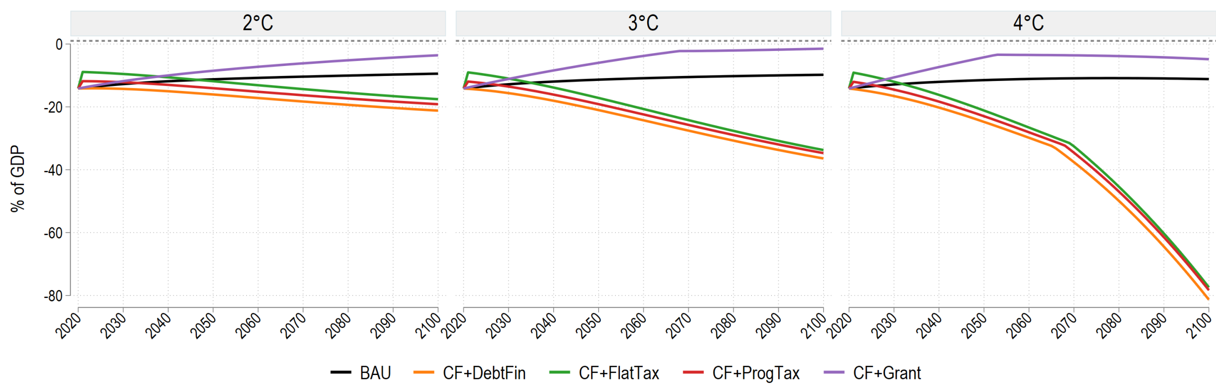
[4] It should be noted that we assume constant interest rates over the course of the model run that are not dependent on debt levels or the probability of debt default under a weaker economy and higher climate damages.

increasing climate damages. While the policy scenarios initially allow the economy to cushion against the negative growth impacts, the damages become eventually too large and the economy hits capacity limits becoming supply-side constrained (Fig. 5.2). The capacity constraints are reached earlier in the grant-financed (*CF+Grants*) scenario due to its strong initial boost to growth before declining. In contrast, the tax- and debt-financed CF scenarios manage to maintain a low growth path in the first half of the century, before also eventually hitting capacity constraints.

5.2 Overall balances

Fiji is a net borrower in 2020 and remains so in the model simulations driven by a large government deficit; yet with considerable differences across the scenarios (Fig. 5.3). While the results follow similar qualitative patterns, net borrowing needs under the policy scenarios (except *CF+Grants*) are much higher under the 3C and 4C.

Figure 5.3: Net savings-to-GDP ratio



Under the *CF+Grants* and baseline scenarios across all temperature trajectories, the net domestic savings deficit narrows, indicating that Fiji's borrowing from the rest of the world decreases compared to the two tax scenarios and the *CF+DebtFin* scenario. For the baseline, this can be explained by the limited impulse for recovery investments due to constrained demand and lack of affordable finance. Rebuilding capital stock requires foreign capital imports, which weigh negatively on net foreign savings. Likewise, the government spending declines overall, that narrows the government deficit and results in higher net savings. However, this comes at the cost for lower economic activity and output. For the *CF+Grants* scenario the grants provided by the rest of the world eliminate further increases in the fiscal deficit, while ability to more quickly and cheaply recover from climate impacts leads to faster economic growth. This results in increased tax revenues and higher government savings that stabilize at a higher level. Although government investments also grow, they do so at a slower rate, causing the $(S_t - I_t)$ gap in the government sector to close. Only, when supply-side constraints are reached, the increase in net savings comes to a halt.

In the *CF+DebtFin* scenario, increased climate damage repair spending is funded by the government budget by issuing sovereign debt, leading to a reduction in overall savings. The government's savings decline faster than in any other scenario, while government investments continue to grow, resulting in a larger saving minus investment gap in the public sector $(S_t^G - I_t^G)$. The government deficit is slightly narrower, when partially funding the climate fund by raising taxes. A more progressive tax scheme thereby is more economically stimulating than a regressive tax scheme. Given the higher accompanying foreign capital import needs to meet the higher economic demand, overall net savings are less negative than in the progressive tax scenario. Although the private sector continues to be a net lender, it is insufficient to improve Fiji's external position.

Our simulation results demonstrate that Fiji needs to increase its borrowing from the rest of the world (RoW) to recover from potential climate impacts and maintain average economic activities. However, this task is challenging, particularly if RoW does not fund climate damage spending or recovery without any cost to Fiji. Our simulations indicate that even under the best-case climate scenario (2C), tax policies can only offer temporary relief as the costs of climate change and maintaining growth continue to rise. While debt financing may seem like an attractive option, the increasing debt will eventually become a significant burden and might not be possible due to fiscal constraints that put a break of lending.[5].

5.3 External balances

Figure 5.4 shows the impact of climate change on external balances. Figure 5.4a shows that the current account-to-GDP ratio in the the 2C baseline falls slightly before recovering. But this comes at a cost of reduced growth that slightly improves the current account deficit. In 2C scenario, the different policies shows a decline in the ratio as the country imports more capital stock to finance its domestic production process. In the 3C and 4C scenarios the current account continues to worsen falling sharply, except in the case of unconditional grants, where the economy hits the supply constraints that also stabilize the ratio.

The trade balance (Fig. 5.4b), or net exports-to-GDP ratio, does not include foreign investments or imported capital, and thus can be affected by changes in exports and imports. Exports, which are proportional to total capital stock, can slow down due to climate damage on capital stock as temperatures rise, leading to worsening of the trade balance. However, since imports are more sensitive to changes in GDP, they decline faster with lower economic activity. Therefore the trade balance is positive under the baseline scenario. Under the other climate policy scenarios, such as increased climate damage spending funded by progressive taxation, the current account balance is affected by changes in government spending, private savings, and net borrowing.

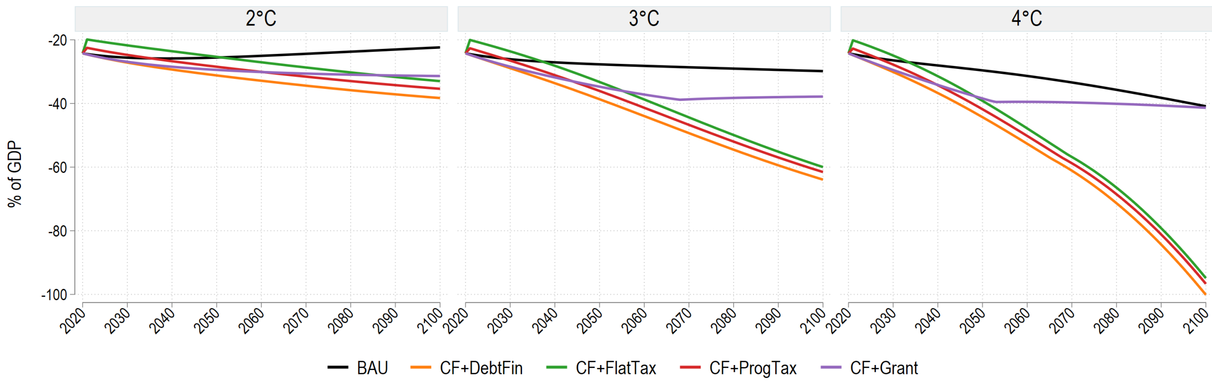
Interest payments for external private and public debt increase substantially under the different climate policy scenarios, reaching highly non-sustainable levels in the 4C temperature trajectory (Fig. 5.4c). Interest payments are higher under the *CF+Debtfin* scenario, as the additional tax revenue in two tax scenarios lowers amount of external debt funding. For the baseline scenario, interest payments-to-GDP ratio (Fig. 5.4c) increase initially, reaching similar ratios around 18% percent or lower under all temperature trajectories. The initial increase is driven by financing requirements for recovery investment, which however, become smaller over time, given the overall lack of demand and output decline. For the *CF+Grants* scenario, interest payments-to-GDP are the lowest across all scenarios, with foreign grants replacing the need to issue external debt for financing the recovery.

5.4 Distributional impacts

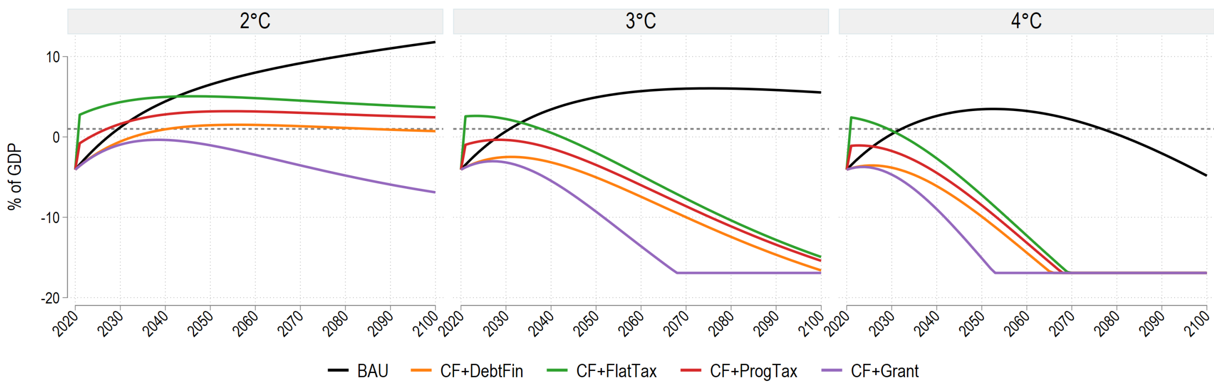
The determination of real wages depends on several factors such as productivity growth, the negative impact of climate change, and the positive impact of increased economic activity. Higher economic growth thus

[5] For example, for Fiji, a 40% debt-to-GDP ratio is taken as an upper limit for borrowing (Nakatani, 2021)

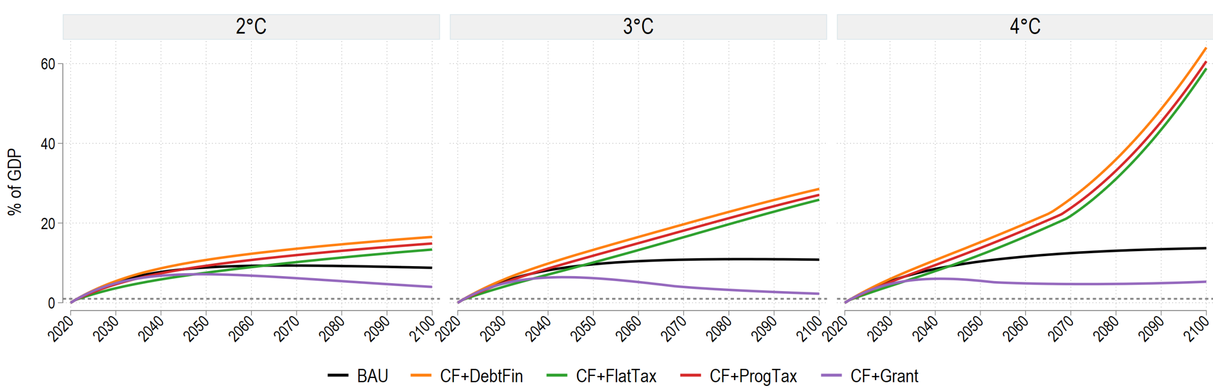
Figure 5.4: External balances



(a) Current account-to-GDP ratio



(b) Net exports-to-GDP ratio



(c) Interest payment-to-GDP ratio

leads to stronger wage growth, as lower unemployment leads to more bargaining power for the workers. Conversely, higher temperature trajectories depress wage growth, directly via a reduction in labor productivity and indirectly via lower economic growth. Hence, climate change and corresponding policy scenarios have implications for wage growth and therefore distributional dynamics, with implications for poverty reduction, inequality, and economic trajectories. To assess the impacts of climate change and different climate policies on income inequality under different scenarios, the Palma Ratio is calculated to show the ratio of capitalists' disposable income per capita to workers' disposable income per capita (Omer and Capaldo, 2022).

We assume that the workers do not save (spend all their income after taxes) therefore their disposable income is goes fully towards consumption or $Disp^W = C^W$.

In contrast, capitalist savings S^K equal:

$$S_t^K = \sigma_0 + \sigma_1(1 - w_t)(1 - \tau_K)GDP_t \tag{27}$$

where σ_1 is the saving rate of capitalists and proportional to profits after tax, $(1 - w_t)(1 - \tau_K)GDP_t$.

Capitalists' disposable income, therefore equals:

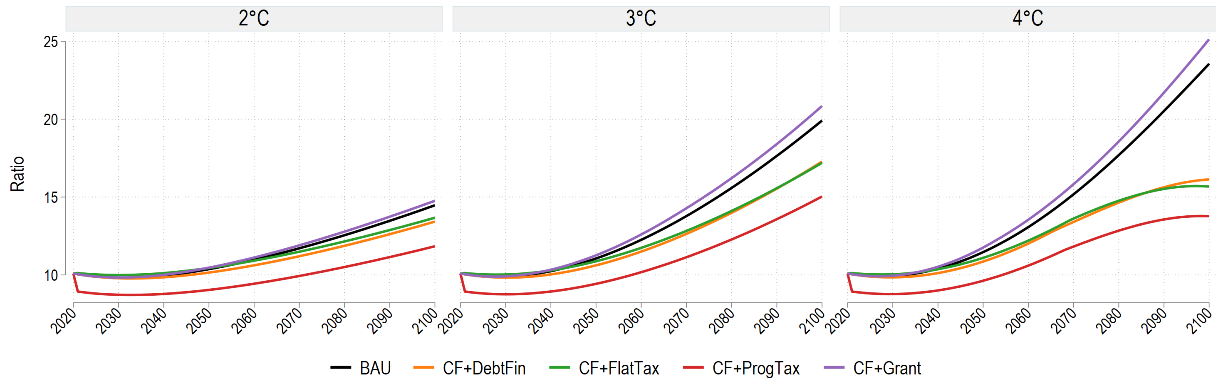
$$Disp_t^K = C_t^K + S_t^K \tag{28}$$

Based on this income disaggregation, we can calculate the Palma Ratio (Palma, 2011; Taylor et al., 2015) as the ratio of average disposable income of capitalists to average disposable income of workers normalized by their respective populations:

$$Palma_t = \frac{Disp_t^K / Pop^K}{Disp_t^W / Pop^W} \tag{29}$$

Our simulations show that stronger and negative climate impact leads to higher income inequality, as shown by the higher Palma Ratio, across all scenarios as they cause a slowdown in output growth, reducing the bargaining power of workers, and hence a reduction in the real wages (Fig. 5.5). Moreover, employment also declines due to lower economic activity. As a result, the wage share goes down (profit share goes up), dragging down the workers' disposable income relative to capitalists' disposable income. Additionally, according to our simulation results, the best distribution scenario is *CF+ProgTax*, where the Palma ratio declines slightly due to progressive taxation, and stabilizes at a lower level compared to other cases. The *CF+Grants* scenario shows patterns of highest income inequality (highest Palma Ratio). The economy grows faster than in the other cases, leading to higher real wages and employment. However, since the CF is financed by the rest of the world, capitalists do not pay extra interest on debt, resulting in a worsening income inequality as the positive impact of the interest payment relief on the capitalists' disposable income exceeds the positive output effect on workers' disposable income. The baseline scenario only performs slightly better (second highest Palma Ratio) as the weaker economic growth cuts into real wages more strongly than in the other scenarios. However, this negative output effect on workers disposable income turns out to be smaller than the net positive interest payment effect of the *CF+Grants* scenario. Finally, *CF+DebtFin* generates better distributional than the other two scenarios as capitalists' interest payments are higher in the debt financing scenario. This income effect for capitalists of additional interest payments stemming from larger debt increases outpaces the higher wage growth induced by stronger economic growth in the *CF+Grants* scenario, hence leading to lower income inequality.

Figure 5.5: Palma ratio



The different scenarios reveal distinct patterns of economic growth, exhibiting significant variations depending on the temperature trajectories considered. However, it is crucial to note that the drivers of these growth patterns differ across scenarios, which presents policymakers with valuable insights for decision-making and strategic planning. In the baseline scenario, the output experiences a decline attributed to a lack of demand resulting from reduced consumption and investment due to the escalating impacts of climate change. Domestic consumption and investment indicators illustrate this downward trend, reflecting the adverse effects of climate-related disruptions on economic activities.

Debt and tax-based policy scenarios, on the other hand, introduce investments financed through a CF that initially stimulates economic growth due to quicker recovery. However, over time, the costs associated with financing the climate fund, such as higher interest payments and lower external balance, start to dampen private and public consumption demand. This eventual decline in demand ultimately leads to a slowdown in economic growth, reducing savings and constraining the fiscal space even further.

The *CF+Grants* scenario exhibits more favorable fundamentals, including interest rates, external balance, and net savings. However, despite these advantages, the capital stock destruction resulting from climate change begins eventually to constrain supply. As a consequence, even with the sounder economic fundamentals, the growth potential becomes limited, emphasizing the urgent need for sustainable approaches to mitigate climate-related risks.

6 Conclusions

Low- and middle-income countries (LMICs) are disproportionately vulnerable to climate change impacts. At the same time, those countries are often financially and fiscally constrained due to a high reliance on capital imports, high debt levels, and low domestic saving rates. As climate change further increases the damages and risk profiles of LMICs, borrowing is likely to become even more expensive making it even more difficult for LMICs to invest in low-carbon, climate-resilient development.

In order simulate climate impacts on LMICs, and the subsequent financing requirements for investments, this paper introduces the "BinD" model, that analyzes the effectiveness of various climate response policies in fiscally-constrained LMICs. In the model, output is demand driven, but limited access to capital markets restrict output by constraining the supply side. We assess economic development of Fiji under three climate futures where temperatures rise to 2C, 3C, and 4C, by the end of the century.

Based on our simulations, the economic growth of Fiji comes to a halt under high temperature scenarios due to lack of demand and growing supply side constraints. This means that the temperature trajectory matters for achieving long-term growth, and it is crucial for the world to stay within the 2C limit to avoid the worst economic impacts of climate change. To mitigate some of these impacts, we test the implementation of a Climate Fund (CF) financed through four channels; debt financing, a flat tax, progressive taxation resulting in higher taxes on capitalists, and unconditional grants from rest of the world similar to a Loss and Damage framework. While the four scenarios show relatively similar recovery paths, climate change impacts and financing of such a fund has different socioeconomic implications that creates trade-offs for economic growth, distribution, external balances, and debt sustainability. Our simulations also suggest that Fiji will generally need to borrow more from the rest of the world to recover from potential climate impacts and sustain average economic activities. Even under the 2C scenario with tax financing, rising debt will become a real burden sooner or later. This highlights the urgent need for the world to grant access to affordable finance and loss and damage compensation to allow the most vulnerable countries to maintain a sustainable future. Our results indicate that climate change poses significant economic risks for LMICs, and the world needs to take action to limit global warming, provide financial support, and design policies that are both effective and equitable.

Lastly, the model can be extended in several directions, noting that one of the model advantages is its simplicity and application in a low data environment. Hence, additions should be suited to address specific research and policy questions. For instance, incorporating more dynamic exchange rates to facilitate currency adjustments could be considered. Additionally, it would be valuable to include the role of the informal sector, which is significant in LMICs and has implications for tax policies. Endogeneizing external factors like remittances, trade relationships, and foreign investment inflows could also provide a more detailed assessment of foreign capital dynamics. Furthermore, population dynamics, including emigration and skill set development, should be taken into consideration, when emphasizing climate impacts on migration dynamics. Lastly, exploring additional adaptation and resilience policies, such as disaster risk financing insurance schemes and disaster risk management strategies, would be beneficial.

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A Model calibration

Table A.1: Exogenous parameters

Parameter	Description (units)	Value
ϵ_K	Capital productivity	0.45
α_0	Autonomous investment	0.0394
α_1	Investment growth from profit share	0.0685
α_2	Investment growth from output	0.001
θ	Share of domestic capital	0.3
δ_0	Normal depreciation rate	0.02
a	Rate of increase in global temperature	0.05
λ_0	Autonomous productivity growth	0.1×0.99^t
λ_1	Productivity growth driven by changes in output	0.5
γ_2	Multiplier for capital utilization on wage growth	0.005
γ_3	Multiplier for climate damages on wage growth	0.005
$\mathbf{u}$	Historic capital utilization rate	0.3
τ_K	Capitalists' class tax rate (baseline)	0.2
τ_W	Workers' tax rate (baseline)	0.2
σ_0	Autonomous private saving	840
σ_1	Private saving driven by profit share and output	0.5
ρ	Loan repayment rate	0.4
Pop_W	Population workers (in thousands)	831.6
Pop_K	Population capitalists (in thousands)	92.4
i_L	Interest on loans	0.05
g_0	Autonomous government spending	1929.63
g_1	Govt. spending driven by output	0.14
i_g	Coefficient of govt. investment	0.0172
r_f	Share of climate fund for govt spending	0.1
λ_X	Share of exports	0.125
λ_M	Share of imports	0.497

Table A.2: Initial values

Variable	Description	Initial value
Y_0	Output	14946.45
GDP_0	Income	9499.66
X_0	Exports	5088.1
M_0	Imports	5447.1
S_0	Savings total	1079.15
S_0^F	Savings foreign	1246
S_0^G	Savings government	-129
S_0^P	Savings private	849.73
L_0	Initial loan amount	0
I_0	Total investment	1268.50
I_0^d	Domestic investment	380.55
I_0^f	Foreign investment	887.95
K_0^d	Domestic capital stock	12213.02
K_0^f	Foreign capital stock	28497.05
G_0	Government spending	2029.457
I_0^g	Intial public investment	698.6
w_0	Unit wage rate	9.97
τ_0	Productivity per employee	20.77
ω_0	Wage share	0.48
C_0^W	Consumption of workers	3647.74
C_0^K	Consumption of capitalists	3101.99
χ	Exchange rate	1
Ω_0	Climate damages	0
CF_0	Climate fund	0