Climate Change and Macroeconomic Outcomes in Low-Income Countries

Alessandro Cantelmo† Giovanni Melina†
International Monetary Fund International Monetary Fund
Chris Papageorgiou†
International Monetary Fund
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Abstract
Climate change poses a challenge on policymakers of low income countries (LICs) in achieving convergence with advanced economies subject to the constraint of limiting emissions. In addition, those countries are the most exposed to natural disasters and extreme weather events. Using a dynamic stochastic general equilibrium model of a LIC, we highlight the effects of weather shocks on economic growth and debt sustainability of such a country. We employ different Representative Concentration Pathways (RPCs) to generate projections of the cumulative effects of climate change on macroeconomic aggregates, in particular on per-capita GDP and public debt, up to the year 2100. Rising temperatures increase both the probability and the magnitude of weather shocks thus dampening economic growth and worsening the debt position of LICs. Fiscal policies aimed at coping with weather shocks, jointly with climate policies and public debt management bring growth and public debt projections to acceptable levels.

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†Research Department, International Monetary Fund, 700 19th Street N.W., Washington, D.C. 20431, United States. Email addresses: acantelmo@imf.org, gmelina@imf.org, cpapageorgiou@imf.org.
1 Introduction

One challenge that climate change poses on policymakers of low income countries (LICs) is to achieve convergence with advanced economies subject to the constraint of limiting emissions. This might entail higher costs and possibly dampen growth (see, e.g. Llavador et al., 2015). In addition, these countries are usually very exposed to natural disasters and extreme weather events that cause high economic as well as human losses. Moreover, there is a somewhat widespread agreement that the rise in temperature over the coming years (“global warming”) will likely make these events more frequent and more powerful (see, e.g., IPCC, 2014).

Growth policies in these countries are deeply linked to their fiscal sustainability. Small developing countries need to rely on foreign private investments as well as public debt to grow, and at the same time, they need to insure themselves against negative weather events (see, e.g. Marto et al., 2017). Global warming will likely increase the frequency and the magnitude of these events thus posing a threat to macroeconomic outcomes of developing countries and, ultimately, on their public debt sustainability.

We therefore assess: (i) the effects of global warming on the most important macroeconomic aggregates and on the sustainability of public debt in countries exposed to extreme weather events, for different projected paths of temperature; (ii) policies those countries might implement to achieve sustainable growth and resilience to extreme weather events. We follow IMF (2017) and (Marto et al., 2017) and use the Debt, Investment and Growth (DIG) model (Buffie et al., 2012) to study the long-run effects of climate change and draw policy implications on LICs. Indeed, the DIG model is a dynamic general equilibrium (DGE) model more suitable than existing Integrated Assessment Models (IAMs) as it accounts for several peculiar features of LICs. However, these contributions analyze such issues in a perfect foresight environment, in which either the weather shock that materializes is known to the agents (Marto et al., 2017) or the path of temperature affects TFP according to a deterministic process (IMF, 2017). Conversely, we analyze a stochastic environment, hence a dynamic stochastic general equilibrium (DSGE) model, in which both the probability and the magnitude of the weather shock will be increasing in temperature, thus also accounting for fat-tail risks. In this sense, our environment is closer to the notion that climate change implies a shift of the stochastic distribution and the one in which weather events are more frequent and more powerful, as predicted by the majority of scientists and empirical studies of climate change (see, e.g., IPCC, 2014). We solve the DSGE model using the solution method developed by Fernandez-Villaverde and Levintal (2016), who show that their methodology is superior to standard global and projection methods in solving DSGE models with rare disasters. In addition, while Marto et al. (2017) consider a specific natural disaster and evaluate policies after it has occurred, and then assess how lower the damages would have been with higher adaptation, we take a different angle and consider the cumulative effects of climate change in the long-run on per-capita GDP and public debt, and how fiscal and climate policies affects the distribution of these macroeconomic outcomes. We use projections of temperature up to the year 2100
and analyze debt sustainability and policy options over such a long horizon, under different Representative Concentration Pathways (RPCs) scenarios and show that the distributions of per-capita GDP and public debt to GDP are negatively affected by higher temperatures and weather shocks. Engaging in climate policies aimed at limiting or reducing emissions decreases the frequency and magnitudes of weather shocks thus alleviating debt distress of LICs and leaving more fiscal space which is crucial to implement growth friendly policies. In addition, fiscal policies such as investment in adaptation capital will help LICs mitigating the damages of weather shocks.

The remainder of the paper is organized as follows. Section 2 presents the DSGE model while Section 3 discusses its calibration. Results are presented in Section 4 and Section 5 concludes.

2 The model

We introduce a two-sector small open economy model featuring a traded and nontraded goods sectors along the lines of (Buffie et al., 2012). Sectors are disparately affected by a natural disaster while the government has alternative public financing instruments (domestic and external debt, grants, and consumption taxes) to implement growth policies and cope with natural disasters. There are five channels through which the economy is impacted by the natural disasters: (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.

2.1 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 $\nu_a$– 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 $\pi_j$ and $\nu_D$ being scaling factors).

In each sector $j$, a firm maximizes profits according to

$$\Phi_{j,t} = P_{j,t} \left( 1 - \frac{D_{j,t}}{(1 + \pi_j z^a t_{t-1})^{\nu_D}} \right) y_{j,t} - w_t l_{j,t} - r_j t_k_{j,t-1},$$  \hspace{1cm} (1)
where \( w \) is the economy-wide wage and \( r_j \) is the sectoral return on capital in sector \( j \).\(^1\) Sectoral output is defined as

\[
y_{j,t} = A_{j,t} z_{t-1}^{\psi_j} k_{j,t-1}^{\alpha_j} l_{j,t}^{-1} \alpha_j, \quad \text{for } j = n, x
\]

and public capital as

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

where \( \rho_z \) is a weight parameter and \( \xi \) 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

\[
\begin{align*}
(1 - D_{z_j}) &= \left(1 - \frac{D_{z_j}}{(1 + \rho_z z_t^z)^{\rho_z}}\right)^{\psi_j}, \quad (1 - D_{k_j}) &= \left(1 - \frac{D_{k_j}}{(1 + \rho_z z_t^z)^{\rho_z}}\right)^{\alpha_j}, \quad \text{and} \\
(1 - D_{A_j}) &= \left(1 - \frac{D_{A_j}}{(1 + \rho_z z_t^z)^{\rho_z}}\right)^{1 - \psi_j - \alpha_j},
\end{align*}
\]

The severity of the damages to public and private infrastructures is controlled by \( \varpi_z \) and \( \varpi_k \), respectively, such that the larger \( \varpi_z \) is, the greater public infrastructure was destroyed relative to private capital and TFP (with \( 1 - \varpi_z \psi_j - \varpi_k \alpha_j \geq 0 \)). 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 effect on the TFP because infrastructure takes some time to rebuild and workers may have spent cleaning roads or rebuilding their houses, so aggregate productivity is assumed to recover slowly.

Profit-maximizing firms demand capital and labor according to

\[
\begin{align*}
P_{j,t} \alpha_j \frac{y_{j,t}}{k_{j,t-1}} &= r_{j,t}, \\
P_{j,t} (1 - \alpha_j) \frac{y_{j,t}}{l_{j,t}} &= w_t,
\end{align*}
\]

for \( j = n, x \). Output elasticities with respect to total public capital can also be derived as

\[
P_{j,t} \psi_j \frac{y_{j,t}}{z_{t-1}} = R_t^z,
\]

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

\[
R_t^{zi} \left( \frac{z_{t-1}}{\rho_z z_{t-1}} \right)^{\frac{1}{\xi}}
\]

\(^1\)Labor is perfectly mobile hence the wage is the same across sectors while returns on private capital are sector-specific, except in the steady state.
\( R_t^{za} \left( \frac{\nu_a^{1-\xi_a}}{(1-p_s)z_{a,t-1}} \right)^{\frac{1}{\xi_a}} \), 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 \( a_j \) (\( j = k, z^i, z^a \)) 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 \( P_{z^i,t} = P_{mm,t} + a_{z^i} P_{n,t} \) and \( P_{z^a,t} = (1 + pr) P_{mm,t} + a_{z^a} P_{n,t} \), respectively.

2.2 Government

Government expenditures are directed to investments in standard and adaptation infrastructure \( z^i \) and \( z^a \), transfers to households \( \Upsilon \), 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 \( \delta_{z^i} P_{z^i} \) involved in the maintenance of the infrastructure, i.e. \( \mu = f \delta_{z^i} P_{z^i} \)).

As Dabla-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 equally bureaucratic and inefficient across the two 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. Public capital therefore evolves according to

\[
\begin{align*}
z^i_t &= (1 - \delta_{z^i}) z^i_{t-1} + (1 - D_s) s_t i_{z^i,t}, \\
z^a_t &= (1 - \delta_{z^a}) z^a_{t-1} + (1 - D_s) s_t i_{z^a,t}.
\end{align*}
\]

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 \( \delta_{z^i} > \delta_{z^a} \). Bevan and Adam (2016), 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.

\(^2\) Liquidity-constrained households do not have to pay fees for using public infrastructure.
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 \((r_{rd,t} = r_d)\), 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-Grohé 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

\[
r_{dc,t} = (1 + D_{r,t}) \left( r_f + \nu_g \eta_g \left( \frac{d_{t} + d_{c,t}}{y_t} - \frac{d_t}{y} \right) \right). \tag{9}
\]

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 \(s^*_t\) be government savings in 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 \(\Xi_t\) 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 \((1 - v)\Delta b_t = v\Delta d_{c,t}\). The government budget constraint is thus given by

\[
P_{z,i_{z,t}} + P_{z_{a,i_{z,a,t}}} + \Upsilon_t + r_{t-1} P_t b_{t-1} +
+r_{dc,t-1} d_{c,t-1} + \Delta s^*_t \leq P_t \Delta b_t + \Delta d_t + \Delta d_{c,t} + r^f s^*_t + \tau^c c_t + \mu z^e_{t-1} + \Xi_t. \tag{10}
\]

We can rewrite the budget constraint above in terms of the fiscal gap \((GAP)\) as

\[
GAP_t = P_t \Delta b_t + \Delta d_{c,t} + (\tau^c_t - \tau^0) P_t c_t - \Delta s^*_t, \tag{11}
\]

where \(GAP_t = EXP_t - REV_t\), i.e. given by the difference between total expenditures and revenues when the consumption tax is kept at its initial value \((\tau^0)\) and concessional debt and grants are exogenous, is covered by domestic and external commercial borrowing, VAT adjustments, and/or savings withdrawals, such that

\[
EXP_t = P_{z,i_{z,t}} + P_{z_{a,i_{z,a,t}}} + \Upsilon_t + r_{t-1} P_t b_{t-1} +
+r_{dc,t-1} d_{c,t-1} + (1 + r_d) d_{t-1} - d_t, \tag{12}
\]

\[
REV_t = r^f s^*_{t-1} + \tau^0 c_t + \mu z^e_{t-1} + \Xi_t. \tag{13}
\]

The fiscal rule for the consumption tax rate allows \(\tau^c\) to respond to both tax and debt deviations from their target, with \(\lambda_1\) 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 $\lambda_2$ controlling the response to deviations from the debt target

$$\tau^c_t = \bar{\tau}^c_{t-1} + \lambda_1 \left( (\tau^c_t)^{\text{target}} - \bar{\tau}^c_{t-1} \right) + \lambda_2 \frac{(P_{t-1}b_{t-1} + d_{c,t-1}) - (Pb + d_c)^{\text{target}}}{y_t}, \tag{14}$$

where the tax target $(\tau^c_t)^{\text{target}} = \tau^c_0 + \frac{\text{GAP}}{\tau^c/\alpha^c}$, ensuring debt sustainability in the long run.

### 2.3 Households

The economy features two types of households: Ricardian and liquidity-constrained (denoted by $r$ and $c$, 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

$$c^i_t = \frac{1}{\rho^i_t} \left( c^i_{x,t} \right)^{-\frac{1}{\epsilon - 1}} + \rho^i_m \left( c^i_{m,t} \right)^{-\frac{1}{\epsilon - 1}} + (1 - \rho_x - \rho_m)^{\frac{1}{\epsilon}} \left( c^i_{n,t} \right)^{-\frac{1}{\epsilon - 1}} \right]^{-\frac{1}{\epsilon - 1}} \quad \text{for} \quad i = r, c, \tag{15}$$

where $\rho_m$ and $\rho_x$ are weights and $\epsilon$ is the intratemporal elasticity of substitution between consumption goods. The associated consumer price index is given by

$$P_t = \left[ \rho_x P_{x,t}^{1-\epsilon} + \rho_m P_{m,t}^{1-\epsilon} + (1 - \rho_x - \rho_m) P_{n,t}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}. \tag{16}$$

Ricardian households face the intertemporal optimization problem

$$\max_{\tilde{\pi}} \sum_{t=0}^{\infty} \beta t \left( c^r_t \right)^{1-\frac{1}{\epsilon_c}} \frac{1}{1 - \frac{1}{\epsilon_c}}, \tag{17}$$

where $\beta$ is the discount factor and $\epsilon_c$ 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 $AC^r_{j,t} = \frac{\nu}{2} \left( i^r_{j,t} - \delta \right)^2 k_{j,t-1}^r$; pays levies on standard public infrastructure $\mu z^i$; saves through domestic bonds $b^c$; and buys foreign debt $b^*$, which carries a real interest rate $r^*$ as well as portfolio adjustment costs $\Theta_t r^* = \frac{\nu}{2} \left( b^* t - \bar{b}^* \right)^2$, where $\bar{b}^*$ is the steady-state value of external private debt. The government levies a value-added tax (VAT) $\tau^c$ on consumption, which affects both Ricardian and liquidity-constrained households.

The income side of the household’s budget constraint

$$\left( 1 + \tau^c_t \right) P_t c^r_t + \mu z^i_{t-1} + P_t b^r_t + \left( 1 + r^*_t - 1 \right) b^*_t \leq w^r_t c^r_t + r^*_{n,t} k^r_{n,t-1} + r^*_x k^r_{x,t-1} \tag{18}$$

$$\left( 1 + \tau^c_t \right) P_t b^r_{t-1} + b^r_t + \frac{1}{1 + a} (\Re_t + \Upsilon_t) + \Phi^r_t \leq w^r_t c^r_t + r^*_{n,t} k^r_{n,t-1} + r^*_x k^r_{x,t-1} \tag{18}$$
is composed of an employment wage $w$ on labor $l^r$ supplied to firms; interest rates $r_x$ and $r_n$ received from tradable and nontradable capital, respectively; interest $r$ received on domestic bonds; a fraction of remittances $R_t$ and government transfers $Y_t$ corresponding to the share of Ricardian households in the labor market; as well as profits $\Phi^r$ from owning domestic firms. The accumulation of private capital, which depreciates annually at rate $\delta_k$, is given by

$$k^r_{j,t} = (1 - \delta_k) k^r_{j,t-1} + i^r_{j,t} \quad \text{for } j = n, x.$$  

(19)

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

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

(20)

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

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

(21)

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

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

(22)

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 $\eta$ governs the level of integration the private sector has in international capital markets. 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, transfers allowance, and pay the same consumption taxes as the Ricardian households, i.e. their budget constraint reads as

$$(1 + \tau_t^c) P_t^{c,c_t} = w_t l_t^c + \frac{a}{1 + a} (R_t + Y_t).$$

(23)

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\[3\] The fraction of liquidity-constrained households in the economy is given by $a > 0$.

\[4\] A low $\eta$ depicts the case in which the country has an open capital account with the private sector easily borrowing from abroad.
2.4 Aggregation and market clearing conditions

Labor markets clear with labor demanded in the tradable and nontradable sectors supplied by both types of households, i.e. \( l_{xt} + l_{nt} = l_t^r + l_t^c = l_t \). Nontradable output produced domestically must match the demand for nontradable goods, public and private investment used in the process of building nontradable public and private capital domestically (with \( a_k \) and \( a_z \) defining their nontradable content)

\[
y_{nt} = \rho_n \left( \frac{P_{nt}}{P_t} \right)^{-\epsilon} c_t + a_k (i_{nt} + i_{xt} + AC_{nt} + AC_{xt}) + a_z i_{z,t} + a_z i_{z,a,t}. \tag{24}
\]

Finally,

\[
\Delta b_t^* + \Delta d_{c,t} + \Delta d_t + \Xi_t + R_t - \Delta s_t^* = \left[ P_{nt} y_{nt} + P_{xt} y_{xt} - r_{t-1}^* s_{t-1}^* - r_{dc,t-1} d_{c,t-1} - r_{dt-1} d_{t-1} - r_{s}^* s_{t-1}^* - P_{ct} c_t + P_{z,t} i_{z,t} - P_{z,a,t} i_{z,a,t} - P_{k,t} (i_{nt} - i_{xt} - AC_{nt} - AC_{xt}) \right], \tag{25}
\]

where the right-hand-side of (25) represents the current account deficit and the left-hand-side the capital account, i.e. the current account balance \( ca_t = -\Delta b_t^* - \Delta d_{c,t} - \Delta d_t - \Xi_t - R_t + \Delta s_t^* \).\(^5\)

3 Calibration

To be completed.

4 Results

To be completed.

5 Conclusions

To be completed.

References

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\(^5\)Under a flexible exchange rate regime \( \Delta \text{reserves} = 0 \).


