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Le, Anh H.; Park, Donghyun; Beirne, John; Uddin, Mohammed Gazi Salah

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DISASTER RISK, INEQUALITY, AND FISCAL SUSTAINABILITY

Anh H. Le, Donghyun Park, John Beirne, and Gazi Salah Uddin

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ABSTRACT

In this paper, we study the implications of climate change on fiscal sustainability and inequality. First, using rich panel data, we show that rising climate-related disaster risks increase government debt and harm fiscal sustainability. We also find that the adverse effect of disaster risks is larger for low-income households, exacerbating inequality. Second, we construct a New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model to examine the implications of the distributional effect of disaster risk. The model features two kinds of households and a fiscal authority. We show that disaster risk has recessionary effects and also causes inequality among households to widen. More specifically, the model indicates that "hand-to-mouth" agents suffer a drop in consumption that is three times larger than that of the Ricardian households. Importantly, we observe a significant rise in sovereign debt due to disaster risk, which poses a challenge to policymakers. Lastly, targeted transfers are recommended but progressive taxes entail a significant fiscal cost.

Keywords: climate change, disaster risk, physical risk, heterogeneous agent, fiscal policy *JEL codes:* E20, E31, E32, E44, G12, Q54

1 Introduction

The rise in global temperature in the last decade has increased the frequency of extreme climatic events. These events include extreme temperatures, extreme wind, extreme rainfall, and land resource depreciation, as well as disasters such as floods, droughts, earthquakes, and tropical cyclones. In light of the huge economic cost associated with such events, climate-related disaster risk has emerged as a high priority for policymakers. In this paper, we examine the effect of climate-related disaster risks on fiscal sustainability and inequality.

By way of context, Figure 1 shows the total number of disaster events in the last 124 years. It is clear that the frequency of disaster events has increased significantly over time, especially in the last 30 years. The rising frequency of disasters highlights the growing threat of climate change, which presents a serious challenge for policymakers.





EMEs = emerging market economies.

Note: We consider droughts, earthquakes, extreme temperatures, floods, mass movements, storms, volcanic activities, and wildfires.

Source: The International Disaster Database (EM-DAT).

Figure 2 shows the median cyclically-adjusted fiscal balance of 192 countries around the world from 1990. The figure clearly shows that fiscal balance declined significantly and reached a record low level during the coronavirus disease (COVID-19) pandemic, when many governments unleashed significant fiscal stimulus in an effort to prevent sharp downturns. The consequent reduction of fiscal space in the post-pandemic era means that policymakers must address disaster risk with relatively limited fiscal space.



Figure 2: Cyclically-Adjusted Balance as % of Potential GDP, Median of All Countries

GDP = gross domestic product. Source: The World Bank, Kose et al. (2022).

It is interesting to see if there are any meaningful differences between the advanced and emerging market economies. Figure 1 shows that the increase in the frequency of disasters is a global phenomenon that affects both groups of countries. However, advanced economies with stronger sovereign debt markets can deal better with climate risk even when they are burdened with a high debt level. In Figure 3, to check whether this is true, we used data from the Notre Dame Global Adaptation Initiative (ND-GAIN) on vulnerability to climate change. It turns out that EMEs are indeed more vulnerable to climate change, and their greater vulnerability may be due to having fewer assets such as deep financial markets for mitigating climate risk.

Figure 3: Vulnerability Index



EMEs = emerging market economies. Source: ND-GAIN, Chen et al. (2015).

The massive destruction resulting from the realization of disaster risk affects the economy by destroying capital and productivity levels, in addition to raising uncertainty for households. Fiscal policy, in particular countercyclical public spending and social transfers to affected households and firms, stands out as the most effective policy response to cushion the large negative impact of disasters. However, the scope for fiscal policy response is limited by the need to restore fiscal sustainability, especially following the reduction of fiscal space that occurred as a result of the global COVID-19 pandemic, the effects of which are still being felt today.

Disasters are likely to have an especially pronounced impact on developing countries and emerging markets for two reasons. First, disasters likely have a bigger impact on low-income households who lack savings to smooth their consumption in the face of a negative shock. Given the larger share of poor "hand-to-mouth" (HtM) agents in developing countries, the impact of disasters is thus likely to be bigger in those countries. Second, the large fiscal policy responses required to adequately cope with disasters creates a challenge for fiscal authorities, especially in countries with limited fiscal space and high debt levels. In particular, developing and emerging market economies have to pay higher premiums on sovereign bonds, which further limits their ability to deal with disaster risks.

This paper aims to shed light on the implications of disaster risk on both inequality and fiscal sustainability. We seek to substantiate our conceptual insights with empirical evidence. First, we provide evidence of climate change affecting both fiscal sustainability and household inequality. We demonstrate that the rise in climate vulnerability increases government debt-to-output ratios and reduces the fiscal sustainability gap. Importantly, we find that climate risk exacerbates income inequality by shifting a higher share of total income to wealthier households. This suggests that lower-income individuals might suffer more from the risks associated with climate change.

In the second part, we enrich a New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model with disaster risk that reduces productivity and capital quality. Additionally, we incorporate the HtM agent and a government budget constraint that finances spending through debt, lump-sum tax, and income tax from two types of households.

The NK-DSGE model generates two significant and interesting findings. First, disaster risk causes recessionary effects in line with the literature but also creates unequal impacts on households. Our findings reveal that the HtM agent suffers a drop in consumption that is three times larger than the Ricardian household due to a lack of consumption smoothing. Second, we observe a substantial increase in sovereign debt due to heightened household demand for bonds (i.e., a 'flight-to-safety') and reduced income tax revenue stemming from significant declines in wages and labor hours. These results are consistent with our empirical evidence.

Regarding policy responses, we recommend implementing targeted transfers to mitigate the inequality arising from disaster risk. Importantly, the fiscal cost is manageable because these targeted transfers can boost gross domestic product (GDP).

2 Literature Review

In this section, we review some studies that are relevant to our paper. Our work contributes to an emerging literature studying the implications of disaster events. Barro (2006, 2009) are pioneers in studying the effects of rare events on asset prices. Recent works focus on how to model disaster risk in macroeconomic models. Fernández-Villaverde and Levintal (2018) and Cantelmo et al. (2024, 2023) use Taylor

Projection to study disaster risk, focusing on the uncertainty of increasing the size of disaster risk. Our paper follows the approach of Gourio (2012), Andreasen (2012), and Isoré and Szczerbowicz (2017), where we use the perturbation method to simulate the shock of disaster risk. We focus on the unequal effect of disaster risk using the setup of two-agent models (Aiyagari, 1994; Bilbiie, 2008; Debortoli and Galí, 2017; Krusell and Smith, 1998). Our results open the problem of the trade-off between sovereign debt management and the need to protect the most vulnerable households in the presence of disaster.

We also contribute to works on using fiscal policy to deal with climate risk. Dafermos and Nikolaidi (2021) show that differentiated capital requirements can alleviate the physical risk in financial sectors. However, green fiscal policy might increase green investment and worsen the financial transition risk for green sectors. Zenios (2022) argues that climate risk can affect fiscal stability by connecting the integrated assessment models with stochastic debt sustainability analysis and highlighting the role of fiscal stability in this aspect. Moreover, the seminal work by Lamperti et al. (2021) highlight the role of financial constraints in amplifying climate risk. They emphasize the need for combined financial policy to target both climate risk and emission reduction. In this regard, Catalano et al. (2020) use an overlapping generation model to investigate some potential fiscal policy implementations for climate change adaptation. They find that early adaptation shows the best outcome but can be hard to implement due to a lack of fiscal space. At the same time, Battiston et al. (2021) provide an outstanding paper about the link between climate risk and financial aspects as well as the need for policy designs and climate macro-financial modelling. Lastly, our work also relates to a set of papers modelling transition risk and financial policy including Benmir and Roman (2020), Carattini et al. (2023), Giovanardi et al. (2023), Le (2023), and Chan et al. (2024).

Our work contributes to the literature on the impact of climate change on fiscal policy as well as fiscal sustainability. Kose et al. (2022) provide an excellent dataset on fiscal space around the world with 202 countries from 1990. Hunjra et al. (2024) find that financial policy uncertainty can play an important role in the transmission of climate change risk. Moreover, Boitan and Marchewka-Bartkowiak (2022) show that climate-vulnerable countries in the European Union have to pay a higher risk premium on their borrowing and this also holds for countries with low fiscal space. This raises the concern of scared fiscal capacity to deal with climate (disaster) risks.

Given the rise in the number of extreme weather events (disasters) and the rise in sovereign debt around the world, we shed light on the empirical work by studying the implications of climate change on the sustainability of fiscal policy as well as the inequality effect of it among different types of households. We highlight the unequal effect of climate change as well as a negative effect on fiscal debt. This suggests a challenging trade-off for policymakers in protecting the most vulnerable households with a limited fiscal space.

Importantly, our model allows for studying the implication of disaster risk on fiscal sustainability. We employ disaster risk in the NK-DSGE model with a fiscal authority. Notably, we also have the HtM agent to characterize the potential unequal effect of disaster risk. The presence of both monetary and fiscal authorities allows us to study the monetary-fiscal interaction to deal with disaster risk. To the best of our knowledge, we are among the first to bring those three aspects into a model.

3 Empirical Evidence

In this section, we provide empirical evidence on the impact of climate change on fiscal sustainability and inequality. To gauge the impact of climate change, we utilize the ND-GAIN Vulnerability Index, which assesses the "propensity or predisposition of human societies to be negatively impacted by climate hazards." A higher index value indicates greater susceptibility to climate risks. This index has been widely applied in recent studies by Kling et al. (2021), Beirne et al. (2021), Hale (2022), Gu and Hale (2023), and Cevik and Jalles (2023).

For our empirical analysis, we adopt the local projection approach pioneered by Jorda (2005). Specifically, we estimate the following model:

$$Y_{i,t+h} = \beta_h S_{i,t} + \gamma_h Y_{i,t-1} + \theta X_{i,t-1} + \delta_i + V_{i,t+h} \quad h = 0, 1, 2, \dots$$
(1)

where $Y_{i,t+h}$ represents the variable of interest, $S_{i,t}$ is the impulse variable, and $X_{i,t}$ is the vector of our control variables, including lags of our impulse variable. Our data set includes annual data from 184 countries for the period 1995–2021. The detailed description of our data can be found in Table 1.

Table 1: Description of Data

Variable	Description	Source
VULt	ND-GAIN Vulnerability index	ND-GAIN
CPI_t	Annual Consumer Price Inflation	World Bank, WDI
CAB_t	Current Account Balance (% to GDP)	World Bank, WDI
GDP_t	GDP (current \$)	World Bank, WDI
FI_t	Financial-Institution Index	IMF, FDI
FM_t	Financial-Market Index	IMF, FDI
FD_t	Financial-Development Index	IMF, FDI
$YieldUS_t$	US 10-year government bond yield	FRED
VIX_t	CBOE Volatility Index, global risk aversion	FRED
WUI_t	World Uncertainty Index	FRED, Ahir et al. (2022)
$GGDY_t$	General government gross debt, % of GDP	World Bank, Kose et al. (2022)
FBY_t	Fiscal balance, % of GDP	World Bank, Kose et al. (2022)
$FBSUSGAP_t$	Sustainability Gap, Fiscal Balance, % of GDP	World Bank, Kose et al. (2022)
$Gini_t$	Gini Index	World Bank, WDI
$Top20_t$	Income share held by the highest 20%	World Bank, WDI
$Low 20_t$	Income share held by the lowest 20%	World Bank, WDI

FDI = Financial Development Index, FRED = Federal Reserve Economic Data, ND-GAIN = Notre Dame Global Adaptation Initiative, US = United States, WDI = World Development Indicators. Source: Authors.

First, we assess the impact of increasing climate change vulnerability on government debt and fiscal sustainability across all countries. In Figure 4, we show the impact of rising climate vulnerability on gross government debt-to-GDP (left) and the sustainability gap (right). With our specification, we observe quite a persistent effect on the debt-to-GDP ratio. The debt-to-GDP ratio increases by nearly 2% at its peak, 2 years after the shock materializes.





GDP = gross domestic product. Note: The unit is % of GDP with 95% confidence bands. The shock hits in t=0. Source: Authors' calculations.

As regards fiscal sustainability, our results indicate a drop in the sustainability gap of nearly 1% on impact. These results highlight the downside risk of climate change on fiscal resources. It is evident therefore that climate change exposure worsens debt dynamics both in terms of debt-to-GDP and the fiscal balance.

On inequality, we examine the effect of climate vulnerability on the Gini index. Figure 5 shows the impact of rising vulnerability on the Gini index on the left. Interestingly, climate change increases income inequality, suggesting that low-income households might suffer more from climate change.

Furthermore, we look at the income share held by the top 20% and the lowest 20%, taken from World Bank data. The results can be seen in Figure 5 on the right panel. The results suggest a shift of income to high-income households, while there is a modest decrease in the income share for the lowest 20% of households. Therefore, we observe the unequal effect of climate change on rich and poor people. This is quite intuitive, as the lowest 20% of households do not have any savings and cannot reduce more of their share since most of them are around or even below the poverty line. Hence, fiscal policy will need to provide social transfers to assist them, but this comes at the cost of fiscal sustainability. Our baseline empirical estimates thus show that overall, higher climate risk vulnerability worsens both fiscal sustainability and inequality.

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Note: The horizon is yearly. The unit is the index level (left) and percentage share of holding (right) with 95% confidence bands. The shock hits in t=0. Source: Authors' calculations.

Going beyond the baseline analysis, we also examine the implications of climate change on fiscal sustainability and inequality for countries with high climate vulnerability risk.

Figure 3 shows that there is some level of heterogeneity in the effect of climate change. Therefore, we investigate the roles of both climate change vulnerability and fiscal sustainability in shaping these effects. To do so, we classify countries with a vulnerability index higher than the mean of our dataset as high-vulnerability risk countries. Similarly, we identify countries with high fiscal sustainability risk using a comparable method.

In Figure 6, we compare the effect of climate change between high-vulnerability and low-vulnerability countries. On the fiscal side, we observe more pronounced effects on government debt. Importantly, the unequal impact of climate change appears to increase significantly more for countries with high vulnerability risk.





Note: The horizon is yearly. The unit is the index level (left) and % of GDP (right) with 95% confidence bands. The shock hits in t=0.

Source: Authors' calculations.

In Figure 7, we compare the inequality impact of climate change for countries with high vulnerability and fiscal sustainability risk at the same time. Importantly, the unequal impact of climate change appears to increase significantly more for countries that are exposed more to climate change and have low sustainable fiscal space.





Note: The horizon is yearly. The unit is in percentage with 95% confidence bands. The shock hits in t=0. Source: Authors' calculations.

Compared to Figure 5, the gap in income share from top-income and low-income households is significantly wider and longer lasting. As mentioned earlier, countries with limited fiscal space encounter challenges in adequately protecting the most vulnerable households from climate change risks. At the same time, from Figure 6, we observe a more pronounced effect on the government debt and the Gini index. Therefore, high vulnerability and sustainability risks amplify the inequality effect of climate change.

Our empirical findings indicate a deterioration in fiscal balances and inequality due to climate-related disaster risk exposure, especially for those economies most vulnerable to climate change. We employ a NK-DSGE framework to explore further, also facilitating interactions across different markets and sectors of the economy simultaneously.

4 A Model with Disaster Risk

To study the fiscal implications of disaster risk, we model how disasters affect the economy and the fiscal authority. We begin with a standard NK-DSGE model featuring

capital and a fiscal authority with distorted income tax. Additionally, to reflect the significant presence of low-income households in developing economies, we introduce a second type of household that lacks saving ability. This departure from the Ricardian household assumption is crucial for our analysis of government spending responses. Apart from these adjustments, the primary innovation compared to a standard New Keynesian model lies in incorporating the destructive impact of disaster risk on productivity and capital, necessitating a higher-order approximation akin to an asset pricing model.

The subsequent model features two types of households. There is a fraction $(1 - \eta)$ of Ricardian households and a fraction η of the HtM agents. HtM agents lack saving ability by assumption and rely solely on labor income.

The government finances public expenditure G_t by raising lump-sum taxes T_t^O, T_t^R , income tax, τ^n , and public debt, B_t . Disaster risk dampens productivity growth, destroys capital, and introduces second-moment effects on agents' preferences.

To better understand how we incorporate disaster risk into the model, we adopt the approach of Gourio (2012). First, we define productivity, z_t , which constitutes the primary source of long-term growth. Thus, we express the standard growth rate of the labor-augmenting total factor productivity (TFP) as follows:

$$\frac{z_{t+1}}{z_t} = e^{\mu + \varepsilon_{z,t+1} + \vartheta_{t+1} \log(1-\Delta)}$$
(2)

with μ as the trend and $\varepsilon_{z,t+1}$ following a normal distribution. To incorporate the disaster risk, we assume it will destroy the productivity level of the economy. We will treat ϑ as a variable that indicates the event of a "disaster" and this is the non-standard term compared to a standard macroeconomic model. Specifically, $\vartheta_{t+1} = 1$ with probability Ξ_t , in which it causes damage with the share Δ to the productivity.

Precisely, $\vartheta_{t+1} = 1$ with probability Ξ_t , indicating the destruction of a significant portion Δ of the current capital stock. Conversely, $\vartheta_{t+1} = 0$ signifies the absence of a disaster event. The probability Ξ_t of such disasters varies over time:

$$log(\Xi_t) = (1 - \rho_{\Xi}) log(\tilde{\Xi}) + \rho_{\Xi} log(\Xi_{t-1}) + \sigma_{\Xi} \varepsilon_{\Xi_t}$$
(3)

where $\tilde{\Xi}$ denotes the mean, ρ_{Ξ} represents the persistence, and ε_{Ξ_t} denotes the independent and identically distributed innovations. After taking expectations, we end up with:

$$E_t(e^{\vartheta_{t+1}\log(1-\Delta)}) = 1 - \Xi_t \Delta \tag{4}$$

4.1 **Ricardian Households**

As mentioned in the beginning, we need an asset pricing model to capture the volatility in asset prices from disaster risk. Therefore, our Ricardian households maximize the following Epstein-Zin-Weil preferences:

$$\tilde{U}_{t} = \left[\left[C_{t}^{O} (1 - L_{t}^{O})^{\zeta} \right]^{1-\psi} + \beta(\Xi) \left(E_{t} \tilde{U}_{t+1}^{1-\gamma} \right)^{\frac{1-\psi}{1-\gamma}} \right]^{\frac{1}{1-\psi}}$$
(5)

with respect to the budget constraint:

$$C_t^O + I_t + T_t^O + \frac{B_t}{p_t} = (1 - \tau^N) W_t L_t^O + P_t^k u_t K_t + Div_t + \frac{B_t R_{t-1}}{p_t}$$
(6)

where C_t^O represents Ricardian household consumption, I_t designates household investment, B_t denotes government bonds, W_t is the hourly wage, and L_t^O denotes total labor supply. P_t^k represents the real return on capital, K_t represents physical capital at time t, R_t is the risk-free policy rate on government bonds, and Div_t is the dividend from firms. Lastly, p_t is the price level. Different from Cantelmo et al. (2023), we also consider the effect of disaster risk on the demand side. Following Gourio (2012) and Isoré and Szczerbowicz (2017), we assume the discount factor, β , is a function of disaster probability and make it time-varying to capture the effects of disaster risk on the demand side.¹ Lastly, τ^n is the real income tax.

Following Gourio (2012), we assume that disasters will influence both productivity growth and physical capital. The capital law of motion is subject to an adjustment cost in changes in investment to capital ratio, as in Christiano et al. (2005) but with the chance that disaster shock can cause the loss of Δ to the physical capital. Hence, when the disaster materializes, it destroys the capital of the current period and affects the

¹This might be important for the dynamic of inflation. If the disaster only dampens the production, it has an inflationary effect. However, if the household also anticipates it, the effect on inflation is ambiguous.

accumulation of the next period's capital as well as the investment decision of the household.

$$K_{t+1} = \left[(1 - \delta_t) K_t + \Gamma \left(\frac{I_t}{K_t} \right) K_t \right]^{e^{\vartheta_{t+1} ln(1-\Delta)}}$$
(7)

We define the stochastic discount factor as follows:

$$Q_{t,t+1} = \frac{\partial \tilde{U}_t / \partial C_{t+1}^O}{\partial \tilde{U}_t / \partial C_t^O} = \beta(\Xi) \left(\frac{C_{t+1}^O}{C_t^O}\right)^{-\psi} \left(\frac{1 - L_{t+1}^O}{1 - L_t^O}\right)^{\zeta(1-\psi)} \frac{\tilde{U}_{t+1}^{-X}}{\left(E_t \tilde{U}_{t+1}^{1-X}\right)^{\frac{-X}{1-X}}}$$
(8)

where $X = \frac{\gamma - \psi}{1 - \psi}$. We can define the Euler equation takes the following form.

$$E_t\left(Q_{t,t+1}\frac{R_t}{\pi_{t+1}}\right) = 1\tag{9}$$

where $\pi_t \equiv \frac{p_t}{p_{t-1}}$ is the inflation rate. Similarly, the first-order conditions with respect to capital takes the following form:

$$R_{t+1}^{k} = e^{\vartheta_{t+1} \ln(1-\Delta)} \left\{ \frac{p_{t+1}^{k} u_{t+1}}{q_{t}} + \frac{q_{t+1}}{q_{t}} \left[1 - \delta_{t+1} + \Gamma_{K_{t+1}}' K_{t+1} + \Gamma_{t+1} \right] \right\}$$
(10)

which relies on the standard Tobin's q, depreciation and utilization rates, and investment adjustment costs, as well as on the possibility of a disaster event, ϑ .

Because of the asset pricing mechanism, a third-order approximation is required for the simulation. We define the risk premium as follows:

$$E_t(\mathsf{Prem}_{t+1}) \equiv E_t\left(\frac{R_{t+1}^k \pi_{t+1}}{R_t}\right) \tag{11}$$

4.2 "Hand-to-Mouth" Households

There is a fraction η of HtM households. It is much simpler compared to our Ricardian household as HtM agents have no assets and saving ability. Hence, they solve the following problem:

$$\max E_t \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{r(1-\sigma)}}{1-\sigma} - \kappa_L \frac{L_t^{r(1+\varphi)}}{1+\varphi} \right)$$
(12)

s.t. $C_t^r = (1 - \tau^N) W_t L_t^r - T_t^r$ (13)

where C_t^r is consumption and L_t^r is the labor of HtM agents. First-order conditions with respect to labor and consumption are as follows:

$$\frac{\left[(1-\tau^{N})W_{t}L_{t}^{r}-T_{t}^{r}\right]^{1-\sigma}}{1-\sigma}-\kappa_{L}\frac{L_{t}^{r(1+\varphi)}}{1+\varphi}=0$$
(14)

$$\kappa_L \left(L_t^r \right)^{\varphi} \left(C_t^r \right)^{\sigma} = (1 - \tau^N) W_t$$
(15)

4.3 **Production Sectors**

 y_t is the aggregation of final goods using a standard constant elasticity of substitution aggregator.

$$y_t = \left[\int_0^1 y_t\left(j\right)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}}$$
(16)

The aggregate price and the demand curve follow:

$$p_t = \left[\int_0^1 p_t \left(j\right)^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}}$$
(17)

$$y_t(j) = y_t \left(\frac{p_t(j)}{p_t}\right)^{-\varepsilon}$$
(18)

The intermediate goods sector is quite standard for a NK-DSGE model. The only innovation belongs to the TFP growth that can be destroyed by the disaster risk.

$$y_t(j) = A_t (u_t K_{j,t})^{\alpha} (z_t L_{j,t})^{1-\alpha}$$
 (19)

where z_t is the productivity level that is affected by the disaster risk² and $u_t K_{j,t}$ represents effective capital, households determined by the utilization rate u_t of capitals. Lastly, A_t is the exogenous TFP shock process.

Intermediate producers can adjust their prices in period t with a Calvo probability of θ . The optimal price is set with respect to the expected value of future profits. However, to solve the model with a third order approximation, we derive it under a non-linearity setup.

$$\max_{p_{j,t}} E_t \sum_{s=0}^{\infty} \left(\theta\right)^s Q_{t+s}(p_{j,t}Y_{j,t+s} - W_{t+s}L_{j,t+s} - P_{j,t+s}^k u_{t+s}K_{t+s})$$
(20)

The optimal reset price does not depend on j and is the same for aggregation, $p_t^* = p_{j,t}^*$. Hence, we have the inflation definition:

$$\pi_t^* = \frac{\epsilon_p}{\epsilon_p - 1} \frac{X_{1,t}}{X_{2,t}} \pi_t \tag{21}$$

where X_1 and X_2 are recursive auxiliary variables and $p_{w,t}$ is interpretable as real marginal cost at time t.

$$X_{1,t} = Y_t p_{w,t} + \theta E_t [Q_{t,t+1} \pi_{t+1}^{\epsilon_p} X_{1_{t+1}}]$$
(22)

$$X_{2,t} = Y_t + \theta E_t[Q_{t,t+1}\pi_{t+1}^{\epsilon_p - 1}X_{2_{t+1}}]$$
(23)

4.4 Central Bank, Government, and Market Clearing

The central bank controls the standard Taylor rule.

$$\ln\left(\frac{R_t}{R_{ss}}\right) = \rho_r ln\left(\frac{R_{t-1}}{R_{ss}}\right) + (1 - \rho_r)\left(\rho_y ln\left(\frac{Y_t}{Y_{t-1}}\right) + \rho_\pi ln\left(\frac{\pi_t}{\pi_{ss}}\right)\right)$$
(24)

In equilibrium, all markets are clear. Hence, the final goods market clearing condition follows:

$$Y_t = C_t + I_t + G_t \tag{25}$$

²The setup with the labor augmenting TFP and capital destruction also helps to bring the effect of disaster risk into the capital market rather only to the total TFP which can be referred to as macroeconomic uncertainty (see Basu and Bundick (2017)).

where G_t stands for autonomous government spending. Total consumption and labor are the combinations of "HtM" and Ricardian households.

$$C_t = (1 - \eta) C_t^O + \eta C_t^r,$$
(26)

$$L_t = (1 - \eta) L_t^O + \eta L_t^r$$
(27)

The government finances public expenditure G_t by raising lump-sum taxes T_t^O, T_t^R , income tax, τ^n , and public debt B_t . For the baseline model, we fix the income tax and set the identical lump-sum transfer (tax) rule following Galí et al. (2007) for both types of households.

$$G_t + \frac{R_{t-1}}{\pi_t} B_{t-1} = (1 - \eta) t_t^O + \eta t_t^r + (1 - \eta) \tau_t^N W_t L_t^O + \eta \tau_t^N W_t L_t^R + B_t$$
(28)

$$\log (G_t) = (1 - \rho_G) \log \left(\overline{G}\right) + \rho_G \log (G_{t-1}) + v_t^G$$
(29)

$$t_t^r - \bar{t}^r = \phi_B \left(B_t - \bar{B} \right) + \phi_G \left(G_t - \bar{G} \right)$$
(30)

$$t_t^O - \bar{t}^O = \phi_B \left(B_t - \bar{B} \right) + \phi_G \left(G_t - \bar{G} \right)$$
(31)

$$\tau_t^N = \tau_{ss}^N \tag{32}$$

4.5 Calibration and Solution Method

The calibration of the macroeconomic part is for emerging market economies following the workhorse model from the International Monetary Fund, henceforth, the Integrated Policy Framework or IPF (Adrian et al., 2020). We set the inflation target at 4% annually and the capital depreciation rate at 3.5% following Chinese calibration from Chang et al. (2019). The disaster-related parameters will follow the literature on disaster risk (Barro et al., 2022; Cantelmo et al., 2024, 2023; Fernández-Villaverde and Levintal, 2018; Gourio, 2012; Isoré and Szczerbowicz, 2017). Lastly, we adopt the approach of Isoré and Szczerbowicz (2017) to detrend the system, ensuring that the binary disaster variable disappears. After detrending, we solve the system using the perturbation

method with a third-order approximation.³ This ensures that we can have a quite accurate solution with the third-order approximation.⁴ We put all of the key parameters in Table 2.

Parameter	Description	Value	Notes
β	Discount factor	0.9945	Real rate of 1.9% annually (IPF)
ϵ_p	Elas. of subst. differentiated goods	6	Christiano et al. (2005)
α	Share of capital in production	0.33	$\frac{i}{y} = 0.263$
θ	Calvo probability	0.75	IPF
δ	Depreciation rate	3.5%	Chang et al. (2019)
κ_I	Investment adjustment cost	1	Chang et al. (2019)
π	Trend Inflation	1.01	IPF, 4% annually
$ ilde{g}$	Public spending	0.1291	g/y=0.14 (IPF)
$ au^N$	Income tax	0.15	IPF
ρ_{π}	Taylor rule reaction for inflation	1.5	IPF
ρ_y	Taylor rule reaction for output	0.0625	IPF
ρ_r	Persistence of interest rate	0.85	IPF
Ĩ	Mean probability of disaster	0.0688	Cantelmo et al. (2023)
Δ	Size of disaster	0.22	Isoré and Szczerbowicz (2017)
σ_{Ξ}	Disaster risk probability (StD)	0.6	Cantelmo et al. (2023)
$ ho_{\Xi}$	Disaster risk probability (Persistence)	0.9	Isoré and Szczerbowicz (2017)
γ	Risk aversion coefficient	3.8	Isoré and Szczerbowicz (2017)
η	Share of HtM agent	0.42	Bracco et al. (2021), average for EMEs
μ	Growth rate of productivity	0.005	Isoré and Szczerbowicz (2017), 2% annually
$\frac{b}{y}$	Debt-to-GDP	0.6	IMF WEO

Table 2: Calibration for Emerging Market Economies

EMEs = emerging market economies, GDP = gross domestic product, HtM = hand-to-mouth, IMF = International Monetary Fund, IPF = Integrated Policy Framework, WEO = World Economic Outlook. Source: Authors' calculations.

5 Numerical Simulation

5.1 Baseline Results

First, the disaster risk creates a recessionary effect. When disaster risk increases, agents become more "patient," leading to a higher propensity to save and a corresponding drop in consumption. This results in a deflationary effect as the demand decreases as well. However, the increase in savings does not lead to higher investment

³The detailed solution method can be found in Isoré and Szczerbowicz (2017) and Gourio (2012).

⁴Fernández-Villaverde and Levintal (2018) use Taylor projection to show that it can outweigh the solution with perturbation methods. However, their approach is about changing the disaster size, not the probability of disaster. Notably, both approaches provide similar effects.

but rather to increased holding of government bonds, causing output to decline. This occurs because capital accumulation becomes less profitable for households as firms demand fewer factors of production. Consequently, the rental rate of capital decreases, further reducing productivity levels. Firms demand fewer production factors due to price stickiness. Since they cannot raise prices to offset the loss in productivity, they cut back on production and also their demand for labor and capital.

With the baseline model, we observe two highly interesting results. First, we see that there is inequality in the effect of disaster risk. The HtM agent's consumption drops around four times more than that of the Ricardian one due to a lack of consumption smoothing motives. When the disaster risk hits the economy, the income of all the households decreases following the diminishing productivity level and the loss of capital. However, the HtM agents cannot smooth their consumption with their savings and suffer more compared to Ricardian households. Hence, they reduce their working hours much less compared to Ricardian households, but this cannot compensate for the damage from the disaster.



Figure 8: The Impulse Response of 10% Increase in Disaster Risk

Dev= deviation, GDP = gross domestic product. Source: Authors' calculations.

Second, government debt rises significantly. As the disaster diminishes TFP growth and destroys capital, it acts as both a supply and demand shock. With the increased depreciation of capital, Ricardian households increase their holdings of risk-free assets, such as government bonds. This refers to the "flight to safe haven" mechanism. Moreover, due to the recessionary effect, total labor hours decrease, leading to a drop in income tax revenue. We do not impose any countercyclical government spending measures, which might result in a higher debt level even with a milder recession.

Overall, the implications of disaster risk pose challenges to debt management and highlight the need to protect the most vulnerable households. Our results underscore a

trade-off problem for the government: reducing the lump-sum tax if not increasing transfers to the most vulnerable households, or containing the rise in their sovereign debt.

5.2 Targeted Transfers

In the baseline result, we completely mute the reaction of targeted instruments, including transfers and income tax. While the income tax can be set to be targeted, it is not practical in real life. It is interesting to see the cost in terms of government debt when transferring to the poor people. To accommodate the targeted transfer, we set the lump-sum tax rule to react to HtM consumption.⁵

$$t_{t}^{r} - \bar{t}^{r} = \phi_{c_{r}} \left(C_{t}^{r} - \bar{C}^{r} \right) + \phi_{B} \left(B_{t} - \bar{B} \right)$$
(33)

As expected, the consumption improves significantly, mostly from the HtM agents. We calibrate the reaction parameter ϕ_{c_r} such that the drop for the HtM agents is only twice as much as the Ricardian agents, compared to three times more in the baseline. The government debt increases by more than 1% compared to the baseline. However, as can be seen in Figure 9, the debt-to-GDP ratio has the same peak response with a slightly more severe recovery path. This comes from the improvement in output because the HtM agents consume all the transfers immediately. Our model recommends a protective policy toward low-income households, given that the differences in fiscal cost (debt/GDP) are small.

⁵We set $\phi_{c_r} = 0.7$ so the peak debt-to-GDP reaction is approximately the same.



Figure 9: The Impulse Response of 10% Increase in Disaster Risk with Targeted Transfers to Poor People

Dev= deviation, GDP = gross domestic product. Note: The blue line is our baseline model. The red line is the model with the targeted transfer. Source: Authors' calculations.

5.3 Progressive Income Taxes

Although a targeted income tax is not practical, progressive income taxes are implemented commonly and show some stabilizing effect through both supply and demand channels (see Auerbach and Feenberg (2000), Dolls et al. (2010)). Hence, it is natural to ask what

a progressive income tax looks like as a policy response to disaster risk shock. First, we define the income of each household as follows:

$$INC_t^O = W_t L_t^O + Profit_t$$
$$INC_t^r = W_t L_t^r$$
(34)

where $Profit_t$ is the total profit from all firms. Following Mattesini and Rossi (2012), we introduce the income tax rule that adjusts with the income level of the household.

$$\tau_t^{N,O} - \tau^{N,O} = 1 - \left(\frac{INC^O}{INC_t^O}\right)^{\phi_N}$$

$$\tau_t^{N,r} - \tau^{N,r} = 1 - \left(\frac{INC^r}{INC_t^r}\right)^{\phi_N}$$
(35)

where ϕ_N is the reaction term. We set $\phi_N = 0.6$ for our analysis.

As we can see in Figure 10, progressive income taxes have targeted effects. The HtM income tax is reduced more following their lower income level. Compared to the baseline, the HtM consumption improves more than that of the Ricardian households. On the aggregate level, the reduction in income tax also boosts the economy and improves output. However, the drop in income tax increases the government debt-to-GDP ratio due to the cost of reduced revenue.



Figure 10: The Impulse Response of 10% Increase in Disaster Risk with Progressive Income Taxes

Dev= deviation, GDP = gross domestic product. Note: The income tax for the baseline is muted. Source: Authors' calculations.

6 Conclusion

In this paper, we aim to shed some new light on the implications of disaster risk for fiscal sustainability and inequality. We provide evidence of climate change affecting both fiscal sustainability and household inequality. We demonstrate that the rise in climate vulnerability increases government debt-to-GDP ratios and reduces the fiscal sustainability gap. Importantly, we find that climate risk exacerbates income inequality by shifting a higher share of total income to wealthier households. This suggests that lower-income individuals might suffer more from the risks associated with climate change.

At the same time, we enrich an NK-DSGE model with disaster risk that reduces productivity and capital quality. Additionally, we introduce the HtM agents, a government budget constraint that finances spending through debt, lump-sum tax, and income tax from two types of households. Our model generates two interesting and significant results. First, we demonstrate that disaster risk has recessionary effects, which is in line with the literature, but it also exacerbates inequality among households. Our results indicate that the HtM agent suffers a drop in consumption that is three times larger than the Ricardian household due to their inability to smooth their consumption. Second, we observe a significant rise in sovereign debt due to the increase in bond demand from households (i.e., flight to safe haven) and the reduction in income tax revenue due to a big drop in wage and labor hours. The model also recommends a policy of targeted transfers for HtM agents which entails a relatively small fiscal cost.

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Disaster Risk, Inequality, and Fiscal Sustainability

This paper analyzes the effects of climate change on budgetary sustainability and inequality. Using panel data, the findings suggest that rising climate-related disaster risks raise government debt and undermine fiscal sustainability, with low-income households bearing the brunt of the impact. According to a New Keynesian Dynamic Stochastic General Equilibrium model, disaster risk generates recessions and increases inequality, particularly among "hand-to-mouth" agents. The paper also shows a considerable increase in sovereign debt due to disaster risk, and it recommends targeted transfers while cautioning against the fiscal cost of progressive taxes.

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