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Climate vulnerability and government resource mobilization in developing countries

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Abstract: There is substantial empirical literature on the impact of climate vulnerability on economic outcomes in developing countries. However, this literature is still weak on the impact of climate vulnerability on tax revenue mobilization. To enrich the existing literature, this paper aims to investigate the effects of climate vulnerability on government revenue mobilization in a sample of 84 developing countries over the period 1995–2019. To achieve this objective, we use the pooled ordinary least square and fixed-effects ordinary least square regressor techniques as developed by Driscoll and Kraay (1998). We obtain three main results. First, climate vulnerability hampers government revenue mobilization in developing countries. Indeed, a variation of 1 per cent in the level of climate vulnerability induces a decrease in government revenues of 0.63 points. Second, climate vulnerability has different impacts on each type of government tax revenue. Regarding the subcomponents of tax revenue (direct and indirect tax), the results confirm the harmful effect of climate vulnerability on all these subcomponents. Furthermore, it appears that direct taxes are the most compromised in terms of magnitude. Third, this effect does not change when climate vulnerability is disaggregated (exposure, sensitivity, and adaptive capacity). However, the climate sensitivity index has a significantly greater effect than the other two. Finally, by applying quantile regression and the two-step system generalized method of moments to control, respectively, distributional heterogeneity and the potential endogenous problem, we also find that climate vulnerability hampers government revenue mobilization in developing countries. These results suggest recommendations relative to the implementation of measures meant to improve the resilience of people to climate change and natural disasters.

Key words: climate vulnerability, developing countries, government revenue mobilization, natural disasters

JEL classification: E62, H20, O13, Q54

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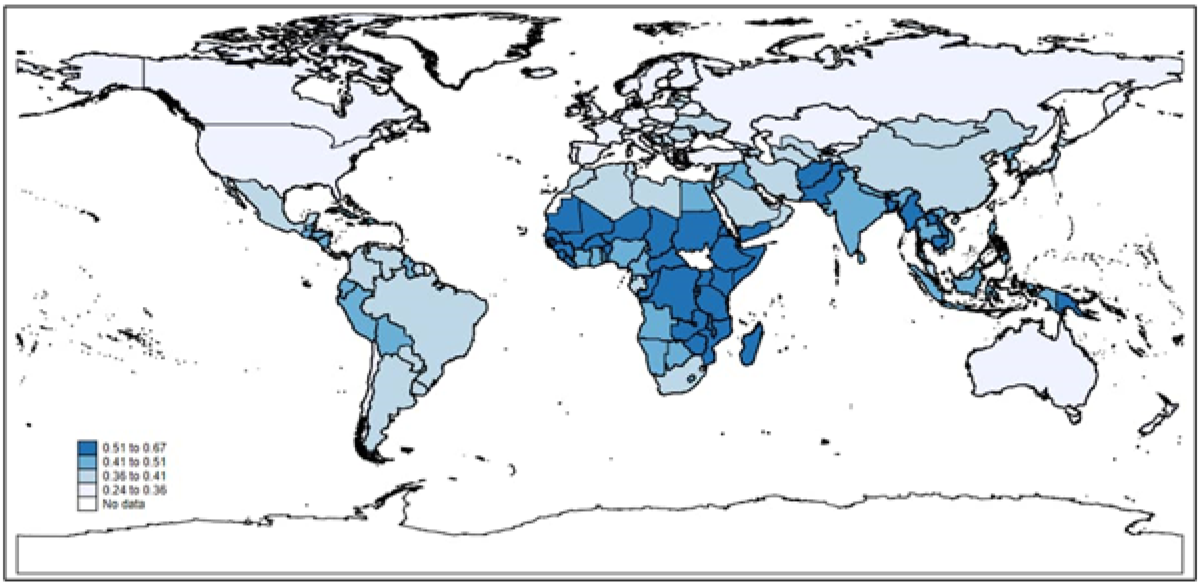
1 Introduction

For almost three decades, literature has continued to pay particular attention to the question of the effects of climate change on economic performance. Indeed, the frequency of meteorological shocks increases the vulnerability of economies to climatic hazards, thus jeopardizing the achievement of the United Nations' Sustainable Development Goals, including the increase in the mobilization of tax revenues (IPCC 2018; Nations Unies 2015). This dramatic increase in climate change-related disasters is reflected in the significant disparities in climate vulnerability between countries across the world (Kling et al. 2021). Moreover, this risk, although common to all countries, remains more pronounced in developing countries, especially in Africa (see Figure 1). They are more susceptible to natural hazards induced by climate change (IPCC 2018). In addition, the governments of these countries have limited capacity (in terms of tax revenue for example) to cope with and respond to natural hazards (Kling et al. 2018), thereby leading to higher economic costs than in other regions (Cavallo et al. 2013; Felbermayr and Gröschl 2013; Mendelsohn and Wang 2017).

Figure 1: Climate vulnerability in the world



Source: authors' calculations using the Notre Dame Global Adaptation Index.

In recent years, several studies have highlighted the economic development costs of climate change-related vulnerability (Alano and Lee 2016; Botzen et al. 2019). Burke et al. (2015), Khan et al. (2021), Kompas et al. (2018) find that both recurrent climate warming and natural disasters have negative effects on long-term economic growth. Evans (2009) and Hallegatte et al. (2011) have focused on human development and poverty. A further important dimension of the costs of climate vulnerability is that related to public finance. Kling et al. (2018) found that climate vulnerability increases the cost of sovereign borrowing. Yet, the cost at which governments can access finance affects public budgets and the ability of governments to invest in climate mitigation and adaptation or to undertake investments in public goods (Kling et al. 2021). In the same vein, Kere et al. (2015) and Noy and Nualsri (2011) investigate the impact of natural disasters on tax revenue mobilization. Despite this latter contribution, the literature on the impact of climate vulnerability on government revenue remains scarce. Climate vulnerability can be defined as the degree to which a system or resource is susceptible to damage by the negative effects of climate change. This climate vulnerability comprises three subcomponents: sensitivity, exposure, and adaptive capacity (IPCC 2018). To the best of our knowledge, this paper is the first to analyse the impact of climate change-related vulnerability on government revenue in developing countries. This paper aims to fill this gap by analysing the effect of climate vulnerability on government tax revenue mobilization in developing countries.

Government tax revenues have an important funding role in government fiscal policies in many developing countries. Akitoby et al. (2020), Kere et al. (2015), and Kling et al. (2018, 2021) found that finances from tax revenues affect public budgets and governments' ability to invest in climate mitigation and adaptation. Low revenue mobilization also constrains possible public goods investments in areas such as infrastructure, education, and public health. In addition, current data show that, for example, developing countries such as African countries recorded during the period 1990–2019 tax revenue mobilization ratios (tax as a percentage of gross domestic product, GDP) between 10 and 25 per cent with an average of 16.5 per cent. In South East Asia, this rate is between 12.5 and 31.4 per cent compared with ratios between 16.5 and 46.3 per cent in OECD countries (OECD 2020). The literature posits various factors as important contributors to such low tax revenue mobilization in developing countries. These include macroeconomic factors (Oz-Yalaman 2019; Piancastelli and Thirlwall 2021), institutional factors (Baum et al. 2017; Castañeda Rodríguez 2018), social factors (Akitoby et al. 2020; Van Den Boogaard et al. 2018), and environmental factors (Kere et al. 2015; Noy and Nualsri 2011).

Two main channels allow us to understand theoretically how climate vulnerability affects the level of tax revenue mobilization in a country. The first mechanism is that of income via growth and the reduction of the country's trade (i.e. imports and exports). Indeed, in a context of vulnerability due to climate risks, the occurrence of a climate risk reduces production capacities, particularly in terms of the depletion of an economy's capital stock (Ward and Shively 2012). This decrease in production induces a decrease in imports and exports, which leads to a direct and indirect reduction in tax revenues. Using the neoclassical growth model, Kere et al. (2015) show that natural disasters can drain the capital stock. The authors show that after a natural disaster, the economy can converge to its former long-run, steady-state equilibrium through faster capital accumulation. In other words, by destroying the capital stock, natural disasters alter the production frontier and reduce output per capita (Kling et al. 2018). In addition, a climate hazard can cause disruptions to infrastructure services, such as power outages and road closures. Public and private businesses may suffer disaster-related losses and thus reduce potential government tax revenues (Kere et al. 2015). The second mechanism is a country's tax structure. Indeed, various empirical studies show that effects on tax revenue are not necessarily uniform and may vary depending on the constituent parts of taxes (e.g., Di John 2006; Savoia et al. 2022; Yogo and Ngo Njib 2018). For example, Yogo and Ngo Njib (2018) insist on decomposing tax revenues into different components to better understand their behaviour. Moreover, they show that different types of taxes constitute a stable basis in terms of tax revenue mobilization in developing countries. Noy and Nualsri (2011) show that the impact of climate change-related natural disasters on tax revenues depends on the macroeconomic dynamics that occur following the disaster shocks as well as on the structure of tax revenue sources.

The contribution of this study is twofold. First, we use a novel and more inclusive climate vulnerability index. This measure of vulnerability has four main specificities. (i) It considers the physical factors of a country (exposure), such as geographical locations and physical climate effects, that contribute to external vulnerability. (ii) It takes into account a country's degree of dependency on sectors that are climate-sensitive (sensitivity), added to the ability of the economy to mitigate potential damages during and after those negative climate shocks (adaptive capacity) while observing the effects of each of them on the type of tax revenue (Cheema-Fox et al. 2022). Moreover, it is a measure that is readily available. (iii) The measure is available, consistently calculated across countries, and for a long period of time, allowing for use in panel research. (iv)

This measure can be evaluated ex ante by investors unlike the realization of natural disasters or climate change that can only be observed ex post by investors. Second, the sources of tax revenue in developing countries are diverse. For example, we can distinguish between direct and indirect taxes, as well as oil and non-oil revenue. Thus, this study has the advantage of breaking down government revenues into its constituent parts. Such a decomposition is advantageous in that it considers the specific features of each developing country and therefore permits a comparative analysis between these countries.

The rest of the paper is structured as follows. Section 2 provides a brief review of the conceptual and theoretical background to set the context. Section 3 presents the data and stylized facts, Section 4 describes the methodology, Section 5 presents the empirical results, Section 6 presents robustness, and Section 7 concludes.

2 Conceptual background and literature review

2.1 Conceptual background

The literature provides several definitions for vulnerability, mostly depending on the disciplines of their origin (Adger 2006; Brooks 2003; Fellmann 2012; Füssel and Klein 2006; Kelly and Adger 2000). For climate change, the concepts of vulnerability refer to the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is defined as the propensity or predisposition of human societies to be negatively affected by climate hazards (Cheema-Fox et al. 2022). Vulnerability is expressed as a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC 2007). This IPCC (2007) definition specifically highlights three components of climate vulnerability: exposure, sensitivity, and adaptive capacity. Thus, a system is vulnerable if it is exposed and sensitive to the effects of climate change and at the same time has only a limited capacity to adapt (Chen et al. 2015; Fellmann 2012).

Climate exposure relates to 'the nature and degree to which a system is exposed to significant climatic variations' (Fellmann 2012: 39; also see IPCC 2001, 2007). Exposure represents the basic climate conditions and stimuli against which a system operates and any changes in those conditions. *Climate sensitivity* reflects the 'degree to which a system is affected, either adversely or beneficially, by climate variability or change' (Fellmann 2012: 39; also see Chen et al. 2015). 'The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)' (Fellmann 2012: 39; also see Chen et al. 2015; IPCC 2001, 2007). *Climate adaptive capacity* is the ability (or potential) of a system to adjust successfully to climate change (including climate variability and extremes) to (i) moderate potential damages, (ii) to take advantage of opportunities, and (iii) to cope with the consequences (IPCC 2007; also see Fellmann 2012). The adaptive capacities of individuals, households, and organizations vary according to their access to information, ownership of or access to resources, the skills of the people within these systems, and the ability to assess climate issues and make decisions (Nelson et al. 2007).

2.2 Literature review

The literature on the impact of climate vulnerability on government revenue remains scarce. However, it is plausible that an increase in the vulnerability of economies to climate change reduces the economic productivity of production factors. This, therefore, reduces the volume of national production and the level of income of economic actors. The latter limits the purchasing power of populations and thus their ability to import and export, which in turn has a negative impact on the countries' administrative capabilities and ultimately reduces tax revenues.

Climate vulnerability and growth

Several studies have investigated the relationship between climate vulnerability and economic performance at the country-level (Alano and Lee 2016; Botzen et al. 2019; Dell et al. 2012). Studies have also examined the influence of climate vulnerability on growth. For instance, the economic growth impact of climate vulnerability on countries is complex and sometimes ambivalent. First, past research has documented higher economic costs for more vulnerable countries and those that have suffered natural disasters and climate change (Cheema-Fox et al. 2022; Kling et al. 2021). For example, Iverson-Love (2022) shows that earthquakes or natural disaster led to a significant decline in Haiti's growth between 1992 and 2019. Raddatz (2009) shows that climate change has negative effects on real GDP per capita in developing countries. Brito (2015), Cavallo and Noy (2010), Hochrainer (2009), and Noy (2009) show that climate vulnerability has negative effects on economic growth. Kanbur et al. (2019) show that high climate vulnerability has a negative effect on the GDP per capita of African countries over the period 1995–2015. In the same vein, Cheema-Fox et al. (2021, 2022) and McDermott (2016) show that, as climate change is more likely to affect more vulnerable countries, they could divert investment from long-term goals, such as improvements in education and building the country's human capital, towards short-term necessities. This, in addition to reduced labour productivity, could reduce the efficiency of the export sector, thereby negatively affecting the government's fiscal revenue mobilization (Burke et al. 2015; Gassebner et al. 2010). Cheema-Fox et al. (2022) argue that the costs of reconstruction combined with the loss in tax revenue resulting from natural disasters could increase the need for public spending.

Second, further literature claims that the occurrence of natural disasters and climate change can be linked to positive externalities that lead to positive economic growth in the long run. For example, Loayza et al. (2012) and Noy and Vu (2010) show that climate change increases the level of GDP per capita. This positive effect is due to the improved productivity of the business sector as a result of the increased capital stock of firms that survived the climate shocks and new technology adoption (Crespo Cuaresma et al. 2008; Skidmore and Toya 2002). De Mel et al. (2014) show that firms that suffered more damage after the Sri Lanka tsunami in 2004 obtained higher profits due to green innovation.

Climate vulnerability and trade

Another mechanism to understand the theoretical link between climate vulnerability and fiscal mobilization is trade. Indeed, the reduction in factor productivity due to changes in climate conditions leads to a decrease in the level of production and hence the export sector's efficiency. According to Beirne et al. (2021), destruction to the infrastructure and reduced agricultural output could also have a negative effect on exports and the trade balance. Gassebner et al (2010) show that when climate change is linked to a drop in production, it enhances the vulnerability of the economy to international trade and thus limits its capacity to mobilize tax revenues. Beirne et al. (2021) as well as Pankratz and Schiller (2021) show that the supply chains of vulnerable countries are also more likely to suffer disruption. This situation requires the government to undertake a substantial fiscal revenue mobilization effort (Cheema-Fox et al. 2022).

3 Data and stylized facts

We seek to assess the effect of climate vulnerability on government revenue in developing countries. The empirical survey in this paper used a sample of 84 developing countries over the period 1995–2019. The dataset consists of a yearly unbalanced panel selected exclusively based on data availability and is compiled from various sources (see Appendix Table A1).

3.1 Measuring climate vulnerability

Many approaches have been used to measure climate vulnerability. We obtain the climate vulnerability data from the Notre Dame Global Adaptation Index (ND-GAIN). This index brings together 74 variables to form 45 core indicators for 181 countries to measure their environmental vulnerability and their readiness to adapt. This index has the advantage of combining the three dimensions of climate vulnerability, notably exposure,[1] sensitivity,[2] and adaptive capacity,[3] the last of which is partly affected by countries' economic, political, and social settings. Geography, however, determines a country's exposure, which is not a matter of choice (Chen et al. 2015; Kling et al. 2021). The ND-GAIN and its subcomponents are scored between 0 and 1. Descriptive statistics show that the index's mean value is 0.46. The climate vulnerability performance matrix (Appendix Table A2) shows that sub-Saharan African countries such as Niger and Democratic Republic of the Congo (DRC) appear at the top of the list of most climate-vulnerable countries. This position is undoubtedly due to Niger's high sensitivity to the desert, which occupies most of its territory, creating strong discontinuities in rainfall and temperature, which ex-post weakens the country's agricultural production fabric and thus the country's nutritional reserves. In DRC, for example, the economy is highly dependent on its plant ecosystem, which is one of its main sources of fiscal revenue.

Significant differences also emerge across regions (Figure 2). Sub-Saharan Africa and Middle East and North Africa–South Asia exhibit the highest climate vulnerability (above the sample's average), whereas the remaining regions record the lowest climate vulnerability index. This result highlights a greater climate vulnerability proliferation in the former groups compared with the latter ones.

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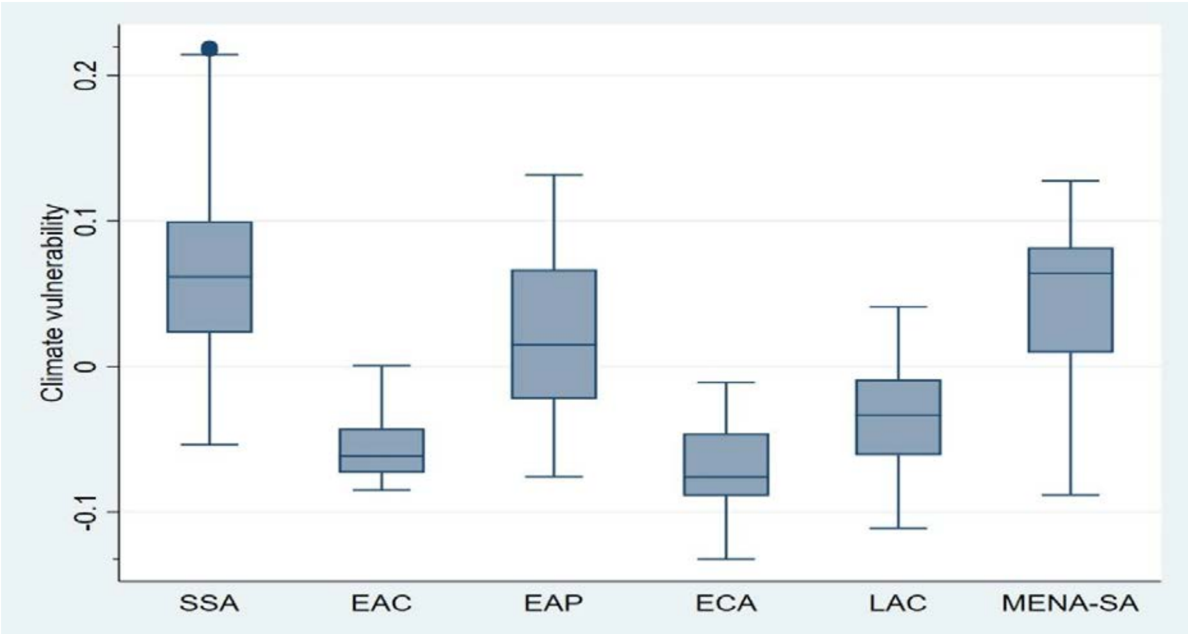
[1] According to Chen et al. (2015), exposure is the extent to which human society and its supporting sectors are stressed by the future changing climate conditions. Exposure in ND-GAIN captures the physical factors external to the system that contribute to vulnerability.

[2] Sensitivity refers to the degree to which people and the sectors they depend on are affected by climate-related perturbations. The factors increasing sensitivity include the degree of dependency on sectors that are climate-sensitive and proportion of populations sensitive to climate hazard due to factors such as topography and demography.

[3] Adaptive capacity is the ability of a society and its supporting sectors to adjust to reduce potential damage and to respond to the negative consequences of climate events. In ND-GAIN adaptive capacity indicators seek to capture a collection of means, readily deployable to deal with sector-specific climate change impacts.

Figure 2: Climate vulnerability index by region (average values)



Note: SSA, sub-Saharan Africa; EAC, East African Community; EAP, East Asia and Pacific; ECA, Europe and Central Asia; LAC, Latin America and Caribbean; MENA-SA, Middle East and North Africa–South Asia. In the box plots, the lower and upper hinges of each box show the 25th and 75th percentiles of the samples, respectively; the columns in the box indicate the median, and the endpoints of whiskers mark the next adjacent value.

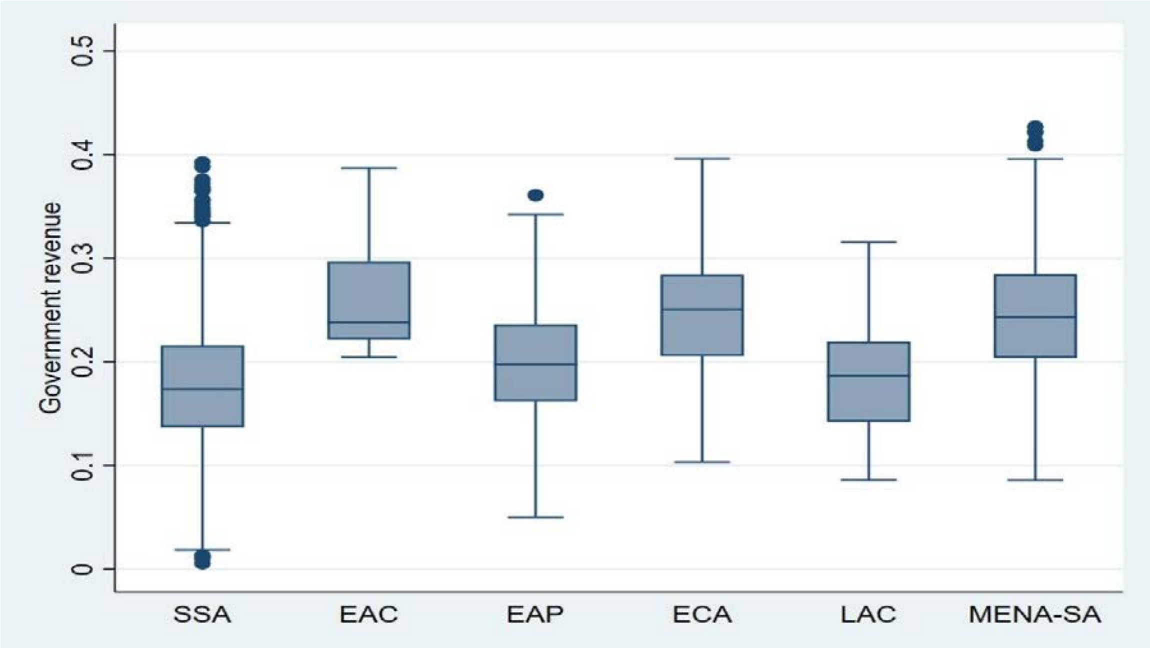
Source: authors' construction using the Notre Dame Global Adaptation Index.

3.2 Measuring government revenue

Government revenues refer to total government revenues. These are collected from the UNU-WIDER Government Revenue Dataset, Version 2021 (see UNU-WIDER 2021). Total government revenues include (i) taxes,[4] (ii) non-tax revenues, (iii) indirect tax, and (iv) direct tax. The descriptive statistics (Appendix Table A1) show the low level of government revenue across the sample. On average, countries mobilized 18.8 per cent of revenue relative to GDP. Countries like Montenegro and China lead the way with over 37 per cent of GDP in government revenue. Sub-Saharan Africa in our sample is far behind, with countries in this region ranking at the bottom with less than 8 per cent of GDP in government revenue. Significant differences appear between the different groups (Figure 3). SSA is the worst region in terms of fiscal revenue mobilization, unlike the other regions.

[4] Data collected exclude social contributions and grants and are expressed as shares of GDP.

Figure 3: Government revenue index by region (average values)

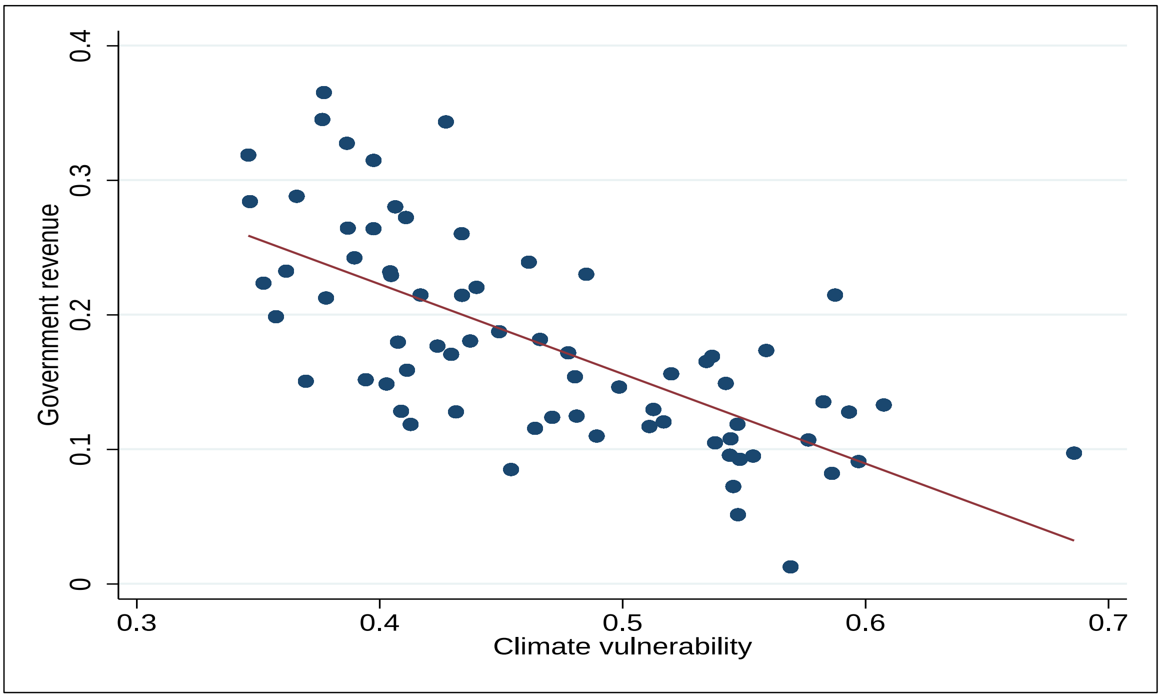


Note: SSA, sub-Saharan Africa; EAC, East African Community; EAP, East Asia and Pacific; ECA, Europe and Central Asia; LAC, Latin America and Caribbean; MENA-SA, Middle East and North Africa–South Asia.

Source: authors' construction using the UNU-WIDER Government Revenue Dataset Version 2021.

By pooling the level of government revenue and the climate vulnerability index of the different countries, Figure 4 shows that there is a potential negative link between the two variables (see the linear trend); this presumption of the sign is confirmed by the correlation Appendix Table A3. This negative link reflects the idea that climate vulnerability is a cost to economies in terms of government revenue.

Figure 4: Relation between climate vulnerability and government revenue



Source: authors' construction using the UNU-WIDER Government Revenue Dataset, Version 2021 and ND-GAIN.

The control variables are sourced from the World Governance Indicator and World Development Indicator databases (see World Bank 2021a, 2021b).

4 Methodology

4.1 Specification of the econometric model

To assess the effect of climate vulnerability on government tax revenue, we estimate a panel model based on the empirical model by Kling et al. (2021). The specification of the model is as follows:

$$GR_{it} = \alpha_i + \alpha_1 cv_{it} + \alpha_3 X_{it} + \mu_t + \varepsilon_{it} \tag{1}$$

where GR_{it} represents the level of the government revenue tax of country i over period t and is composed of two main categories: (i) government revenue, which takes into account taxes, non-tax revenues, and social contributions (Oppel et al. 2021); and (ii) taxes, consisting of direct taxes and indirect taxes. cv_{it} is the measure of climate vulnerability that captures the degree of reliability of an economy to climate hazards and its ability to adapt. X_{it} is the vector of the k control variables of the model. The control variables include control of corruption, agriculture, inflation, aid, and GDP per capita. α_i represents the country fixed-effects that controls for unobservable characteristics that are time-invariant and specific for each individual, μ_t represents the time-specific effect that measures the effects on temporal variation in climate vulnerability and tax revenue mobilization of changes in unobservable variables assumed to be common to all countries and ε_{it} is error term. t=1, 2, 3, . . . T and i=1, 2, 3 . . . N represent the study period and the individuals in the sample, respectively.

These variables are described as follows. Agriculture is measured as the share of value added in agriculture (as a percentage of GDP). In addition, the agricultural sector is more often subject to politically motivated tax exemptions, as it is considered a sector providing food for subsistence (Agbeyegbe et al. 2006). The literature recognizes that the agricultural sector is a difficult sector to tax in developing countries because of its high informality. Thus, an a priori negative empirical link between tax revenues and agricultural components is conceivable (Agbeyegbe et al. 2006; Gupta 2007). Official development aid is made up of grants, preferential budgeted loans, and transfers from developed to developing countries. Official development assistance has differential effects on fiscal resources (Morrissey and Torrance 2015). Recent works acknowledge that aid improves the level of fiscal resources in developing economies (Clist 2016; Clist and Morrissey 2011; Mascagni 2016a, 2016b). GDP per capita in constant dollars measures a country's income level and level of economic development. Importantly, a high GDP per capita indicates increased consumption of goods and services, which implies more government revenue. It is expected that GDP per capita is positively associated with tax resources (Gupta 2007). Inflation is measured by the consumer price index, which reflects the annual percentage change in cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as once a year. So, the existence of increased inflation implies a reduction in the demand for goods and services and therefore a reduction in fiscal resources. The literature shows that inflation tends to reduce revenues (Mahdavi 2008). We expect inflation to reduce government revenue mobilization. We also add variables of governance that may facilitate resource mobilization. The literature shows that the existence of good governance improves a country's performance in tax resource mobilization (Baum et al. 2017). Thus, we expect corruption control to decrease revenue mobilization.

4.2 Estimation method

The estimation of Equation (1) is done with the pooled ordinary least square (POLS) regressor technique of Driscoll and Kraay (1998). The advantage of this technique is that it not only takes into account the heterogeneities between groups but also corrects the potential heteroscedasticities and autocorrelations that may exist between variables while considering the cross-sectional dependencies within the groups. Also, this estimator can handle missing values and does not impose any restriction on the limiting behaviour of the number of individuals with respect to the temporal dimension of the panel. Likewise, the Driscoll–Kraay fixed-effects estimator has the advantage of proposing a non-parametric variance–covariance matrix that not only generates consistent standard errors under the assumptions of homoscedasticity and autocorrelation but also produces standard errors that are robust to cross-sectional dependence. The Driscoll–Kraay standard deviation estimation thus ensures that the covariance matrix estimator is consistent regardless of the cross-sectional dimension and eliminates the deficiencies of other large-scale consistent covariance matrix estimation methods (Hoechle 2007). Thus, the POLS and fixed-effects regressors technique of Driscoll and Kraay (1998) could provide consistent and unbiased coefficients (Gehring et al. 2017; Hoechle 2007).

5 Empirical results

5.1 Preliminary evidence

Table 1 shows the empirical results of the effect of climate vulnerability on government revenues-to-GDP, following the POLS and Driscoll–Kraay fixed-effects approach. We find evidence that climate vulnerability undermines tax government revenue in developing countries, regardless of the methodological approach used (Columns 1–4). The results are statistically significant at conventional levels. The results indicate that a 1 percentage point increase in the climate vulnerability index is associated with a 0.63 percentage point decrease in the fiscal government revenue-to-GDP ratio on average (see Column 4). This result is in line with some of the literature's predictions and findings (see Kere et al. 2015; Kling et al. 2021). The findings suggest that climate vulnerability limits the financial and sometimes physical capacity of individuals on the one hand and the country's fiscal structure on the other. Considering this last argument, in most countries in our sample, tax government revenues are subject to agricultural revenues, extractive revenues, and imports that are sometimes very sensitive to climate and natural hazards. Climate change and disasters increase people's vulnerability and reduce their agricultural production, which is one of the main livelihoods of the major part of the rural population in developing countries. This fall in agricultural income alters their purchasing power and therefore the population's ability to import goods and services and hence the fiscal sustainability of the economy.

Table 1: Effect of climate vulnerability on government revenue

Variables	POLS with Driscoll–Kraay		FE with Driscoll–Kraay	
	(1)	(2)	(3)	(4)
Climate vulnerability	−0.7231***	−0.6516***	−0.9981***	−0.6437***
	(0.0143)	(0.0174)	(0.0639)	(0.0878)
Control of corruption		−0.0051**		−0.0061**
		(0.0000)		(0.0001)
Agriculture		−0.0006		−0.0016***
		(0.0005)		(0.0001)
Log inflation		0.0012		0.0006
		(0.0022)		(0.0010)
Public aid		0.0093***		0.0065***
		(0.0014)		(0.0011)
Log GDP per capita		−0.0074		0.0019
		(0.0044)		(0.0059)
Constant	0.5190***	0.5023***	0.6454***	0.4616***
	(0.0057)	(0.0439)	(0.0288)	(0.0832)
Observations	1,626	1,398	1,626	1,398
R-squared	0.431	0.498		
R-squared_*w*			0.224	0.330

Note: POLS, pooled ordinary least square; FE, fixed effects. *, **, and *** denote statistical significance at 10, 5, and 1 per cent levels, respectively. Standard errors are reported in parentheses.

Source: authors' calculations based on study data.

As for the other variables, the governance quality captured by corruption and the shares of agriculture as a percentage of GDP negatively affect government tax revenue, while public aid is positively and significantly associated with the government tax revenue ratio.

5.2 Sensitivity analysis tax components

The literature documents that different types of taxes provide a stable basis for tax revenue mobilization in developing countries (Di John 2006; Ebeke and Ölçer 2013; Moore 2014; Yogo and Ngo Njib 2018). In addition, Noy and Nualsri (2011) show that the impact of natural disasters on tax revenues depends both on the macroeconomic dynamics that occur following the disaster shocks as well as on the structure of revenue sources (income taxes, consumption taxes, and direct and indirect taxes). Thus, we also analyse the effect of climate vulnerability on the tax structure of the sample. For the decomposition into tax revenue to direct and indirect taxes, the result supports the harmful effect of climate vulnerability on all these subcomponents of total tax revenue (see Table 2). It appears that direct taxes are the most compromised in terms of magnitude. Indeed, a 1 percentage point increase in the climate vulnerability index is associated with a 0.691 and 0.216 percentage point decrease, respectively, in the direct and indirect tax-to-GDP ratio on average. This result is in line with those of Di John (2006), Savoia et al. (2022), and Yogo and Ngo Njib (2018). Climate vulnerability through its negative effects on consumer and enterprise revenue affects the tax base and thereby reduces a country's level of direct tax, that is, climate change-induced productivity losses that reduce sectoral output or labour demand. This change on the revenue side directly determines the level of government direct tax (Bachner and Bednar-Friedl 2019).

Table 2: Effect of climate vulnerability on types of government tax revenues

Variables	POLS Driscoll–Kraay			POLS-FE Driscoll–Kraay		
	Total tax	Direct tax	Indirect tax	Total tax	Direct tax	Indirect tax
Climate vulnerability	−0.2649***	−0.4624***	−0.1003***	−0.127**	−0.691***	−0.216***
	(0.0239)	(0.0380)	(0.0094)	(0.0534)	(0.170)	(0.026)
Agriculture	0.0004***	0.0042***	0.0035***	0.0000	0.0004	0.0013**
	(0.0000)	(0.0007)	(0.0004)	(0.0001)	(0.0013)	(0.0006)
Control of corruption	−0.0007***	−0.0133***	−0.0074***	−0.0011***	−0.0208***	−0.0151***
	(0.0002)	(0.0025)	(0.0026)	(0.0001)	(0.0036)	(0.0016)
Log inflation	0.0086***	0.0728***	0.0655***	0.0045***	0.0341***	0.0366***
	(0.0013)	(0.0107)	(0.0072)	(0.0006)	(0.0056)	(0.0030)
Public aid	−0.0007	−0.0071	−0.0629***	−0.0005	−0.0112	−0.0329***
	(0.0012)	(0.0103)	(0.0113)	(0.0008)	(0.0097)	(0.0086)
Log GDP per capita	−0.0005	−0.0956***	−0.0684***	0.0237***	0.1952**	−0.0310
	(0.0012)	(0.0223)	(0.0153)	(0.0053)	(0.0930)	(0.0484)
Constant	0.2346***	−1.1594***	−1.0843***	0.0630	−2.4702*	−0.9722
	(0.0139)	(0.3820)	(0.1691)	(0.0874)	(1.3490)	(0.5909)
Observations	1,518	1,390	1,425	1,518	1,390	1,425
R-squared	0.439	0.310	0.359			
R-squared_*w*				0.362	0.315	0.284

Note: POLS, pooled ordinary least square; FE, fixed effects. *, **, and *** denote statistical significance at 10, 5, and 1 per cent levels, respectively. Standard errors are reported in parentheses.

Source: authors' calculations based on study data.

5.3 The sensitivity analysis with the type of climate vulnerability

Vulnerability is defined as the extent to which an economic system is susceptible of being damaged due to climate change (Schneider et al. 2001). Such climate-related damage is sometimes related to climate hazards, such as floods, storms, mudslides, and droughts. Thus, climate risks are numerous and vary, making climate vulnerability a concept whose analysis of externalities on economic variables, such as economic growth, investment, and tax revenues, should be made according to the degree of exposure, sensitivity, and adaptive capacity of each country to climate risk (Adger 1999; Eakin 2005; Ward and Shively 2012). Following this logic, an important step in analysing our results is to assess the sensitivity of our results by decomposing the climate vulnerability index into its three dimensions, notably exposure, sensitivity, and adaptive capacity. The results in Appendix Table A4 also confirm the adverse effect of these subcomponents of climate vulnerability on government tax revenues.

6 Robustness

In this section, we perform several robustness tests to confirm our hypothesis. First, we investigate the potential endogeneity problem between climate vulnerability and the model's control variables. Second, we consider the substantial heterogeneities between the groups in terms of climate vulnerability, in particular by performing a quantile regression. Finally, we test the sensitivity of the results from the baseline specification by using trade openness and its components (importation and exportation) as additional control variables.

6.1 The endogeneity problem

Using climate vulnerability and some control variables, including macroeconomic and institutional variables, to explain fiscal revenues might lead to an endogeneity bias due to the components of the climate vulnerability index (Kling et al. 2021). Indeed, the construction of the vulnerability index is subject to the consideration of economic, ecological, and socio-cultural variables (Chen et al. 2015). Faced with this potential problem, we rewrite Equation (1) as the following dynamic equation given the strong inertia of government revenue:

$$GR_{it} = \alpha_0 + \alpha_1 GR_{it-1} + \alpha_2 cv_{it} + \alpha_3 X_{it} + \mu_i + \nu_t + \varepsilon_{it} \quad (2)$$

GR_{it} denotes the lag government tax revenue in a country i for year t. cv_{it} represents the climate vulnerability index and X_{it} is the vector of control variables, which are the same variables specified before. μ_i is an unobserved country-specific effect, and ν_t is a time-specific effect. ε_{it} is the error term.

We investigate Equation (1) by using the two-step system generalized method of moments (GMM) approach developed by Blundell and Bond (1998). This is used to solve three main potential econometric problems such as heteroscedasticity, endogeneity, and over-identification relying on our empirical model specification. By eliminating fixed effects through first differencing, the system-GMM approach allows the correction of omitted variable bias and endogeneity bias by using lagged (one to two lags) endogenous regressors as effective instruments (Roodman 2009). Combined with Windmeijer's (2005) standard error correction, the two-step GMM estimators are more robust than the one-step estimators. We use Hansen's test to check the orthogonality of the instruments to the error terms and to know whether the error terms are autocorrelated, we make use of Arellano–Bond's statistic. The model's validity is conditional by the quality of the instruments chosen (Hansen's test) and on the absence of autocorrelation of the second-order errors (AR(2)).

The GMM estimation results are reported in Table 3 and remain unchanged. Indeed, climate vulnerability is strongly undermining tax government revenue in developing countries, regardless of all the different subcomponents of government tax revenue. If this effect does not change, then we take into consideration the three main climate vulnerability subcomponents (see Appendix Table A5). Statistical tests widely validate our econometric method and the strong statistical significance of the coefficients associated with the lagged dependent variable confirms the inertia effect in the tax revenue ratio that legitimates the choice of dynamic specification.

The *p*-values of Hansen's test and the Arellano–Bond tests for serial correlation (AR(1) and AR(2)) are reported at the bottom of Table 3 and confirm the validity of our econometric approach. Indeed, we reject the null hypothesis of no first-order residual serial correlation but accept the hypothesis of no second-order serial correlation. The Hansen test statistic for the over-identifying restrictions is not significant, suggesting that the set of instruments used satisfies the exogeneity condition required to get consistent estimates in the estimated models.

Table 3: Effect of climate vulnerability on government revenue with two-step system-GMM

	Two step system-GMM with type of tax resources							
	Government revenue		Total tax		Direct tax		Indirect tax	
Total revenue	0.5849***	0.6106***						
	(0.0837)	(0.0971)						
Total tax			0.9039***	0.8905***				
			(0.0259)	(0.0315)				
Log direct tax					0.9264***	0.8747***		
					(0.0248)	(0.0316)		
Log indirect tax							0.8674***	0.7155***
							(0.0637)	(0.1181)
Climate vulnerability	−0.3091***	−0.2931**	−0.0352**	−0.0823**	−0.0102**	−0.9647**	−0.0410**	−0.2778**
	(0.0892)	(0.1274)	(0.0136)	(0.0340)	(0.0049)	(0.4788)	(0.0196)	(0.1102)
Control of corruption		0.0003		0.0001*		0.0016		0.0001
		(0.0002)		(0.0001)		(0.0017)		(0.0002)
Agriculture		−0.0012*		0.0001		−0.0117**		−0.0011*
		(0.0006)		(0.0004)		(0.0051)		(0.0006)
Public aid		−0.0006		0.0011*		0.0113		0.0029
		(0.0018)		(0.0006)		(0.0084)		(0.0032)
Log inflation		0.0024**		−0.0028*		−0.0048		−0.0009
		(0.0011)		(0.0015)		(0.0102)		(0.0020)
Log GDP per capita		−0.0086		−0.0061		−0.2132**		−0.0275**
		(0.0101)		(0.0061)		(0.0901)		(0.0105)
Constant	0.2310***	0.2890**	0.0316***	0.0973	0.0087***	1.8153*	0.0323**	0.3751***
	(0.0563)	(0.1214)	(0.0098)	(0.0603)	(0.0032)	(0.9517)	(0.0148)	(0.1258)
Observations	1,282	1,140	1,574	1,444	1,430	1,307	1,523	1,268
Number of instruments	10	49	12	33	16	40	15	34
AR(1)	2.22e−05	0.000300	7.37e−05	0.000357	1.48e−05	7.82e−05	0.000817	0.00944
AR(2)	0.872	0.731	0.332	0.299	0.133	0.363	0.357	0.401
Hansen's test	0.549	0.693	0.177	0.120	0.582	0.140	0.128	0.438

Note: *, **, and *** denote statistical significance at 10, 5, and 1 per cent levels, respectively. Standard errors are reported in parentheses

Source: authors' calculations based on study data.

6.2 Quantile approach

To probe deeper into the relationship between government tax revenues and climate vulnerability we perform quantile regression analysis based on the cross-section data. This approach allows us to examine the nexus throughout the entire distribution of climate vulnerability. Table 4 resumes the baseline results. When we consider the influence of climate vulnerability on government tax revenue, we can see that they all have a positive impact. This effect is the same with all the climate vulnerability subcomponents (see Appendix Tables A6–A8). The findings show that at 1 per cent level, the effect is negative and statistically significant at the lower (10th–25th) and higher (50th–75th) quantiles. However, at the 95th quantiles, the elasticity of the climate vulnerability index is not statistically significant. This statement supports previous claims that climate vulnerability is harmful to government tax revenue as it deters tax collection capacity in developing countries.

Table 4: Quantile analysis of the effect of climate vulnerability on government revenue

	Bootstrapped quantile regression				
	q(0.1)	q(0.25)	q(0.50)	q(0.75)	q(0.95)
Climate vulnerability	−0.3502***	−0.2909***	−0.2534***	−0.1769***	−0.0641
	(0.0170)	(0.0220)	(0.0171)	(0.0210)	(0.0551)
Control of corruption	0.0005***	0.0005***	0.0004***	0.0003***	0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Agriculture	−0.0013***	−0.0010***	−0.0007**	−0.0003*	−0.0012***
	(0.0001)	(0.0002)	(0.0003)	(0.0002)	(0.0003)
Public aid	0.0033***	0.0057***	0.0099***	0.0113***	0.0141***
	(0.0005)	(0.0011)	(0.0005)	(0.0010)	(0.0013)
Log inflation	−0.0056***	−0.0053***	−0.0023*	0.0001	0.0039***
	(0.0011)	(0.0009)	(0.0012)	(0.0011)	(0.0014)
Log GDP per capita	−0.0259***	−0.0128***	0.0002	0.0185***	0.0246***
	(0.0021)	(0.0022)	(0.0035)	(0.0022)	(0.0053)
Constant	0.4584***	0.3421***	0.2253***	0.0619***	0.0049
	(0.0220)	(0.0203)	(0.0328)	(0.0227)	(0.0605)
Observations	1,518	1,518	1,518	1,518	1,518
R-squared	0.2400	0.2447	0.3002	0.3209	0.3495

Note: *, **, and *** denote statistical significance at 10, 5, and 1 per cent levels, respectively. Standard errors are reported in parentheses.

Source: authors' calculations based on study data.

6.3 Robustness check: adding trade openness as a control variable

This section addresses another robustness check for the validity of our findings. We test the sensitivity of the baseline results using an additional control variable, namely the level of trade openness and its components (imports and exports). Theoretically, Gnangnon and Brun (2018) find that increase in the volume of trade enhances tax revenues by making it more likely to be taxed through domestic consumption and corporate profits. In the same vein, Kere et al. (2015) and Ward and Shively (2012) show that climate vulnerability reduces production capacities, particularly in terms of the depletion of an economy's capital stock. This reduced production induces a decrease in imports and exports, which in turn leads to a drop in direct or indirect taxes.

Table 5 reports the estimation result. The results are broadly consistent with our finding that climate vulnerability harms government tax revenue in developing countries. Also, the coefficients associated with the trade component are positive and significant (Columns 2 and 3, respectively) whereas trade openness itself is non-significant (Column 1).

Table 5: Sensitivity effect of climate vulnerability on government tax revenue with other control variables

Variables	(1)	(2)	(3)
Total resources	0.5839***	0.6287***	0.7709***
	(0.0390)	(0.0361)	(0.0878)
Climate vulnerability	−0.3265***	−0.2661***	−0.3432***
	(0.0906)	(0.0780)	(0.1043)
Log trade	0.0130		
	(0.0103)		
Exports of goods and services		0.0002*	
		(0.0001)	
Imports of goods and services			0.0006***
			(0.0002)
Control variable	Yes	Yes	Yes
Observations	1,036	1,036	1,036
Number of ID	63	63	63
Number of instrument	32	38	28
AR(1)	8.49e−05	4.19e−05	0.000709
AR(2)	0.827	0.812	0.737
Hansen's test	0.344	0.278	0.560

Note: *, **, and *** denote statistical significance at 10, 5, and 1 per cent levels, respectively. Standard errors are reported in parentheses.

Source: authors' calculations based on study data.

7 Conclusion

Motivated by the persistence of climate change irregularities and the low level of revenue mobilization observed in developing countries, this paper aims to analyse the effects of climate vulnerability on government revenue mobilization in a sample of 84 developing countries over the period 1995–2019. The study disaggregates the fiscal resources into its different components and climate vulnerability into its three dimensions (climate exposure, sensitivity, and adaptive capacity). The estimation of our model is done using POLS and fixed-effects ordinary least square regressor technique of Driscoll and Kraay (1998). To control for the potential endogeneity inherent to the structure of our variables, the system-GMM estimation approach of Blundell and Bond (1998) with heteroscedasticity corrected standard deviations following the procedure of Windmeijer (2005) is also used. Three main results emerge from this study. First, climate vulnerability weakens government revenue mobilization in developing countries. Indeed, a variation of 1 per cent in the level of climate vulnerability induces a decrease of 0.63 points of government revenues. Second, climate vulnerability has different impacts on each type of government tax revenue. In effect, for the subcomponents of total tax revenue (direct and indirect tax), the result supports the harmful effect of climate vulnerability on all of them. although it appears that direct taxes are the most compromised in terms of magnitude. Third, this effect does not change when climate vulnerability is disaggregated (exposure, sensitivity, and adaptive capacity). However, the costs in terms of tax revenues in developing countries are more important when the climate sensitivity index is compared with the two others. All these results are robust to the endogeneity problem control and quantile approach. These results suggest recommendations for the implementation of measures to improve the resilience of people to climate change and natural disasters. The first is to assess the baseline climate change knowledge of the population. The second is to define and implement more suitable programmes based on the vulnerability profile of the groups.

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Appendix

Table A1: Summary statistics

Developing countries	*N*	Mean	SD	Min	Max
Total revenue	1,626	0.187	0.082	0.01	0.471
Tax	1,381	0.178	0.088	0.006	0.929
Non-tax revenue	1,381	0.122	0.113	−0.719	0.903
Social contribution	1,992	0.026	0.034	−0.004	0.174
Grants	1,447	0.06	0.081	−0.029	0.768
Indirect taxes	2,064	0.103	0.061	−0.054	0.685
Direct taxes	1,920	0.049	0.032	−0.061	0.247
Climate vulnerability	2,088	0.468	0.078	0.323	0.705
Climate sensitivity	2,064	0.375	0.081	0.213	0.629
Climate exposure	2,088	0.444	0.078	0.267	0.722
Adaptation capacity	2,016	0.593	0.137	0.316	0.896
Control of corruption	2,088	36.93	21.021	−7.408	97.886
Agriculture	2,088	16.071	10.971	−1.463	66.914
Inflation	1,992	11.31	41.838	−18.109	1,058.374
Public aid	1,946	4.342	2.247	−1.441	19.814
Trade	2,040	82.642	50.263	−260.592	478.633
GDP per capita	2,088	3,546.158	2,919.345	207.726	16,438.641

Source: authors' calculations based on study data.

Table A2: Data description

	Definition	Source
Climate vulnerability	Degree to which a system or resource is susceptible to damage from the negative effects of climate change	ND-GAIN 2020
Exposure	The extent to which human society and its supporting sectors are stressed by the future changing climate conditions. Exposure in ND-GAIN captures the physical factors external to the system that contribute to vulnerability.	ND-GAIN 2020
Sensitivity	The degree to which people and the sectors they depend upon are affected by climate-related perturbations. It includes the degree of dependency on sectors that are climate-sensitive and proportion of populations sensitive to climate hazard due to factors such as topography and demography.	ND-GAIN 2020
Capacity	The ability of society and its supporting sectors to adjust to reduce potential damage and to respond to the negative consequences of climate events.	ND-GAIN 2020
Government resources revenue	Tax revenue refers to compulsory transfers to the central government for public purposes.	GRD 2021
Control of corruption	Measures perceptions of corruption, conventionally defined as the exercise of public power for private gain	V-DEM 2021
Agriculture	Measure the annual growth rate of agricultural value added in constant local currency	WDI 2021
Inflation	Measure the consumer price index, which reflects the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as once a year.	WDI 2020
Official development assistance	Represents grants, preferential budgeted loans and transfers from developed to developing countries.	WDI 2020
Trade openness	The sum of exports and imports of goods and services measured as a share of gross domestic product.	WDI 2020
GDP per capita	Annual percentage growth rate of GDP per capita based on constant local currency. GDP per capita measures a country's income level and level of economic development	WDI 2020

Note: ND-GAIN, Notre Dame Global Adaptation Index; GRD, Government Revenue Database; V-DEM, Varieties of Democracy; WDI, World Development Indicators; GDP, gross domestic product.

Source: authors' compilation based on study sources in table (see UNU-WIDER 2021; V-DEM 2021; World Bank 2021b).

Table A3: Countries ranking for both climate vulnerability and government revenue (in % GDP)

Country	Climate vulnerability	Rank	Government revenue	Rank	Country	Climate vulnerability	Rank	Government revenue	Rank
Montenegro	0.3763618	9	38.76877	1	India	0.5199700	63	16.90314	44
China	0.4046846	22	37.70348	2	Papua	0.5344804	65	16.53212	45
Malaysia	03695709	8	36.57378	3	Saint Lucia	0.3572838	5	15.99396	46
Cameroon	0.4810382	53	34.63922	4	Moldova	0.4337109	36	15.60744	47
Myanmar	0.5474552	73	34.34302	5	Congo, DR	0.5294656	64	15.39628	48
Afghanistan	0.5861139	81	32.74122	6	Cote d'Ivoire	0.5168408	62	15.1258	49
Senegal	0.5424429	68	31.94433	7	Bolivia	0.4950913	57	15.0646	50
Ukraine	0.3864597	12	31.58672	8	Bhutan	0.5444036	70	14.90462	51
Guatemala	0.4709735	50	28.72013	9	Uzbekistan	0.3895888	14	14.88495	52
North Macedonia	0.365816	7	28.47379	10	Mauritania	0.5691142	77	14.86184	53
Pakistan	0.5380139	67	27.97538	11	Rwanda	0.5931867	83	14.6346	54
Niger	0.6858308	87	27.30956	12	Armenia	0.4074706	24	14.2857	55
Ethiopia	0.5764104	78	26.45065	13	Mexico	0.4087914	25	13.83101	56
Peru	0.4552597	45	26.39366	14	Turkey	0.361476	6	13.5195	57
Belize	0.4613543	46	26.09423	15	Guyana	0.4775701	51	13.29688	58
Albania	0.4338397	37	25.37528	16	Lao Republic	0.5482173	74	12.97173	59
Equatorial Guinea	0.4540265	44	25.34783	17	Cambodia	0.5440788	69	12.95641	60
Bulgaria	0.3465358	3	25.27176	18	Nicaragua	0.4674737	49	12.82932	61
Costa Rica	0.3778782	11	24.83641	19	Romania	0.4063895	23	12.80795	62
Solomon Islands	0.587442	82	24.22734	20	Morocco	0.3974174	17	12.46412	63
Bosnia a	0.3769901	10	24.18456	21	Jamaica	0.4287295	32	12.40189	64
Burkina Faso	0.582586	79	23.24655	22	Argentina	0.3967127	16	12.0313	65
Mongolia	0.4167723	29	23.1833	23	Kenya	0.5368003	66	11.9265	66
Federated States of	0.6009366	85	23.02111	24	Honduras	0.4659423	48	11.86257	67
Panama	0.3942427	15	22.91957	25	Madagascar	0.5536721	75	11.70144	68
Fiji	0.4398181	39	22.53065	26	Dominican	0.4313555	35	11.51843	69
Azerbaijan	0.4112169	27	22.03263	27	Mauritius	0.4237447	30	10.98277	70
Botswana	0.4830119	54	21.76329	28	Tunisia	0.3868579	13	10.84861	71
Russian Federation	0.3458985	2	21.583	29	Nigeria	0.5148138	61	10.54095	72
Yemen	0.5455365	71	21.47305	30	South Africa	0.4107853	26	10.33436	73
Georgia	0.4042723	21	21.30967	31	Egypt	0.4441368	40	9.85443	74

Paraguay	0.4127084	28	20.7964	32	Vietnam	0.4985584	58	9.72064	75
Ecuador	0.4538398	43	19.88392	33	Indonesia	0.4639223	47	9.49908	76
Maldives	0.5472283	72	18.87673	34	El Salvador	0.4491272	41	9.25609	77
Cuba	0.4313539	34	18.30799	35	Brazil	0.3974597	18	9.08511	78
Eswatini	0.5126433	60	18.13287	36	Serbia	0.4272492	31	8.49501	79
Tajikistan	0.4027924	20	18.04561	37	Belarus	0.3367392	1	8.20256	80
Kyrgyzstan	0.3521218	4	17.95656	38	Togo	0.5109797	59	7.5418	81
Ghana	0.4892903	56	17.8128	39	Mali	0.6074736	86	7.24584	82
Thailand	0.4294052	33	17.40858	40	Philippines	0.4803413	52	5.26031	83
Republic of Congo	0.5971075	84	17.35484	41	Samoa	0.4850278	55	1.26719	84
Vanuatu	0.5591136	76	17.0695	42					
Cape Verde	0.4372076	38	16.90843	43					

Source: authors’ calculations based on study data.

Table A4: Effect of climate vulnerability dimension on government revenues

Variables	POLS regression with Driscoll–Kraay						POLS-FE regression with Driscoll–Kraay					
Sensitivity	−0.4669***	−0.2790***					−0.5314***	−0.2824***				
	(0.0112)	(0.0173)					(0.0558)	(0.0621)				
Exposure			−0.4374***	−0.3089***					−0.4157**	−0.2708		
			(0.0145)	(0.0216)					(0.1869)	(0.1812)		
Capacity					−0.3895***	−0.3479***					−0.3798***	−0.1691***
					(0.0077)	(0.0104)					(0.0250)	(0.0331)
Control of corruption		−0.0002***		−0.0001		0.0001***		−0.0002***		−0.0002***		−0.0002***
		(0.0000)		(0.0000)		(0.0000)		(0.0001)		(0.0001)		(0.0001)
Agriculture		−0.0018***		−0.0018***		−0.0015***		−0.0014***		−0.0015***		−0.0016***
		(0.0004)		(0.0004)		(0.0003)		(0.0001)		(0.0002)		(0.0001)
Log inflation		0.0062***		0.0049***		0.0013		−0.0001		0.0001		0.0005
		(0.0018)		(0.0017)		(0.0021)		(0.0010)		(0.0012)		(0.0012)
Public aid		0.0102***		0.0077***		0.0100***		0.0067***		0.0068***		0.0070***
		(0.0014)		(0.0018)		(0.0009)		(0.0012)		(0.0012)		(0.0012)
Log GDP per capita		0.0053		0.0178***		−0.0138***		0.0151**		0.0256***		0.0112**
		(0.0040)		(0.0049)		(0.0032)		(0.0061)		(0.0051)		(0.0042)
Constant	0.3577***	0.2199***	0.3807***	0.1654***	0.4131***	0.4641***	0.3813***	0.1644**	0.3699***	0.1034	0.4075***	0.1922***
	(0.0060)	(0.0322)	(0.0086)	(0.0515)	(0.0066)	(0.0288)	(0.0198)	(0.0676)	(0.0760)	(0.0983)	(0.0137)	(0.0444)
Observations	1,623	1,396	1,626	1,398	1,587	1,378	1,623	1,396	1,626	1,398	1,587	1,378
R-squared	0.198	0.349	0.158	0.396	0.386	0.473						
R-squared_*w*							0.138	0.322	0.158	0.384	0.179	0.308

Note: POLS, pooled ordinary least square; FE, fixed effects.

Source: authors' calculations based on study data.

Table A5: Effect of climate vulnerability dimension on type of tax government revenues

	Two-step system-GMM with type of tax resources and components of vulnerability											
Variables	Total revenues			Total tax			Direct tax			Indirect tax		
Total resources	0.6469***	0.6556***	0.5396***									
	(0.0842)	(0.0953)	(0.0812)									
Total tax				0.917***	0.9052***	0.9007***						
				(0.0176)	(0.0190)	(0.0211)						
Log direct tax							0.9056***	0.9089***	0.9079***			
							(0.0163)	(0.0125)	(0.0239)			
Log indirect tax										0.8675***	0.9883***	0.8198***
										(0.0590)	(0.0098)	(0.0596)
Sensitivity	−0.4259***			−0.0198**			−0.1821**			−0.1424**		
	(0.1308)			(0.00821)			(0.0745)			(0.0659)		
Exposure		−0.3924**			−0.0286***			−0.1539*			−0.0081*	
		(0.1603)			(0.0097)			(0.0807)			(0.0048)	
Capacity			−0.2159***			−0.0200***			−0.1023*			−0.0764***
			(0.0498)			(0.0062)			(0.0558)			(0.0284)
Constant	0.2318***	0.2462***	0.2242***	0.0207***	0.0277***	0.0276***	−0.2118***	−0.2034***	−0.2130***	0.0673**	0.0055*	0.0635***
	(0.0623)	(0.0834)	(0.0443)	(0.00531)	(0.0063)	(0.0065)	(0.0452)	(0.0515)	(0.0561)	(0.0296)	(0.0029)	(0.0225)
Observations	1,282	1,223	1,248	1,574	1,633	1,587	1,477	1,477	1,445	1,432	1,432	1,392
Number of ID	70	70	68	72	74	72	73	73	71	74	74	72
Number of instrument	10	8	10	8	7	7	11	10	7	14	13	10
AR(1)	1.53e−05	1.12e−05	3.20e−05	8.14e−05	4.30e−05	7.00e−05	1.26e−05	1.18e−05	1.60e−05	0.00239	0.00247	0.00252
AR(2)	0.762	0.630	0.884	0.328	0.157	0.241	0.380	0.380	0.445	0.377	0.396	0.263
Hansen’s test	0.609	0.135	0.599	0.102	0.134	0.125	0.564	0.791	0.380	0.290	0.166	0.500

Source: authors’ calculations based on study data.

Table A6: Effect of type of climate vulnerability on government tax

	Quantile and bootstrapped quantile regression of type of climate vulnerability and total tax														
Variables	q(0.1)	q(0.25)	q(0.50)	q(0.75)	q(0.95)	q(0.1)	q(0.25)	q(0.50)	q(0.75)	q(0.95)	q(0.1)	q(0.25)	q(0.50)	q(0.75)	q(0.95)
Sensitivity	−0.008	−0.02	−0.11***	−0.16***	−0.08**										
	(0.01)	(0.01)	(0.009)	(0.02)	(0.04)										
Exposure						−0.14***	−0.16***	−0.15***	−0.09***	−0.07***					
						(0.0310)	(0.0146)	(0.0170)	(0.0117)	(0.0232)					
Capacity											−0.17***	−0.14***	−0.13***	−0.08***	−0.008
											(0.008)	(0.01)	(0.01)	(0.01)	(0.02)
Constant	0.06*	0.09***	0.07***	0.07**	0.04	0.16***	0.18***	0.09***	−0.01	−0.01	0.37***	0.29***	0.17***	0.02	−0.02
	(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)	(0.02)	(0.01)	(0.03)	(0.02)	(0.03)	(0.03)	(0.01)	(0.04)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,498	1,498	1,498	1,498	1,498

Source: authors' calculations based on study data.

Table A7: Indirect tax

Variables	Quantile and bootstrapped quantile regression				
	q(0.1)	q(0.25)	q(0.50)	q(0.75)	q(0.95)
Climate vulnerability	−0.2911***	−0.2281***	−0.1883***	−0.1613***	−0.0313
	(0.0148)	(0.0218)	(0.0229)	(0.0170)	(0.0316)
Control of corruption	0.0002**	0.0004***	0.0004***	0.0003***	0.0001
	(0.0001)	(0.0000)	(0.0001)	(0.0001)	(0.0001)
Agriculture	−0.0009***	−0.0006***	−0.0004***	−0.0003	−0.0004
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0003)
Public aid	0.0027***	0.0028***	0.0054***	0.0078***	0.0100***
	(0.0007)	(0.0009)	(0.0006)	(0.0009)	(0.0010)
Log inflation	−0.0042***	−0.0044***	−0.0035***	−0.0033***	−0.0001
	(0.0009)	(0.0011)	(0.0009)	(0.0012)	(0.0013)
Log GDP per capita	−0.0241***	−0.0125***	−0.0044**	0.0029*	0.0195***
	(0.0020)	(0.0017)	(0.0018)	(0.0017)	(0.0029)
Constant	0.3860***	0.2741***	0.1961***	0.1371***	−0.0255
	(0.0197)	(0.0202)	(0.0228)	(0.0174)	(0.0240)
Observations	1,425	1,425	1,425	1,425	1,425
R-squared	0.1385	0.2007	0.2566	0.2455	0.2262

Source: authors' calculations based on study data.

Table A8: Direct tax

Variables	Quantile and bootstrapped quantile regression				
	q(0.1)	q(0.25)	q(0.50)	q(0.75)	q(0.95)
Climate vulnerability	−0.1015***	−0.0658***	−0.0532***	−0.0665***	−0.0101
	(0.0147)	(0.0132)	(0.0126)	(0.0245)	(0.0512)
Control of corruption	0.0002***	0.0001***	0.0001***	0.0001**	0.0001
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0002)
Agriculture	−0.0007***	−0.0005***	−0.0002**	−0.0002***	−0.0003
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0003)
Public aid	0.0017*	0.0025***	0.0044***	0.0053***	0.0045***
	(0.0009)	(0.0005)	(0.0004)	(0.0006)	(0.0012)
Log inflation	−0.0012*	−0.0005	0.0006	0.0018**	0.0050**
	(0.0007)	(0.0004)	(0.0006)	(0.0007)	(0.0019)
Log GDP per capita	−0.0095***	−0.0025**	0.0034**	0.0057***	0.0226***
	(0.0013)	(0.0012)	(0.0015)	(0.0021)	(0.0060)
Constant	0.1449***	0.0775***	0.0239	0.0208	−0.1032*
	(0.0145)	(0.0166)	(0.0170)	(0.0270)	(0.0617)
Observations	1,390	1,390	1,390	1,390	1,390
R-squared	0.1852	0.2024	0.2279	0.2085	0.1442

Source: authors' calculations based on study data.