Institut de Recerca en Economia Aplicada Regional i Pública
Research Institute of Applied Economics
Document de Treball 2023/03 1/48 pág.
Working Paper 2023/03 1/48 pag.

"Fiscal crises and climate change"

Jorge M. Uribe

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Abstract

Climate change adaptation depends crucially on the fiscal space of countries. The historical accumulation of high debt levels among emerging and low-income developing countries, which are disproportionately affected by climate change, poses a significant concern. In light of this issue, we empirically examine the potential trade-off between reducing vulnerability to climate change and maintaining fiscal stability. Our findings indicate that governance, as a measure of institutional quality, is the key determinant of both fiscal stability and climate change preparedness. Thus, there is no inherent trade-off between the two aims. Higher levels of institutional quality result in increased preparedness for climate hazards and a lower likelihood of fiscal crises. However, our survival analysis also highlights that fiscal stability is contingent upon the debt burden, particularly the interest paid on that debt. This could potentially result in fiscal instability. In light of these findings, international efforts to address the consequences of climate change should aim to maintain relatively constant interest payments on debt among emerging and low-income countries during their ecological transition. Our results further suggest that enhancing human habitat conditions, while considering the role of governance, is the most effective means of simultaneously reducing the likelihood of a fiscal crisis and increasing preparedness for climate hazards. A reduction in the human habitat vulnerability index by one unit results in approximately a 40% decrease in the probability of a fiscal crisis, while an equivalent increase in governance reduces the probability by 55%.

JEL classification: E44, E62, F34, Q54.

Keywords: Climate vulnerability, Climate hazards, Macroeconomic instability, Duration analysis, Survival analysis, Debt-overhang.

Jorge M. Uribe: Universitat de Barcelona & Universitat Oberta de Catalunya. Email: juribe@uoc.edu

1. Introduction

Climate change is a major threat to macroeconomic and fiscal stability of countries, with their ability to adapt dependent on their fiscal capacity. High fiscal capacity countries are better equipped to handle mitigation and adaptation strategies, while factors like good governance are key for the effective implementation of climate change adaptation strategies. On the other hand, limited fiscal capacity, common among emerging markets and low-income developing economies, hinders their adaptation efforts and increases their vulnerability to climate change, which is greater than in advanced economies (Bolton et al., 2022).

We contribute to this debate, by studying the relationship between climate adaptation and fiscal crises. We make three contributions. First, we analyze whether there is a trade-off between reducing a country's vulnerability to climate change and avoiding a fiscal crisis. Our findings suggest that there is no inherent trade-off between these two goals. This is because institutional quality largely determines fiscal stability and most of the factors and policies that build resilience against climate change are associated with a greater institutional quality. That is, institutions can be understood either as a mediator between climate adaptation and the probability of experiencing a fiscal crisis, or as an underlying common cause of both. Our analysis shows that there is no trade-off in either case.

Next, we move one step forward and ask if there are any dimensions that, if attended, can simultaneously address climate change adaptation and reduce the likelihood of experiencing a fiscal crisis, in addition to the effect of institutions. We show that there are a few such factors related to improving the "human habitat" of countries, but they are rather limited in number, considering the multiple fronts in which climate change is expected to impact human societies.

Finally, we support recent arguments made in the literature (Gomez-Gonzalez, et al., 2022) that it is the interest paid on debt that directly affects the probability of fiscal crises, rather than the level of such debt (both expressed as a percentage of the gross domestic product, GDP). In this case, provision of long run funding at low cost will play a crucial role during the ecological transition of emerging market economies and low income developing countries, which are disproportionately affected by fiscal crises (and by climate change). In principle, a lower interest on debt could compensate for a higher debt burden. This would make it feasible to implement climate change adaptation initiatives without compromising fiscal stability.

Our results employ survival analysis to model the duration of fiscal stability periods (i.e. the time elapsed before a fiscal crisis event is observed), conditioning on macroeconomic, debt-related and institutional covariates informed by the previous literature, alongside the climate vulnerability and readiness indicators from the Notre Dame Global Adaptation Initiative, ND-GAIN (Chen et al., 2015; ND-Gain, 2022)[1].

We are able to isolate the fronts in which governments should prioritize efforts for climate change adaptation aiming to simultaneously improve fiscal prospects in the future. For instance, as we have said before, one key area for fiscal authorities to focus on is reducing the vulnerability of the human habitat of countries. This can be achieved in a variety of ways, as human habitat encompasses three dimensions: exposure, sensitivity and adaptive capacity. The last two can be intervened through policy. Regarding adaptive capacity, improvements in the quality of trade and transport, and the number of paved roads, will positively impact the human habitat and hence fiscal stability outcomes. Reducing sensitivity to the age dependency ratio and to urban concentration will act in the same direction. The exposure components of human habitat are: projected change in warm periods, and projected change in flood hazard. Although those indicators are clearly not actionable by individual countries, they emphasize where contingent strategies should be prepared in such countries.

The ways in which human habitat can influence fiscal outcomes can be inferred from the recent literatures that: a) analyze the greater fiscal pressures that countries prone to natural disasters face (e.g. Marto et al., 2018; Cantelmo et al., 2023), which are related with the loss in productivity and fiscal revenues associated to the occurrence of natural disasters and, with greater social unrest; b) the literature that examines the link between productivity and growth on the one hand and investment in roads as infrastructure on the other hand (Martinius et al, 2017; Caliendo and Parro, 2016; De Soyres et al., 2020; Fiorini et al., 2021;) and, c) finally, the set of studies that analyze the relationship between population aging and rapid urban concentration on the one hand, and economic growth on the other hand (e.g. Edwards, 1996; Hernderson, 2003; Gollin et al., 2016; Cavallo et al., 2018). Overall, our findings highlight the complex relationship between climate change adaptation, macroeconomic stability, and development agendas, emphasizing the need for an integrative approach to address all of these issues. For the first time, this study also incorporates the impact of fiscal crisis into this integrated effort.

[1] ND-Gain country index monitors the vulnerability to climate events and the level of preparedness in a society to face the extreme shocks that climate change is expected to bring. It has been recently used, for instance, by Russo et al. (2019), Blicharska et al. (2021), Kling et al. (2021), Dechezleprêtre et al. (2022), among others and has been compared to other indicators such as the INFORM index (Marri-Ferrer 2017) and the WorldRiskIndex (Birkmann et al., 2011) by Feldmeyer et al. (2021). In short, all three indexes are found to capture well the main vulnerabilities to climate change as highlighted in recent IPCC reports.

We highlight four aspects in terms of vulnerability, two capacity indicators (i.e. quality of trade and share of paved roads) and two sensitivity indicators (i.e. the dependency ratio and urban concentration), in the human habitat dimension, according to our empirical results, presented in section 4. They offer a low hanging fruit approach to climate adaptation that does not compromise, but rather supports, a country's pursuit of fiscal stability, in addition to the beneficial effect achieved through institutions (e.g. governance). But our contribution goes beyond this fact. Our results also indicate that reducing the vulnerability of countries in other sectors others than human habitat, such as food, ecosystems, and health, do not alter the probability of facing a fiscal distress episode, when the role of institutional factors is taken into account[2]. Policy actions in these additional sectors are not in opposition to the aim of preserving fiscal stability.

Focusing on the readiness component of the ND-Gain indicators, which accompanies the vulnerability dimension of human habitat that we have just described, a similar narrative emerges. Readiness measures how prepared a country is to mobilize resources to mitigate climate change impacts. According to our results, improving readiness of countries in economic, and social and especially in governance reduces the probability of facing a fiscal crisis. Of the three, governance is the facet that promises better results for both reducing the probability of fiscal crisis and increasing the level of preparedness of a country's for climate change. Governance consists of the following components: political stability and non-violence, control of corruption, rule of law and regulatory quality and it is therefore, also a proxy for institutional quality. We show that improvements in these dimensions both, reduce the probability of fiscal crises and increase preparedness for climate change adaptation, much more than any other macroeconomic or debt related variable. The intuition is again, that flexibility and capacity for adaptation are in general effective ways to make a country more resilient in the face of crises of all kinds, including fiscal and climate-related crises. In the same way, increasing readiness will necessarily be accompanied by better institutional frameworks, which reduce the probability of fiscal (or other types of) crises. Hence, there is not a trade-off in the readiness dimension either.

A note of caution comes along with our third contribution. Naturally, our results hold under a *ceteris paribus* assumption, in which other variables in our Cox-modeling framework such as the level of debt (or crucially the interest paid on that debt), the rents from natural resources, etc. are assumed to be constant to the intervention (i.e. strategies for climate change adaptation). In practice, the high fiscal cost of climate adaptation, which inevitably will increase debt levels and,

[2] This conclusion holds whether we consider institutions to be a common cause for both, solid fiscal outcomes and resilience to climate change, or a mediator between the latter and the former.

perhaps, the interest paid on that debt, means that the call by Bolton et al. (2022) for fiscal support from advanced economies for funding climate change adaptation efforts in high-debt developing countries remains valid. As noted by these authors, the most vulnerable countries happen to be as well the most indebted ones, and although some of the actions required for climate adaptation may not have a direct fiscal cost, they all have a very large opportunity cost. Therefore, a coordinated fiscal effort across the globe, and specially supported by advanced economies, is required for facing the climate crisis. Our results do not contradict this conclusion, but enrich the discussion, regarding where to prioritize fiscal efforts in order to preserve fiscal stability and emphasize the necessity to keep interest paid relatively constant during the ecological transition of emerging markets and low-income developing countries. Only in this way, the causal chain from debt burden to fiscal crises can be broken. This strategy opens the door for climate adaptation coordination and emphasizes where it is needed.

In terms of contribution, we are the first to study the relationship between vulnerability/preparedness to climate change and fiscal stability. Indeed, there are surprisingly few studies investigating the broader topic covering the interplay between fiscal outcomes and climate change adaptation, most of them originating outside academia in the shape of technical notes and reports (e.g. Buhr et al., 2018; Volz et al., 2020; Arwala et al. 2021; Bunchner et al., 2021; Aligishiev et al., 2022; Bolton et al., 2022) with few exceptions, invariantly focusing on studying the relationship between the cost of sovereign debt and climate risks, or the relation between the cost of funding climate adaptation and sovereign debt markets (e.g. Ameli et al., 2021; Kling et al, 2021; Klusak et al., 2021; Beirne et al., 2021). Our study also enhances the field of climate finance, by adding to the unchartered territory of sovereign credit risk and climate change.

The rest of this document is organized as follows. Section 2 revised the related literature. Section 3 presents our methodology for assessing fiscal crisis and climate vulnerability and readiness for adaptation. Section 4 presents our data and preliminary analysis estimates. Section 5 contains our main results and robustness exercises and section 6 concludes

2. Related Literature and contribution

We contribute on three different fronts. On the one hand, we contribute to the recent literature, (mainly produced by multilateral organizations) which analyzes the complex interplay between sovereign debt and climate change. Secondly, we contribute to the old literature on fiscal crises and their determinants, and finally, we add to the recently born field of climate finance.

2.1. Climate change and sovereign debt

Bolton et al. (2022) summarizes the first strand of the literature and contributes in several directions. These authors analyze the various facets of the relationship between climate and debt. For instance, they explore the fiscal cost of climate adaptation and the fiscal constraints that may arise to enforce said adaptation. They also study the role of green bonds to finance climate adaptation and, whether it can be said that there is a premium for going green in the market of sovereign debt (i.e. a greenium). They find that there is no greenium. In the same group of reports, there have been numerous contributions by a variety of organizations frequently including, in addition to the Center for Economic Policy Research, the United Nations, the International Monetary Fund, and the Inter-American Development Bank (e.g.. Buhr et al., 2018; Voltz et al., 2020; Delgado et al., 2021; Buchner et al., 2021; Aligishiev et al., 2022).

In short, these reports highlight the challenges and opportunities faced by countries in developed and emerging economies in addressing the impacts of climate change through fiscal and other policies. They are usually based on a variety of methodologies, such as interviews, surveys conducted with finance ministers and other key stakeholders, and a variety of data sources on national statistics on emissions, energy generation sources and fiscal revenue obtained from selling fossil fuels. Then, they use these inputs to estimate scenarios of GDP losses and fiscal losses for countries due to climate change risks (both physical and of the transition), or to estimate scenarios of required investments to mitigate climate hazards at the aggregate country level, and generally as well in carbon intensive sectors of the economy such as agriculture, transport, utilities and industry, or in banks, which are known to be largely invested in stranded assets of the ecological transition.

Although these reports provide a detailed overview of the fiscal policies and initiatives that have been implemented by countries around the world to address climate change, highlighting the challenges faced by these countries in securing sufficient resources for climate action, as well as the challenges in designing and implementing effective fiscal policies that can address the impacts of climate change, these writings are mainly descriptive, and lack a proper measuring of the fiscal stress faced by countries, under different conditions of climate vulnerability. Indeed, this dimension has been totally ignored by this literature. Hence, more accurate measures of fiscal distress conditioning on climate vulnerability indicators, as the ones provided in this study are urgently needed.

Policy reports so far have provided recommendations on best practices for future policymaking, which are generally aligned with the need for increasing investment in climate-related initiatives, the importance of improving the efficiency and effectiveness of fiscal policies and programs to address climate change, and the need to prioritize the allocation of resources to address the most pressing climate change impacts. Such recommendations are nevertheless too broad and, frequently, do not recognize the currently very limited fiscal space of countries (Kose et al., 2022), especially the most vulnerable to climate change. We agree with the overall conclusion of these studies, in that it is essential to deploy multiple instruments to finance climate adaptation, and the urgency of global coordination. We add to this conclusion by providing specific routes of climate adaptation that improve as well as fiscal outcomes, and more importantly, we show that in principle there is no inherent trade-off between fiscal stability and climate adaptation, due to the role of governance and, more broadly, institutional quality.

2.2. Fiscal crises

There are numerous methodologies in the literature for forecasting fiscal risks or the related sovereign debt crises (e.g., Fioromanti, 2008; Dawood et al, 2017). The most popular approach in the literature and among policy makers is using the signaling methodology due to Kaminsky et al. (1998), originally designed to forecast currency crises. This method involves determining signal variables through a wide range of indicators that effectively predict fiscal distress. This approach focuses on anticipating fiscal crises by organizing relevant variables into leading indicators. For instance, Hernández de Cos et al. (2014) utilized this approach to create leading indicators for fiscal stress in countries within the Euro Zone. Similarly, Baldacci et al. (2011) created a fiscal stress index that provides early warning signals of fiscal sustainability issues. Another trend in literature is the use of binary outcome models to estimate the probability of observing fiscal or other types of crises (e.g. Lane and Milesi-Ferretti, 2017; Hilscher and Nosbusch, 2007; Maltritz and Molchanov, 2014) and the use of multinominal models, especially in the context of banking crises (e.g., Bussiere and Fratzscher, 2006; Caggiano et al., 2014; Duprey and Kalus, 2022). Authors focusing on fiscal crises emphasize on variables such as foreign-income, risk premium, wars, world growth, governance and other institutional variables, such as control of corruption and property rights to forecast this type of crisis.

These previous studies inform our selection of variables in our duration analysis. Moreover, in methodological terms, as duration analysis can be understood as a generalization of logit and probit models, which ignore the timing of the events, we generalize these previous contributions. The only other study that employs duration analysis to study fiscal crises is due to Gomez-

Gonzalez et al. (2022), which unlike us, focuses on the relationship between a country's income diversification (as a result of its economic complexity) and fiscal performance.

Recently, Machine Learning (ML) models have been employed to capture the nonlinear nature of macroeconomic systems and improve traditional techniques' out-of-sample performance (Fioramanti, 2008; Jarmulska, 2022; Valencia et al., 2022). One downside of ML models is that they can be considered "black boxes", meaning their results are difficult to interpret due to model complexity. Determining the impact of predictors is critical in applications like predicting fiscal stress or fiscal crises, as a model can be deemed unreliable if a predictor's effect is counterintuitive or difficult to gauge.

In this study we expand upon the existing literature on fiscal distress by employing the indicators recently developed at the International Monetary Fund of fiscal crises (see Medas et al., 2018, and Moreno-Badia et al., 2022). Our focus is distinct from most of previous studies, which concentrate on forecasting fiscal crises by utilizing a broad array of variables. Instead, our objective is to identify which factors in the climate change literature, related to climate vulnerability and readiness of countries, affect the probability of a country entering into a fiscal distress state in the years ahead. Additionally, we confirm that, in the short term, when the variables of governance and human habitat are relatively constant, monitoring a country's interest on debt payments is more relevant than focusing excessively on the debt to GDP ratio, which may not effectively predict the likelihood of a fiscal crisis, once we control for the interest paid. This finding aligns with recent calls in the literature that the debt to GDP ratio has varying and country-specific impacts on borrowing costs, making it challenging to use as a benchmark for establishing fiscal alerts (Furmer and Summers, 2020; Caselli et al., 2022; Gomez-Gozalez et al., 2022).

2.3. Climate Finance

Giglio et al (2022) summarize various studies in the recent literature that aim to incorporate climate risk into macro-finance models. They review the empirical literature on the pricing of climate risks across different asset classes such as real estate, equities, and fixed income securities. They also discuss how investors can use these assets to build portfolios that hedge against climate risk. The authors conclude that there is a need for further exploration of the interactions between climate change and financial markets, and the potential implications of these interactions for the financial sector and the global economy. However, the interplay between climate hazards and sovereign debt markets is less well understood. Recent contributions in this direction are found in Kling et al. (2021), Beirne et al. (2021), and Bolton et al. (2022) who establish a solid statistical association between climate vulnerability and the cost of debt. On a related matter, Baker et al. (2022) review the literature on corporate and municipal bond markets and establish that under certain conditions green bonds are priced slightly higher by a few basis points compared to traditional bonds, except when they are released at the same time as regular bonds by the same issuer. In that case, the green bonds tend to gain a higher premium over time in the secondary market. These bonds, particularly those that are low risk or small in size, are typically held more tightly by investors. This aligns with the concept of assets that offer non-pecuniary benefits (e.g. Fama and French, 2007; Pedersen et al., 2021; Oehmke and Opp, 2022; Pastor et al., 2021; Baker et al., 2022). On the contrary, as mentioned before, Bolton et al. (2022) find no evidence of any difference in premium between government green and regular bonds.

We depart from this literature as we focus on modeling the credit risk incarnated in fiscal distress episodes of governments, by modeling the historical probabilities of the fiscal event, and not the equilibrium prices under risk-neutral probabilities of green bonds, or the impact on observed variables on such prices. Nevertheless, our contribution is more direct in addressing key policy questions regarding the ecological transition that governments face in the current environment of record-high debt levels and complements the equilibrium approach, in the same way that reduced form models of credit risk complement arbitrage pricing of credit risk events.

3. Methodology

In this section, we present the indicator of fiscal crises (section 3.1) and the climate vulnerability and readiness for adaptation indicators (section 3.2) that we use in our models. In Section 3.3 we describe the framework of survival analysis, in which we posit our duration model of the time elapsed before a fiscal crisis is observed. In the last section, we explain three possible roles of institutions in our modeling framework, and how these determine the shape of our models in the results section using causal diagrams.

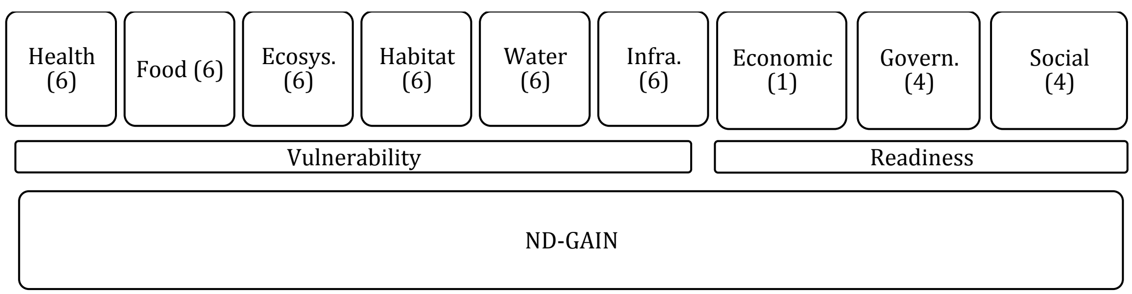
3.1. Fiscal crises indicator

Following Medas et al. (2018) and Moreno-Badia et al. (2022) we define a fiscal distress episode as a period of severe budget strain resulting in exceptional government measures. Using the authors' data from 1995 to 2015 and their criteria for a fiscal crisis, we extend the series from 2016 to 2020. These criteria include: (1) credit events, such as non-payment of debt or debt restructuring losses, (2) substantial external funding from organizations like the IMF or European Union, (3) implicit violation of internal public debt through high inflation or arrears, and (4) loss of market confidence, evidenced by restricted market access, defaults, high borrowing costs, or yield spikes.

3.2. Measuring climate vulnerability and readiness for adaptation

We use the ND- Gain index and its components, to measure climate vulnerability and adaptation to climate change capacity. As stated on the website of Notre Dame Global Adaptation Initiative, The ND-GAIN Index aims to synthesize a country's susceptibility to the impacts of climate change, along with its preparedness to enhance resilience in the face of climate hazards. The main index can be decomposed into two dimensions, vulnerability and readiness. See Figure 1.

Figure 1. Graphical description of the ND-GAIN country index and its components



Note: This figure was adapted from the web page of Notre Dame GAIN. It shows the components of the ND-Gain indicator, vulnerability and readiness, and the subcomponents of each: 6 sectors in the former case, and three dimensions in the latter. It also shows the number of original series that are used to construct each of the sectors and dimensions in brackets.

Vulnerability refers to the predisposition of a given country to be negatively impacted by climate hazards, while readiness is how prepared a country is to take on adaptation actions, leveraging public and private sector responses. In turn, vulnerability indicators can be divided into seven supporting-of-life sectors: health, food, ecosystems, habitat, water and infrastructure, which are assessed in three dimensions: exposure, sensitivity and adaptive capacity. Readiness can be decomposed in three fronts: economic, social and governance. The division can be pursued even further, until reaching very actionable indicators on the side of policy-makers. Indeed, only exposure indicators are not actionable.

3.3. Survival Analysis

The primary objective of this study is to investigate the relationship between climate vulnerability and readiness for adaptation to climate change, and instances of fiscal distress. As per our definition of fiscal crisis, the dependent variable is binary and takes a value of one during periods of fiscal distress, and a value of zero otherwise, for each country. Consequently, we adopt a probability approach to model the time elapse before a fiscal crisis is observed.

In the field of duration analysis, the dependent variable *T* represents the time taken for an event to occur, and is either discrete or continuous. Modeling of such events can be approached either parametrically or semi-parametrically. Indeed, it is recommended to use non-parametric analysis of raw data to determine the best approach. If the non-parametric hazard function is found to be highly non-monotonic through preliminary analysis, evidence against the use of parametric functions exists, and in such cases, the Proportional Hazards (PH) Model of Cox (1972) is preferred.

The survival function to the event of crisis, $S(t)$, can be described as $S(t) = P(T > t)$, interpreted as the probability of the event occurring beyond time *t.* Then, assuming a continuous cumulative distribution function, $P(T \leq t)$, sometimes denoted as $F(t)$, we have that:

$$S(t) = 1 - P(T \leq t), \tag{1}$$

$$= 1 - \int_0^t f(s)\partial s$$

$$= \exp\left\{ - \int_0^t \lambda(s)\partial s \right\}$$

$$= \exp\{-\Lambda(t)\}, \tag{2}$$

where $f(s) = \lim_{\Delta \to 0} \frac{1}{\Delta} P(t \leq T < t + \Delta)$, is the probability density function (interpreted as the instantaneous rate at time t); $\lambda(t)$ is the hazard function (interpreted as the instantaneous rate at time t, given that the event of crisis has not occurred prior to time t); and $\Lambda(t)$, which is the cumulative hazard function. Surprisingly, $\Lambda(t)$ does not have an intuitive interpretation in traditional survival analyses in which the event is death, because it could be interpreted as the number of events up to time t, if the individual were "resurrected" after each event (without resetting the time to zero), but in our case, the intuition is less intricate as a country can be in a fiscal crisis event, and then leave that event, so it can be "resurrected". The hazard function can be expressed as:

$$\lambda(t) = \frac{f(t)}{S(t)}$$

$$= -\frac{\partial}{\partial t} \log \mathrm{S(t)}$$

$$= \frac{\partial}{\partial t} \log \Lambda(\mathrm{t}), \tag{3}$$

and the density function also has a closely link to the hazard and the cumulative hazard in the following way:

$$f(t) = \lambda(t)\, S(t)$$

$$= \lambda(t) \exp\left\{ -\int_0^t \lambda(s) \partial s \right\}$$

$$= \lambda(t) \exp\{-\Lambda(t)\}, \tag{4}$$

Cox (1972) proposed the following model for the hazard function given covariates $z \in \mathbb{R}^P$:

$$\lambda(t; z) = \lambda_0(t) \exp\{z^T \beta\} \in \mathbb{R}^P, \tag{5}$$

Here, $\lambda_0(\cdot)$ is a completely unspecified function, except that it must be non-negative. This model combines great flexibility, via a non-parametric $\lambda_0(\cdot)$ with the possibility of introducing covariates via the exponential term in equation 5. Notice that in Cox modeling framework, proportional hazards for two different individuals are constant, as the hazard ratio HR is given by:

$$HR = \frac{\lambda(t;z)}{\lambda(t;z\prime)} = \exp((z - z')^T \beta), \tag{6}$$

Under constant HR assumption, we have that:

$$\frac{\partial log[\lambda(\cdot)]}{\partial z_k} = \beta_k, \tag{7}$$

for all k, implying that the coefficients can be interpreted as the constant proportional effect of the corresponding covariate on the conditional probability of completion of a spell, which in this study is a country entering a period of fiscal distress.

For specifications that explicitly model the baseline hazard using a parametric model, estimation can be performed through the method of maximum likelihood. In the absence of explicit modeling of the baseline hazard, the conventional estimation method is partial likelihood estimation, as developed by Cox (1972). The critical aspect of this method is that the ratio of hazards between any two individuals depends on covariates but not on duration.

In the presence of censoring, censored spells contribute to the log-likelihood function only in the denominator of uncensored observations, as is the case for most advanced countries in our sample. Censored observations do not enter the numerator of the log-likelihood function.

Ties in durations can be handled through several methods, such as the exact, Efron, and Breslow methods, which are attempted in this paper for robustness purposes.

Suppose we have observations (t_i, δ_i) as well as covariates $z_1, \ldots, z_n, i = 1, \ldots, n$. We assume no ties (meaning that all t_i are different) and define $D \subseteq \{1, \ldots, n\}$ as

$$D = \{I | \delta_l = 1\}, \tag{9}$$

which is the index of fiscal crises times. For any $t \geq 0$ we further define the risk set:

$$R(t) = \{I | t_l \geq t\}, \tag{10}$$

which is the index set of subjects at risk of fiscal crisis at time t.

We have the following alternatives. The original exact partial likelihood estimator, suggested by Cox(1972), where the likelihood to maximize is given by:

$$L(\beta) = \prod_{l \in D} \frac{\exp(z_l^T \beta)}{\sum_{k \in R(t_l)} \exp(z_k^T \beta)}\,. \tag{11}$$

This procedure has the advantage that it does not depend on λ_0, it does not depend on the actual event times, only their order, and censored observations only appear in the risk set. If instead we have ties, Breslow (1975) propose to maximize the following likelihood:

$$L(\beta) = \prod_{l=1}^{r} \frac{\exp(z_l^T \beta)}{\left(\sum_{k \in R(t_l)} \exp(z_k^T \beta)\right)^{d_l}}\,, \tag{12}$$

while Efron (1977) replace sum by $j - 1$ times average, as follows:

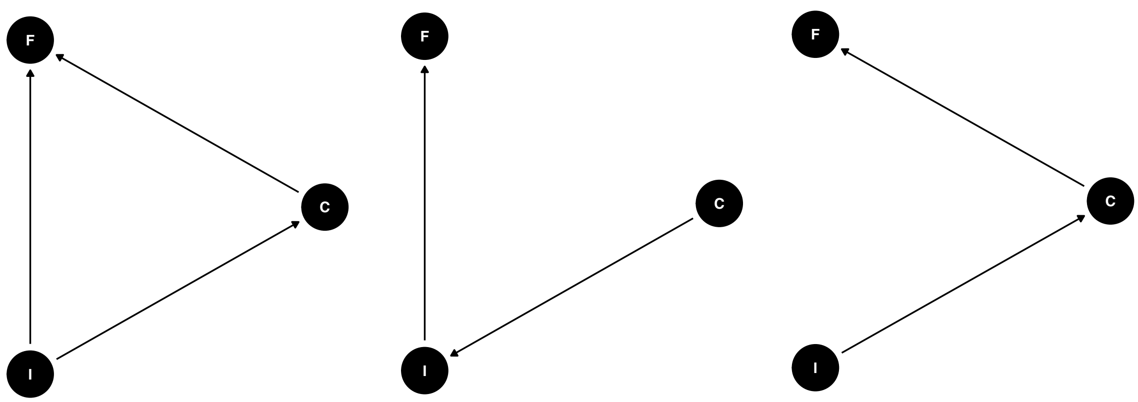
$$\sum_{k \in B_{I(j-1)}} \exp\left(z_k^T \beta\right) \approx (j-1) \frac{1}{d_l} \sum_{k=1}^{d_l} \exp\left(z_{lk}^T \beta\right). \tag{13}$$

3.4. Assessing the role of institutions

In Figure 2 we present three Directed Acyclic Graphs (DAGs), or in other words, three causal diagrams, representing three different models of causal paths involving fiscal distress episodes, F, climate vulnerability and readiness indicators (in short, climate indicators), C, and institutions, I. Model 1 indicates that institutional quality has a direct effect on both climate indicators and fiscal crises. In Model 3, institutional quality serves as a mediator between climate indicators and fiscal crises. Model 3 postulates that institutional quality influences climate resilience indicators, which then impact fiscal crises. Other variables, such as macroeconomic and debt variables, have been omitted from the figure for simplicity but are considered to have a separate effect on fiscal crises.

Figure 2. Directed acyclic graphs describing three possible roles of institutions in relation to climate vulnerability and adaptation capacity indicator, as determinants of fiscal crises

Model 1 *Model 2* *Model 3*



Note: In the figure, I refers to indicators of institutional quality such as the rule of law or regulatory quality; C are indicators of climate resilience, i.e., vulnerability or readiness; F is the event of a fiscal crisis. Model 1 presents institutions as a common cause for both, climate change adaptation capacity, C, and fiscal crises, F. Model 2 depicts institutional indicators, I, as a mediator of climate adaptation capacity and vulnerability, C, and fiscal crises, F. Model 3 illustrates the case when institutions are the cause (parent) of climate indicators, which in turn cause F. Other variables (macroeconomic and debt variables) were kept out of the figure for simplicity, but they are thought of as entering in the DAGs causing F in an independent path.

In Model 2 any improvement in institutions will only affect F. Depending on the signs and significance of the estimated relationships, a trade-off between climate adaptation and fiscal stability could emerge. For instance, whenever an improvement in terms of climate adaptation leads to a reduction of institutional quality indicators a trade-off could be said to be present.

In Model 1, institutions is an omitted confounding variable of both climate indicators and fiscal distress, thus, if we want to estimate the impact of climate adaptation on the probability of a fiscal distress episode, the model needs to include institutions as a control. On the contrary, in Model 2, as institutions are a mediator of climate indicators, if we include them in the model as a control variable, the total causal effect of climate adaptation on fiscal outcomes will disappear, even though there is indeed a causal relationship between climate adaptation and fiscal distress episodes[3]. Finally, in Model 3, controlling for institutions may have an effect on the accuracy of the estimation of the causal relationship between C and F, but otherwise has no effect. In Models 1 and 3, any improvement in institutions is expected to improve both C and F, meaning that it is expected to reduce the vulnerability to climate change and the probability of facing a fiscal crisis (see Pearl, 2009).

4. Data

Our sample spans the period 1995 to 2020 and consists of 171 countries, where 81.29% are emerging market economies (including in this category low-income developing countries) and, 18.71% are advanced economies. Of the 139, 55.56% were implementing some sort of fiscal rule by the end of the sample. In Table A1 of the Appendix a list with the countries and their classification is found.

In Table 1 we present summary statistics of the macroeconomic and debt related variables considered in this study. We have different types of variables, ranging from traditional indicators of macroeconomic performance, such as real GDP growth, inflation, terms of trade, uncertainty (measured as the VIX), aggregate demand proxies and capacity absorption indicators; some variables that are expected to affect fiscal performance such as the rents coming from natural resources (gas, oil, forest, coal, etc.); debt-related variables such as fiscal balances, fiscal revenue, the ratio of debt to GDP of the country, the implicit interest paid on debt, etc. We also include, as can be seen in the last rows of the table, a large set of institutional factors, such as the indices constructed by the World Bank on regulatory quality, the rule of law, voice and accountability, control of corruption, etc., and some demographic factors such as population (first row), and the Harvard's indicator o historical ethnic fractionalization. We have restricted our sample to those variables that can be reliably tracked during the whole sample period for the 171 countries that we considered in our study.

[3] They are a "bad control" as explained in Angrist and Pischke (2009, 2014).

Table 1. Summary statistics of macroeconomic and debt-related variables in our sample

Indicator	*Abbreviation*	*Source*	*Median*	*Mean*	*Std.Dev*	*Max.*	*Min.*
Population in millions	pop	WEO	40.34	9.06	143.87	1433.78	0.04
Inflation rate, average of the year	inf_avg	WEO	30.69	3.79	1033.89	65374.08	-72.73
Real GDP growth	growth	WEO	3.5	3.74	5.74	124.71	-66.66
Log of per capita real consumption	ccon	Penn World Tables	10.88	10.75	2.05	16.64	5.59
Log of per capita domestic sbsorption	cda	Penn World Tables	11.13	11	2.08	16.88	5.74
Log of expenditure-side real GDP at current PPPs in mil. 2017US$	cgdpe	WEO	11.09	10.97	2.14	16.85	5.25
Log of output-side real GDP at current PPPs in mil. 2017US$	cgdpo	WEO	11.1	10.98	2.14	16.84	5.26
Log of capital stock at current PPPs in mil. 2017US$	cn	Penn World Tables	12.35	12.25	2.27	18.44	6.02
Chicago Board Options Exchange Volatility Index	vix	Bloomberg	20.01	17.67	6.12	32.7	11.09
Financial openness, Chinn-Ito index	kaopen	Ito's web	0.26	-0.15	1.57	2.32	-1.92
Terms of trade change in %	tot	WEO	109.85	100.41	44.63	579.83	14.14
Interest expenses as % GDP	interest	WEO (estimate)	1.83	1.43	2.28	17.71	-18.48
Gross debt as % of GDP, general government	debt	WEO	57.34	46.88	44.97	658.22	0
Primary balance as % GDP	primary_balance	WEO	-0.4	-0.6	6	126.46	-80.63
Fiscal balance as % GDP	total_balance	WEO	-2.16	-2.36	6.39	125.14	-80.63
Fiscal revenue as % GDP	revenue	WEO	27.88	25.31	13.89	164.05	0.64
Oil rents as % of GDP	oil_rents	World Bank	3.65	0.01	9.53	66.68	0
Coal rents as % of GDP	coal_rents	World Bank	0.28	0	1.97	48.69	0
Forest rents as % of GDP	forest_rents	World Bank	2.03	0.27	4.25	40.41	0
Mineral rents as % of GDP	mineral_rents	World Bank	0.75	0.01	2.28	24.83	0
Gas rents as % of GDP (gas_rents)	gas_rents	World Bank	0.44	0	2.31	68.68	0
Natural resources rents as % of GDP	rents	World Bank	5.09	0.37	12.54	245.95	-20.44
Historical ethnic fractionalization	frac	HIEF-Harvard	0.58	0.62	0.24	1	0
Voice and accountability	vae	World Bank	-0.05	-0.06	0.96	1.8	-2.26
Political stability and absence of violence	pve	World Bank	-0.09	0	0.97	1.76	-3.18
Government Effectiveness	gee	World Bank	-0.05	-0.21	0.96	2.44	-2.31
Regulatory quality	rqe	World Bank	-0.05	-0.18	0.94	2.26	-2.63
Rule of law	rle	World Bank	-0.08	-0.25	0.97	2.13	-2.35
Control of corruption	cce	World Bank	-0.06	-0.31	0.99	2.47	-1.81
Human Development Indicator	hdi	World Bank	0.66	0.69	0.16	0.96	0.23

Note: The table shows the median, mean, standard deviation, maximum and minimum of all the macroeconomic or debt-related variables considered in our study.

Naturally, we do not include all these variables in our survival models, because we do not have a sufficiently large number of events to guarantee enough degrees of freedom in our estimations. Moreover, not all of them should be included in our final model, as many of them proxy for the same general factors (e.g. institutional quality) and therefore constitute a “bad control” in causal terms (Angrist and Pischke, 2009, 2014; Cinelli et al., 2022). Instead, we analyze all of them in a first step, aiming to select what variables to include in the survival specification of our results.

In Table 2 we present the summary statistics for the climate vulnerability indicators that we described in the methodology. We have multiplied times 10 the original indicators that we retrieved from the ND-Gain Web, except for the ND-Gain indicator itself (first row after the names in the table), which was divided by 10. The reason for these transformations is to ensure that the units of both, the general ND-Gain indicator and the sub-indices that composed it are comparable, and that the standard deviation is around unity in all cases, aiming to facilitate interpretation within easy-to-read magnitudes in our survival estimates.

Table 2. Summary statistics of the climate vulnerability and readiness indicators

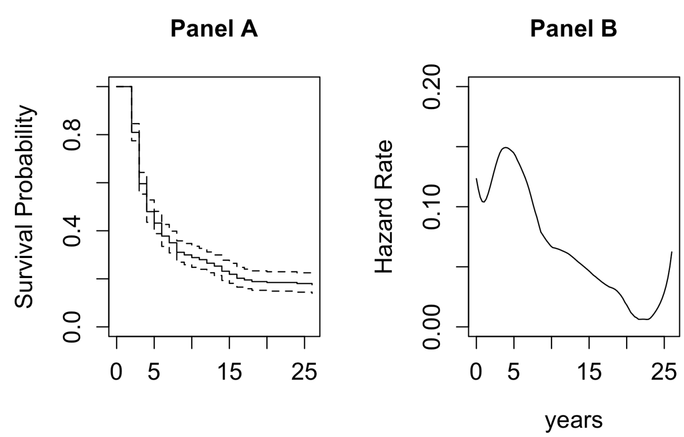
Indicator	*Abbreviation*	*Source*	*Median*	*Mean*	*Std.Dev*	*Max.*	*Min.*
ND- Gain Indicator	gain	ND-Gain Web	4.75	4.62	1.06	7.73	2.54
Readiness	readiness	ND-Gain Web	4.06	3.74	1.33	8.15	1.16
Vulnerability	vulnerability	ND-Gain Web	4.5	4.39	0.93	7.07	2.49
Economic Readiness	economic	ND-Gain Web	4.17	4.05	1.35	8.81	0
Governance Readiness	governance	ND-Gain Web	4.96	4.67	1.78	9.06	0.97
Social Readiness	social	ND-Gain Web	3.03	2.54	1.57	7.99	0.79
Capacity	capacity	ND-Gain Web	5.53	5.49	1.78	9.32	1.81
Ecosystem Services	ecosystems	ND-Gain Web	4.65	4.72	0.91	6.83	2.17
Exposure	exposure	ND-Gain Web	4.35	4.42	0.75	7.22	2.67
Food	food	ND-Gain Web	4.68	4.72	1.5	8.88	1.07
Human Habitat	habitat	ND-Gain Web	5.17	5.2	0.97	8.16	2.39
Health	health	ND-Gain Web	4.84	4.63	1.71	8.66	1.23
Infrastructure	infrastructure	ND-Gain Web	3.68	3.5	1.17	8.13	0.85
Sensitivity	sensitivity	ND-Gain Web	3.66	3.53	0.91	6.54	1.59
Water	water	ND-Gain Web	3.64	3.49	1.1	7.8	0.12

Note: The table shows the median, mean, standard deviation, maximum and minimum of all the vulnerability and readiness indicators considered in our study. We have multiplied times 10 the original gain indicator, and divided by 10 the other indicators to make their units comparable in the specification of our models.

Now we describe our dependent variable, namely, the indicator of fiscal crises explained in the methodology. We have two events in our sample, the event of crisis, where the crisis variable is equal to one, and the event of non-crisis, where this variable is equal to zero. In total, we have 1694 years/country where the variable is equal to one (years when a country has experienced a fiscal crisis) and 1728 years/country where it is equal to zero (years when a country has not experienced a fiscal crisis), which makes for a relatively well-balanced sample[4]. However, the duration, understood as the number of consecutive years a country stays in the same event, varies between the two types. The average duration of the event of crisis is 4.9 years, while the average duration of the non-crisis event is 13.19 years. Most advanced economies have been in the event of non-crisis during the whole sample period (26 years), while some emerging markets have experienced several events of crisis in this time window.

In Figure 3, Panel A, we show the Kaplan-Meier (KM) estimates of the survival probability to a fiscal crisis, computed using information for all individuals in our study. As can be observed, from this preliminary analysis of the data, the survival probability to a fiscal crisis decreases in a nonlinear way, with bellow 20% of countries surviving during the whole sample period.

Figure 3. Survival to fiscal crises and hazard ratio



Note: Panel A of the figure show the Kaplan Meier estimate of the survival probabilities to a fiscal crisis. Panel B shows the non-parametric hazard rate estimate. Survival estimates and hazards use information for 171 countries from 1995 to 2020.

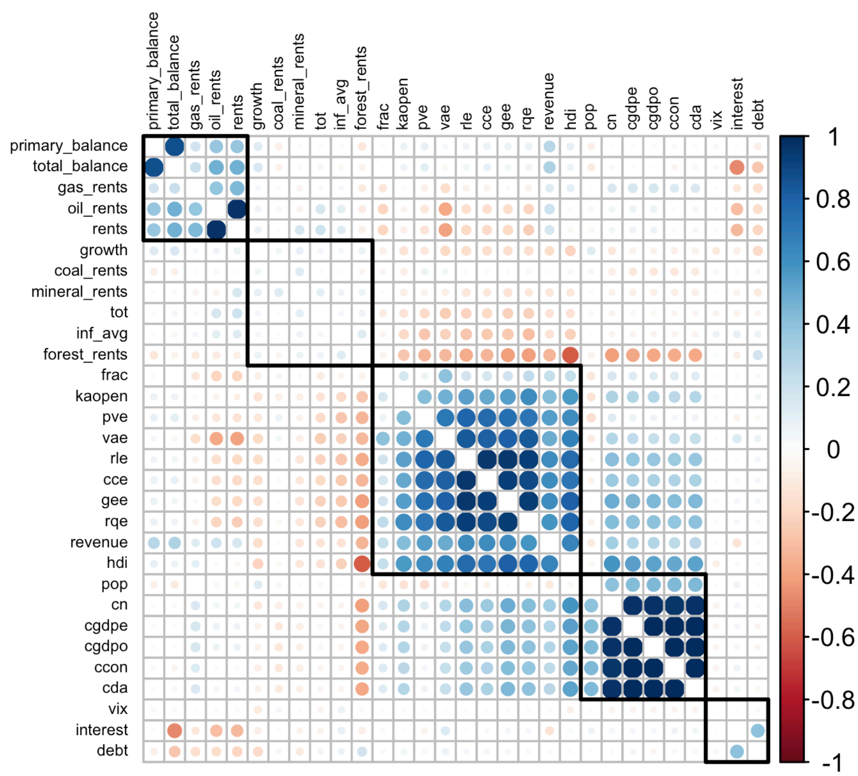
Panel B of Figure 3 presents the no-parametric estimates of the hazard rate using an Epanechnikov's kernel. This estimate is useful in determining if a monotonic function (e.g. exponential, Weibull) can model the duration of fiscal distress episodes, or if it's necessary to use covariates in the context of a proportional hazards model. The data indicate that monotonic functions cannot model the survival probability in our sample, making the use of more advanced

[4] Notice that we have lost information due to lack of information in our indicators, circa 23% of the simple with complete information, given the number of countries and the number of years.

survival models necessary. Indeed, the risk of a fiscal crisis is increasing at the end of the period (not the sample).

In Figure 4 we show the pairwise correlation of the macroeconomic and debt-related variables in our dataset. We have ordered the correlation matrix using a hierarchical clustering algorithm. Clusters identified are shown within five black squares.

Figure 4. Pairwise correlation of the macroeconomic and debt related variables

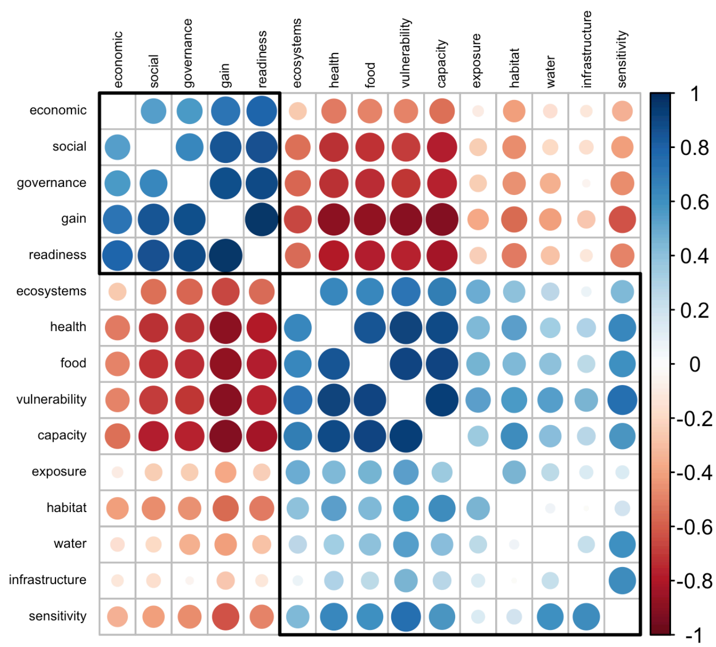


Note: The figure shows the pairwise correlation between the macroeconomic and variables related to debt in our sample. We have clustered the variables according to such correlation and identified five groups, marked with black squares.

The first cluster corresponds to a cluster of fiscal income variables, such as balances and rents. The second cluster (with almost zero correlation among the variables within) includes macroeconomic performance indicators such as growth, terms of trade, or inflation. The third is a large cluster of institutional variables. The fourth group is a cluster of variables related to the size of the economy (including absorption and population). The fifth and last group, at the bottom of the figure, consists of the debt to GDP ratio, the VIX and the interest paid. In our specifications we will consider one variable to represent each cluster, except for the second and last cluster, in which we will consider more than one variable, because the correlation between the indicators in each of these clusters is observed to be relatively low.

In Figure 5 we present the same plot, but this time for the ND-Gain indicators. In the figure it is evident that correlation among the indicators is very high, for instance, the readiness indicator and its components (i.e. governance readiness, economic readiness, social readiness) are clustered together with the general gain indicator, at the top of the figure. The vulnerability indicator and its components are clustered together in the second box. However, it can be noted that there is also a large negative correlation between readiness and vulnerability indicators (see outside of the black boxes). For this reason, it is not convenient to include all the indicators in the same specification to model the survival to a fiscal crisis. We will consider them separately in our proportional hazards models of the next section.

Figure 5. Pairwise correlation of the vulnerability and readiness indicators



Note: The figure shows the pairwise correlation between the climate vulnerability and readiness indicators in our sample. We have clustered the variables according to such correlation and identified three groups, marked with black squares.

5. Results

5.1. Assessing the role of institutions

Table 3 shows the results of estimating a Cox proportional hazards model of the time elapsed before a fiscal crisis is observed. The models accounted for 204 events of crisis. Such events do not correspond with the number of countries in our sample (171), as one country may contribute more than once to the pool of crisis events, by entering several times into crisis in non-consecutive rounds over the years.

We start with the preferred modeling specification used in Gomez-Gonzalez et al. (2022), which is greatly informed by the literature on fiscal crises summarized in section 2. Then, we add the vulnerability and readiness indicators related to climate change. As can be seen, we estimate 10 specifications of the Cox model, which differ depending on the vulnerability and readiness indicators considered (see Figure 1). A positive and significant coefficient can be interpreted as highlighting a factor that contributes to increasing the probability of a fiscal crisis, according to equation 2. All 10 specifications include the following base-line variables: the ratio of debt to GDP (debt), real growth (growth), log of per capita domestic absorption (cda), inflation (inf_avg), terms of trade (tot) and rents of natural resources as a percentage of GDP (rents). Those variables, which are defined in Table 1, are consistent with the literature on fiscal crises and also with our preliminary analysis of pairwise correlations conducted in the Data section.

We observe that a greater debt to GDP ratio is generally associated with an increase in the probability of a fiscal crisis of 0.01. However, this result is statistically significant only half of the times (see specifications 1, 4, 5, 8, 10). Real growth, inflation, terms of trade and rents tend to be non-significant across all the specifications. Inflation and rents are significant only in two cases. When they are significant, inflation increases the probability of a fiscal crisis and rents reduce it, as expected. Interestingly, cda is always significant; the effect of a unitary increase in the indicator is a reduction of the probability of a fiscal crisis by the order of 0.15-0.26, depending on the specification. This result is distinct in our model compared to the previous literature that has documented a significant role of these macroeconomic indicators in forecasting fiscal outcomes (e.g. Hilscher and Nosbusch, 2007; Lane and Milesi-Ferretti, 2017; Valencia et al., 2022). The difference arises because we take into account the timing of the events, but not the calendar time or the variation of an indicator for forecasting a fiscal crisis. That is, the focus in duration analysis is on predicting years ahead the occurrence of an event, instead of exploiting the year-to-year variation of indicators, which this past literature does, at the cost of ignoring timing. In this way, our approach contributes to the previous literature to understand fiscal crises, beyond our main contribution of linking fiscal events with climate change vulnerability.

Turning our attention to the vulnerability and readiness indicators we have that all of them but water and infrastructure are statistically significant in all specifications from 1 to 9, which include each indicator in a separate regression. The sign of the statistically significant coefficients is in agreement with expectations, as an increase in the vulnerability indicators increases the probability of facing a fiscal crisis, while an increment of a unit in the readiness indicators reduces such a probability. If we include all indicators simultaneously in the regression (which according to Figure 2 present a high correlation) only habitat and governance retain their significance, with the expected signs.

Table 3. Cox model of fiscal crises

	1	2	3	4	5	6	7	8	9	10
Predictors	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*
debt	0.01 * (0.00 – 0.01)	0.01 (-0.00 – 0.01)	0.01 (-0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 ** (0.00 – 0.02)	0.01 (-0.00 – 0.01)	0.01 (-0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 (-0.00 – 0.01)	0.01 ** (0.00 – 0.02)
growth	-0.04 (-0.12 – 0.03)	-0.03 (-0.10 – 0.04)	-0.07 (-0.14 – 0.01)	-0.04 (-0.11 – 0.03)	-0.03 (-0.10 – 0.04)	-0.03 (-0.10 – 0.04)	-0.03 (-0.10 – 0.04)	-0.05 (-0.12 – 0.02)	-0.04 (-0.11 – 0.03)	-0.04 (-0.12 – 0.03)
cda	-0.18 * (-0.32 – -0.04)	-0.26 *** (-0.40 – -0.12)	-0.19 * (-0.33 – -0.04)	-0.22 ** (-0.36 – -0.08)	-0.18 * (-0.32 – -0.03)	-0.27 *** (-0.42 – -0.12)	-0.20 ** (-0.35 – -0.05)	-0.25 *** (-0.39 – -0.10)	-0.15 * (-0.30 – -0.00)	-0.25 ** (-0.43 – -0.08)
inf avg	0.01 (-0.01 – 0.02)	0.02 * (0.00 – 0.03)	0.01 (-0.01 – 0.02)	0.01 (-0.00 – 0.03)	0.01 (-0.00 – 0.03)	0.02 * (0.00 – 0.03)	0.01 (-0.00 – 0.03)	0.00 (-0.01 – 0.02)	0.01 (-0.00 – 0.03)	0.00 (-0.02 – 0.02)
tot	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	-0.00 (-0.01 – 0.00)	0.00 (-0.00 – 0.01)	-0.00 (-0.01 – 0.00)
rents	-0.00 (-0.02 – 0.01)	0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.01)	-0.00 (-0.02 – 0.01)	-0.03 * (-0.05 – -0.01)	-0.00 (-0.02 – 0.02)	-0.01 (-0.03 – 0.01)	-0.02 (-0.03 – 0.00)	-0.01 (-0.02 – 0.01)	-0.04 ** (-0.06 – -0.01)
food	0.39 *** (0.21 – 0.56)									0.05 (-0.28 – 0.38)
water		0.19 (-0.01 – 0.38)								-0.04 (-0.28 – 0.19)
health			0.37 *** (0.22 – 0.52)							0.12 (-0.16 – 0.39)
ecosystems				0.38 ** (0.13 – 0.62)						-0.13 (-0.47 – 0.21)
habitat					0.72 *** (0.43 – 1.01)					0.40 * (0.08 – 0.73)
infrastructure						-0.12 (-0.32 – 0.09)				-0.17 (-0.44 – 0.09)
economic							-0.35 ** (-0.58 – -0.13)			-0.02 (-0.22 – 0.19)
governance								-0.60 *** (-0.78 – -0.43)		-0.55 *** (-0.77 – -0.33)
social									-0.28 ** (-0.46 – -0.10)	0.14 (-0.10 – 0.39)
Observations	204	204	204	204	204	204	204	204	204	204
R^2 Nagelkerke	0.194	0.120	0.210	0.144	0.213	0.110	0.150	0.326	0.149	0.367
AIC	683.780	701.208	679.891	695.628	679.301	703.370	694.282	648.992	694.469	652.720
log-Likelihood	-334.890	-343.604	-332.946	-340.814	-332.650	-344.685	-340.141	-317.496	-340.235	-311.360

** p<0.05 ** p<0.01 *** p<0.001*

Note: results of a Cox model for the probability of fiscal crises including climate vulnerability and readiness indicators from ND-Gain. The variables are defined in tables 1 and 2.

From this analysis, we can assert that there is no trade-off between reducing vulnerability to climate change and preserving fiscal stability. In all the cases, improvements in terms of climate change adaptation lead to a reduction of the fiscal crisis probability, but in two cases, water and infrastructure, where the effect is non-significant. Notice that even in such cases there is no trade off, as it means that improving in these dimensions do not affect the likelihood of a fiscal crisis.

However, if institutions turn out to be a confounding variable as in Model 1 from Figure 2, or an intermediate effect as in Model 2 of the same figure, including them in our Cox model would change our conclusions. Only if Model 3 were correct, including institutions would not affect our point estimates, although more precise estimates are possible to obtain by adding them as a control.

Table 4. Cox model of fiscal crises including rle

	1	2	3	4	5	6	7	8	9	10
Predictors	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*
debt	0.01 ** (0.00 – 0.02)	0.01 ** (0.00 – 0.02)	0.01 ** (0.00 – 0.02)	0.01 ** (0.00 – 0.02)	0.01 *** (0.00 – 0.02)	0.01 ** (0.00 – 0.02)	0.01 ** (0.00 – 0.02)	0.01 * (0.00 – 0.01)	0.01 ** (0.00 – 0.02)	0.01 ** (0.00 – 0.02)
growth	-0.04 (-0.11 – 0.03)	-0.04 (-0.11 – 0.03)	-0.05 (-0.12 – 0.02)	-0.04 (-0.11 – 0.03)	-0.03 (-0.10 – 0.04)	-0.03 (-0.10 – 0.04)	-0.04 (-0.11 – 0.03)	-0.05 (-0.12 – 0.02)	-0.04 (-0.11 – 0.03)	-0.04 (-0.12 – 0.03)
cda	-0.16 * (-0.30 – -0.01)	-0.17 * (-0.31 – -0.02)	-0.16 * (-0.30 – -0.01)	-0.16 * (-0.31 – -0.02)	-0.13 (-0.28 – 0.02)	-0.20 ** (-0.35 – -0.05)	-0.14 (-0.29 – 0.01)	-0.25 ** (-0.41 – -0.08)	-0.16 * (-0.31 – -0.01)	-0.27 ** (-0.46 – -0.08)
inf avg	0.00 (-0.02 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.02 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.02 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.02 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.02 – 0.02)
tot	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.01)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.01)
rents	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.03 * (-0.05 – -0.00)	-0.02 (-0.04 – 0.00)	-0.01 (-0.03 – 0.01)	-0.02 (-0.03 – 0.00)	-0.01 (-0.03 – 0.01)	-0.04 ** (-0.06 – -0.01)
rle	-1.00 *** (-1.36 – -0.63)	-1.07 *** (-1.40 – -0.74)	-0.95 *** (-1.31 – -0.58)	-1.08 *** (-1.43 – -0.72)	-0.94 *** (-1.28 – -0.60)	-1.09 *** (-1.41 – -0.76)	-1.04 *** (-1.38 – -0.71)	0.01 (-1.01 – 1.03)	-1.06 *** (-1.41 – -0.71)	0.24 (-0.89 – 1.37)
food	0.11 (-0.10 – 0.31)									0.04 (-0.29 – 0.38)
water		0.03 (-0.18 – 0.24)								-0.06 (-0.30 – 0.18)
health			0.14 (-0.03 – 0.32)							0.11 (-0.17 – 0.39)
ecosystems				0.00 (-0.29 – 0.30)						-0.12 (-0.46 – 0.22)
habitat					0.41 ** (0.11 – 0.71)					0.41 * (0.09 – 0.74)
infrastructure						-0.17 (-0.40 – 0.07)				-0.17 (-0.43 – 0.09)
economic							-0.12 (-0.32 – 0.09)			-0.02 (-0.23 – 0.19)
governance								-0.61 * (-1.14 – -0.07)		-0.68 * (-1.32 – -0.04)
social									-0.03 (-0.23 – 0.17)	0.14 (-0.10 – 0.39)
Observations	204	204	204	204	204	204	204	204	204	204
R^2 Nagelkerke	0.312	0.309	0.318	0.309	0.335	0.316	0.313	0.326	0.309	0.367
AIC	654.828	655.788	653.218	655.850	648.181	653.800	654.536	650.991	655.778	654.549
log-Likelihood	-319.414	-319.894	-318.609	-319.925	-316.091	-318.900	-319.268	-317.496	-319.889	-311.275

** p<0.05 ** p<0.01 *** p<0.001*

Note: results of a Cox model for the probability of fiscal crises including climate vulnerability and readiness indicators from ND-Gain, alongside institutions. The variables are defined in tables 1 and 2.

In Table 4 we include as a control variable institutions, which are expected to impact the probability of fiscal crisis from the previous literature. We only use one variable among the large set of variables provided by the World Bank and other sources, the rule of law (rle), due to the large correlation among these type of variables that we estimate (see Figure 2). Nevertheless, the results that follow do not change at all, when considering other indicators of institutional quality, such as control of corruption, voice and accountability, government effectiveness, or regulatory quality (see Figures A2 to A5 in the Appendix).

An increment of a unit (which also corresponds to one standard deviation of the variable, according to Table 2) virtually vanishes the probability of suffering a fiscal crisis. This is not surprising; as an increment of such a magnitude is dramatic and has been observed during the sample period in very rare occasions (for instance in the cases of China and Korea) and, when occurred it took decades not a year.

Interestingly, the effect of most of the vulnerability and readiness indicators also disappears (except for habitat and governance, which we will analyze in greater detail later on). In any case, we can discard Model 3 from Figure 1, as it is evident that institutions are either a mediator of the effect (as in Model 2) or an omitted variable (as in Model 1). The difference between Models 1 and 2 is crucial, nonetheless, in terms of causality, as in the former case there is not causal path from climate adaptation to fiscal stability, after controlling for institutions (again except for habitat and governance). On the other hand, according to Model 2, institutions are a mediator, and as such, there should not be included in the Cox regression, as they are a bad control (Angrist and Pischke, 2009, 2014; Cinelli et al., 2022), and adding them would disappear the true causal effect they assert on fiscal stability. However, in the two cases there is no trade off between fiscal stability and adaptation to climate change, under the implicit ceteris paribus assumption of our model.

Now we analyze this ceteris paribus assumption. Climate adaptation requires resources and fiscal space and there is currently none in emerging market and low-income economies, which are the ones that can expect the worst scenarios in terms of climate hazards in the coming decades. Thus, climate adaptation will necessarily result in an increment of the debt levels and the debt to GDP ratio of (at least) the most vulnerable economies. Notice that in Table 4, after the inclusion of the rule of law estimate, debt became significant always. Meaning that an increase in one percentage point (p.p.) of the ratio would result in an increment of the probability of a fiscal crisis of 1% (0.01*100). This effect is relatively low in economic terms, as it means that if the ratio increases from 70% to 100% the probability would increase only 30%.

All in all, debt levels do not seem to provide an sufficient indicator of the probability of fiscal distress episodes, which is in line with recent claims by Furmer and Summers (2020) and in line with the theoretical framework due to Mehrotra and Sergeyev (2021), which shows that conditions for sustainability are not necessarily tied to the debt to GDP ratio and other metrics popular in the empirical literature (see Reinhart and Rogoff, 2010)[5]. Moreover, from our results we have that, improvements in terms of institutional quality, which are associated to climate adaptation, would largely outpace the costs in terms of fiscal instability, as a result of greater debt levels.

However, to explore possible scenarios in greater detail that could be related with higher debt levels in the future, arising from climate change adaptation, in Table 5 we have included the implicit interest paid on this debt as a predictor variable. As can be noticed, once interest (as a percentage of GDP, see Table 1) is included, the significance of the debt level disappears. In seven out of ten specifications the interest paid turns out to be statistically significant and the sign of the coefficient implies that an increment in the interest that countries paid of a 1 p.p. increases the probability of facing a crisis in 12%, In other words, if the interest burden goes from 1.43 (average scenario) to 6% of GDP (approximately two standard deviations of the variable above the average, reassembling a crisis scenario, see Table 1), the probability of a fiscal crisis would increase for that country in 54.72%, which is significant in economic terms.

From this analysis we can conclude that the effect of debt levels on fiscal stability is largely (or totally) mediated by the interest paid. Interest variable increases the probability of a fiscal crisis (rather than the debt level itself). Considering the interest paid, concerns will likely arise depending on the country's situation. One way to intervene is by reducing, or keeping constant, the interest paid by emerging and low-income development countries during the ecological transition (while improving their adaptation to climate change), rather than restricting debt levels to certain thresholds. The focus should be on allowing new loans at very low or zero interest, even in an environment of higher interest rates in the international debt markets. If global coordination is needed in some aspect it is here, as evidenced by our analysis of interest as a mediator of the debt to GDP ratio on the probability of facing a fiscal crisis.

So far we have answered two out of three research questions. Namely, is there a trade off between fiscal stability and climate adaptation? Evidence points to not, even after controlling for debt

[5] Caselli et al. (2022) recently calibrated the model of debt sustainability developed by Mian et al. (2022), using data before and after the pandemic, including in the sample a variety of emerging and advanced economies. These authors find that debt-ratios and safe-primary-deficits are likely to vary over time and to be country-dependent.

levels and interest paid. What policy interventions could help to preserve fiscal stability in the mist of climate change? For which the answer is keeping interest payments constant at current levels, rather than reducing or keeping constant outstanding debt levels. There is still a third question that must be answered: are there any factors in the climate change adaptation strategies that help to preserve as well fiscal stability, in addition to those related with the institutional framework (governance) of the country?

Table 5. Cox model of fiscal crises including interest paid

	1	2	3	4	5	6	7	8	9	10
Predictors	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*
debt	0.00 (-0.01 – 0.01)	0.00 (-0.01 – 0.01)	0.00 (-0.01 – 0.01)	0.00 (-0.01 – 0.01)	0.01 (-0.00 – 0.02)	0.00 (-0.00 – 0.01)	0.00 (-0.01 – 0.01)	0.00 (-0.01 – 0.01)	0.00 (-0.01 – 0.01)	0.01 (-0.00 – 0.02)
interest	0.12 * (0.01 – 0.23)	0.12 * (0.01 – 0.23)	0.12 * (0.01 – 0.24)	0.12 * (0.01 – 0.24)	0.11 (-0.01 – 0.22)	0.11 (-0.00 – 0.22)	0.12 * (0.00 – 0.23)	0.11 (-0.00 – 0.22)	0.12 * (0.00 – 0.23)	0.11 (-0.01 – 0.24)
growth	-0.03 (-0.10 – 0.04)	-0.02 (-0.10 – 0.05)	-0.04 (-0.11 – 0.04)	-0.03 (-0.10 – 0.05)	-0.02 (-0.09 – 0.05)	-0.02 (-0.09 – 0.05)	-0.02 (-0.10 – 0.05)	-0.04 (-0.11 – 0.04)	-0.02 (-0.10 – 0.05)	-0.04 (-0.11 – 0.04)
cda	-0.17 * (-0.31 – -0.03)	-0.18 * (-0.33 – -0.03)	-0.17 * (-0.31 – -0.02)	-0.18 * (-0.32 – -0.03)	-0.14 (-0.29 – 0.00)	-0.20 ** (-0.36 – -0.05)	-0.16 * (-0.31 – -0.01)	-0.25 ** (-0.42 – -0.09)	-0.18 * (-0.33 – -0.03)	-0.27 ** (-0.46 – -0.08)
inf avg	-0.00 (-0.02 – 0.02)	0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.02)	0.00 (-0.02 – 0.02)	0.00 (-0.02 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.02 – 0.02)	0.00 (-0.02 – 0.02)	0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.02)
tot	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.01)
rents	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.02 (-0.04 – 0.00)	-0.01 (-0.04 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.03 * (-0.06 – -0.01)
rle	-1.03 *** (-1.40 – -0.66)	-1.11 *** (-1.45 – -0.78)	-0.98 *** (-1.35 – -0.61)	-1.10 *** (-1.45 – -0.74)	-0.98 *** (-1.33 – -0.63)	-1.12 *** (-1.45 – -0.79)	-1.09 *** (-1.43 – -0.75)	-0.09 (-1.11 – 0.93)	-1.12 *** (-1.48 – -0.77)	0.12 (-1.00 – 1.25)
food	0.11 (-0.09 – 0.32)									0.07 (-0.27 – 0.41)
water		0.01 (-0.19 – 0.22)								-0.08 (-0.32 – 0.16)
health			0.15 (-0.02 – 0.33)							0.12 (-0.17 – 0.40)
ecosystems				0.05 (-0.25 – 0.35)						-0.07 (-0.42 – 0.28)
habitat					0.39 * (0.09 – 0.69)					0.41 * (0.08 – 0.74)
infrastructure						-0.13 (-0.37 – 0.11)				-0.14 (-0.41 – 0.12)
economic							-0.10 (-0.31 – 0.10)			-0.02 (-0.23 – 0.19)
governance								-0.57 * (-1.11 – -0.03)		-0.64 * (-1.27 – -0.00)
social									0.01 (-0.20 – 0.21)	0.20 (-0.05 – 0.46)
Observations	204	204	204	204	204	204	204	204	204	204
R^2 Nagelkerke	0.328	0.325	0.334	0.325	0.347	0.329	0.328	0.339	0.324	0.378
AIC	652.187	653.309	650.494	653.230	646.660	652.116	652.252	648.979	653.324	653.192
log-Likelihood	-317.094	-317.655	-316.247	-317.615	-314.330	-317.058	-317.126	-315.489	-317.662	-309.596

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

Note: results of a Cox model for the probability of fiscal crises including climate vulnerability and readiness indicators from ND-Gain. The variables are defined in tables 1 and 2.

5.2. Alternative specifications

In Table 6 we have relaxed some of the main assumptions in the baseline PH Cox modeling framework. Our aim is to test how our main conclusions change if we change our estimation strategy. The first column, labeled as base line 1, presents the model estimated by exact maximum likelihood. This model corresponds to column 10 in Table 5 before, but this time we have removed the vulnerability and readiness indicators, except for habitat and governance, to ease exposition. We have also removed the rule of law, as it is highly correlated with governance, and governance seems to be the key proxy for institutional quality, according to columns 8 and 10 in the same Table 5. We have removed the debt level as well and kept only the interest paid, following our previous analysis.

Table 6. Fiscal crisis modeling with alternative specifications for testing robustness

	base line 1	**breslow 1**	**efron 1**	**base line 2**	**breslow 2**	**efron 2**
Predictors	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*
interest	0.14 *** (0.06 – 0.23)	0.10 ** (0.04 – 0.16)	0.12 *** (0.05 – 0.18)	0.16 *** (0.08 – 0.24)	0.11 *** (0.05 – 0.17)	0.13 *** (0.07 – 0.19)
growth	-0.04 (-0.11 – 0.04)	-0.03 (-0.09 – 0.03)	-0.04 (-0.10 – 0.03)			
cda	-0.22 ** (-0.37 – -0.07)	-0.17 * (-0.30 – -0.04)	-0.19 ** (-0.33 – -0.06)	-0.21 ** (-0.36 – -0.06)	-0.16 * (-0.29 – -0.03)	-0.18 ** (-0.31 – -0.05)
inf avg	-0.00 (-0.02 – 0.02)	-0.00 (-0.01 – 0.01)	-0.00 (-0.01 – 0.01)			
tot	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)			
rents	-0.02 * (-0.05 – -0.00)	-0.02 * (-0.04 – -0.00)	-0.02 * (-0.04 – -0.00)	-0.02 * (-0.05 – -0.00)	-0.02 * (-0.04 – -0.00)	-0.02 * (-0.04 – -0.00)
habitat	0.36 * (0.08 – 0.65)	0.29 * (0.03 – 0.54)	0.33 * (0.07 – 0.59)	0.37 * (0.08 – 0.66)	0.29 * (0.03 – 0.55)	0.33 * (0.07 – 0.60)
governance	-0.56 *** (-0.74 – -0.37)	-0.48 *** (-0.64 – -0.31)	-0.50 *** (-0.67 – -0.33)	-0.55 *** (-0.73 – -0.37)	-0.47 *** (-0.63 – -0.31)	-0.49 *** (-0.65 – -0.33)
Observations	204	204	204	204	204	204
AIC	640.889	1182.829	1152.273	636.052	1177.878	1147.638
log-Likelihood	-312.444	-583.414	-568.136	-313.026	-583.939	-568.819

* *p<0.05* ** *p<0.01* *** *p<0.001*

Note: results of a Cox model for the probability of fiscal crises including climate vulnerability and readiness indicators from ND-Gain. The variables are defined in tables 1 and 2.

In the next columns we can observe the same model estimated using the estimators proposed by Brewlow and Efron for considering ties. There are not significant changes with respect to the baseline, the effect on the probability of a fiscal crisis of habitat remains between 0.29 and 0.36, and that of governance between -0.48 and -0.56, depending on the specification.

In the next columns, labeled baseline 2, breslow 2 and efron 2, we have removed the non-significant macroeconomic variables, to show that the main effects of our focus variables are invariant to these transformations of the model. Traditional macroeconomic variables lack statistical power in our framework and their exclusion does not alter our main conclusions in any case.

Recently, Stensrud et al. (2020) have questioned the validity and necessity of testing the Proportional Hazards assumption. These authors recommend using bootstrapping to construct standard errors in the Cox modeling framework due to a possibly incorrect variance estimator, when the statistical model includes covariates other than the treatment group indicator. In Table A6 of the Appendix we estimate the baseline model 1 of Table 6, and provide 95% confidence intervals constructed by bootstrapping with 1,000 simulations. In all cases both, the point estimate and the significance remained unaltered for all variables in the model.

Having the caveat in mind raised by Stensrud et al. (2020), we have tested the assumption of constant proportional hazards, in the sake of completeness. We have conducted an individual test for each covariate in our baseline model using Schoenfeld's residuals. For all variables the statistic indicates that the null hypothesis of constant proportional hazards is not rejected at 99% confidence level, except for cda. In the Appendix we report the graphical tests for proportional hazards of our two main variables, habitat and governance (see Figures A1 and A2). Other results are available upon request.

cda could be removed from our model and replaced by population (pop), which is correlated with it, and also proxy for the size of the economy and for capacity absorption (see Figure 1). We have done so, in results that we do not report here, finding that in this case, the effects of habitat and governance increase with respect to our baseline. That is, in the baseline model that replaces cda with pop (log of population in millions), a one unit increment in habitat leads to an increase of 38% in the crisis probability, while an increment in governance of the same magnitude leads to a reduction in the crisis probability of 62%. In all cases our qualitative conclusions remained unaltered or would be strengthened by this transformation of the model. We opted for conducting our analysis based on the results reported here, which are more conservative.

6. How to reduce the vulnerability of human habitat?

In this section, and in Table 7, we analyze in more detail how the indicator of human vulnerability affects the probability of a country's suffering a fiscal crisis.

Table 7. Cox model of fiscal crises including habitat components

	1	2	3	4	5	6	7	8
Predictors	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*
interest	0.15 *** (0.06 – 0.23)	0.13 ** (0.04 – 0.21)	0.13 ** (0.05 – 0.22)	0.13 ** (0.05 – 0.21)	0.14 ** (0.05 – 0.22)	0.13 ** (0.04 – 0.21)	0.16 *** (0.07 – 0.24)	0.14 ** (0.04 – 0.23)
growth	-0.04 (-0.12 – 0.03)	-0.05 (-0.12 – 0.03)	-0.05 (-0.12 – 0.03)	-0.04 (-0.11 – 0.04)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.03)	-0.04 (-0.12 – 0.04)
cda	-0.22 ** (-0.37 – -0.07)	-0.25 ** (-0.40 – -0.10)	-0.27 *** (-0.42 – -0.12)	-0.26 *** (-0.41 – -0.12)	-0.23 ** (-0.38 – -0.08)	-0.19 * (-0.37 – -0.01)	-0.23 ** (-0.38 – -0.08)	-0.16 (-0.34 – 0.03)
inf_avg	-0.00 (-0.02 – 0.02)	0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.02)	0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.01)	0.00 (-0.01 – 0.02)	-0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.02)
tot	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.01)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.01)
rents	-0.02 * (-0.05 – -0.00)	-0.02 (-0.04 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.03 * (-0.05 – -0.00)
governance	-0.57 *** (-0.76 – -0.39)	-0.63 *** (-0.81 – -0.45)	-0.63 *** (-0.82 – -0.45)	-0.66 *** (-0.86 – -0.46)	-0.59 *** (-0.78 – -0.40)	-0.52 *** (-0.77 – -0.28)	-0.59 *** (-0.77 – -0.40)	-0.48 *** (-0.74 – -0.23)
habitat	0.35 * (0.07 – 0.64)							
warn		0.05 (-0.08 – 0.18)						0.02 (-0.12 – 0.16)
floods			0.03 (-0.11 – 0.17)					0.08 (-0.08 – 0.23)
urban_cont				0.04 (-0.09 – 0.16)				0.13 (-0.02 – 0.27)
dependency					0.13 (-0.03 – 0.29)			0.16 (-0.06 – 0.38)
quality_trade						0.20 (-0.09 – 0.50)		0.27 (-0.04 – 0.58)
roads							0.08 (-0.00 – 0.16)	0.03 (-0.06 – 0.13)
Observations	201	201	201	201	201	201	201	201
R^2 Nagelkerke	0.367	0.348	0.347	0.348	0.355	0.353	0.359	0.377
AIC	628.013	633.536	633.900	633.737	631.644	632.269	630.382	635.004
log-Likelihood	-306.007	-308.768	-308.950	-308.868	-307.822	-308.134	-307.191	-304.502

** p<0.05 ** p<0.01 *** p<0.001*

Note: results of a Cox model for the probability of fiscal crises including habitat components and readiness indicators from ND-Gain. The variables are defined in tables 1 and 2.

As a vulnerability indicator, human habitat consists of three dimensions: exposure, sensitivity and adaptive capacity. Exposure refers to the level of stress a country will face as a consequence of future changing climate conditions. This dimension reflects physical factors, which are beyond a country's control that contribute to vulnerability. Sensitivity measures the degree of a country's population dependence on sectors, which are affected by climate related events. In this dimension topographic and demographic factors play a key role. On its side, adaptive capacity refers to the capacity of society to mitigate potential harm and respond to the effects of climate events. Adaptive capacity indicators measure the availability of resources and strategies that can be quickly implemented to address sector-specific impacts of climate change.

Each of these dimensions, in turn, consists of two indicators- in the case of human habitat-: exposure is conformed by a) the projected change of warn periods (warn) and b) the projected change of flood hazards (flood). Sensitivity is composed by a) urban concentration (urban_cont) and b) the age dependency ratio (dependency). Finally, adaptive capacity consists of a) quality of trade and transport related infrastructure (quality trade) and b) share of pave roads (roads). Further details on data sources and transformation of original raw variables before they enter the ND-Gain country index can be consulted at the ND-Gain technical document (Chen et al., 2015).

In Table 6 we have added each of the aforementioned human habitat dimensions to our model of fiscal crises. An interesting feature of the new set of estimations is that individual components are not significant, while the aggregate indicator is. This means that it is an overall improvement in the indicator that can contribute to reducing fiscal pressures in addition to the positive effect of institutions. To understand the interplay of human habitat with fiscal distress episodes it is necessary to delve deeper into the sub-indicators that make up the former. Our emphasis will be on the sensitivity and adaptive capacity aspects, which can be influenced by policies and are frequently the subject of attention in development literature.

6.1. The sensitivity dimension

Let us begin with the sensitivity dimension. This encompasses urban concentration and the age dependency ratio. Urban concentration measures the concentration of a country's population within cities and concentration of the urban population in cities of 750,000 inhabitants or more[6]. According to Lankao (2008), countries with a high concentration of urban populations in a single or a few urban areas are more susceptible to the impacts of climate change. This sensitivity is highest in countries where the urban sector is highly concentrated and the population is highly urbanized. In turn, the age dependency ratio considers the population under 14 or above 65 years old, as the most vulnerable groups to climate hazards (Wolf et al., 2010), and it indicates what percentage of the population belong to these groups.

[6] Urban concentration is the product of Herfindahl's index of concentration of the urban population, weighted by the percent of a country's urban population.

As suggested by the previous definitions, the sensitivity aspect of human habitat is likely influenced by a country's ability to implement successful development strategies in the past. This, in turn, affects the likelihood of the country navigating turbulent times without experiencing a financial crisis.

Consider the case of urban concentration. Gollin et al. (2016) differentiate between two forms of urbanization developments, each with its own unique developmental impact. One type of urbanization is characterized by a structural transformation and cities are classified as "production cities", which house a combination of workers in both tradable and non-tradable sectors. On the other hand, the other pattern involves urbanization that is not linked to structural transformation and it's associated with "consumption cities". In consumption cities, the majority of workers are in non-tradable and low-productivity service sectors and urbanization is generally accompanied by negative growth. This differentiation is supported by Frick and Rodríguez (2018) empirical findings that urban concentration has a positive impact on economic growth in high-income nations, however it does not in developing countries. Rapid urbanization in regions like Latin America and Africa, frequently have been matched with rapid development of the informal service sector, the surge of oversized primal cities prone to political instability and dictatorships (Ades and Glaeser, 1995) and even a reduction of economic growth (Henderson, 2003). The countries in this group are not only less developed, but also more prone to fiscal instability.

The second sensitivity indicator, the age dependency ratio, is also a common topic in the economic development literature. This can be traced back to Leff's (1969) seminal work, and since then, several researchers have provided evidence of the negative effect of the age dependency ratio on saving rates, investment, and growth, even after controlling for the positive impact of life expectancy on savings (e.g., Edwards, 1996; Li et al., 2007; Cavallo et al., 2018). In essence, this negative relationship exists because an aging population leads to an increase in dissavers relative to savers, resulting in lower saving rates and, also, higher demands for social security, which can contribute to fiscal pressure and the potential for a fiscal crisis

6.2. The adaptive capacity dimension

As for adaptive capacity, the first indicator is quality of trade and transport infrastructure. It refers to the perception that professionals in logistics have on areas such as ports, railroads, roads, information-technology and etc., of a given country. Its inclusion in ND-Gain obeys the rationale provided by studies by Malik and Temple (2009) and Jayachandran (2006), which have demonstrated the significance of transportation infrastructure for migration and development.

Migration from areas with challenging climates can lead to improved human health over time, as demonstrated by Deschenes and Moretti (2009).

The quality of trade and transport infrastructure reveals the ability of both the public and private sectors to effectively provide and manage essential infrastructure. It is believed that this ability is a reflection of the capability to sustain this infrastructure in the face of future changes, including those brought about by climate change.

Paved roads index is the ratio of the total length of roads that are paved, expressed as a percentage of the stated length of the public road network[7]. This metric reflects the durability of the road system and the social and economic activities it supports. It complements the first capacity indicator, which primarily serves as a proxy for measuring transportation infrastructure between major cities. The presence of paved roads indicates a country's ability to implement transportation enhancements, particularly in rural areas[8].

Fiorini et al. (2021) document that a reduction in input tariffs leads to a greater boost in firm productivity in regions where improved roadways enhance access to other domestic markets. Roads amplify the transmission of tariff reductions to the cost of imported inputs and encourage firms to take advantage of this cost advantage while improving productivity. Therefore, road infrastructure supplements the benefits of trade liberalization. In the same line, results in Martinius et al. (2017) suggest that new roads increase firms' exports and are associated with higher employment. These findings may be rationalized with help of the theoretical frameworks provided by De Soyres et al. (2020) or Caliendo and Parro (2015), which highlight the trade impact of infrastructure investments through cross- border input-output linkages.

In all likelihood, the same factors that lead infrastructure investment to positively impact productivity and, possibly, export diversification can be seen contributing to fiscal resilience, through diversification of fiscal revenues (see Gomez-Gonzalez et al., 2022 for direct evidence on this).

When examining both sensitivity and adaptive capacity indicators related to human habitat, it becomes evident that a country's ability to deal with climate change is largely determined by its success in implementing previous development initiatives. Human habitat can serve as an indicator of this past success, as countries with a robust and adaptive economic network, capable of adapting to changes in international trade and demographic pressures, typically score highly in

[7] Paved roads are defined as those made of macadamized crushed stone, bitumen or equivalent, concrete, or cobblestones.
[8] See Redding and Turner (2015) for a survey of this literature.

terms of human habitat. Taken together with the fact that governance is the most significant institutional factor in determining fiscal crises, this highlights the need to consider climate change adaptation and fiscal stability in tandem in any development agenda. Improving the sensitivity and adaptive capacity dimensions of human habitat will increase a country's ability to cope with climate change, not so much because the number of paved roads or the degree of urban concentration directly determine fiscal outcomes, but rather because these indicators reflect strategic planning and flexibility, which are key factors that influence fiscal outcomes.

6.3. The exposure dimension of climate change

When it comes to exposure, particularly the projected duration of warm periods and projected floods, several studies in the literature have explored the connection between the materialization of climate hazards and fiscal pressures. Overall, this body of research suggests that countries that are more exposed to these hazards will need to allocate a larger portion of their fiscal revenues towards repairing infrastructure and supporting vulnerable populations following natural disasters.

Using a non-linear general equilibrium approach, Cantelmo et al. (2023) investigate the impact of weather shocks on the growth and development of disaster-prone countries. These authors examine the macroeconomic consequences of natural disasters through two main channels: the destruction of capital (private and public) which is modeled as a permanent decrease in the existing capital stock and a temporary decrease in productivity growth. They find that: a) countries vulnerable to disasters tend to experience lower annual growth compared to those that are not; b) the impact of these disasters leads to substantial consumption losses in terms of welfare; c) with the effects of climate change, this growth gap could escalate to nearly 3% per year, with the welfare losses becoming almost five times greater. As a result, these authors also document how a decrease in output leads to a reduction in government revenue and an increase in public debt. On average, countries vulnerable to disasters have a public debt that is 1.56% of GDP higher than those that are not, and under a climate change scenario, this difference could increase to 11% of GDP [9]. According to our results, these higher debt levels can translate to higher interest payments and therefore increase the probability of a fiscal crisis. This result is in line with those in Marto et al. (2018) who find that major natural disasters, in addition to causing permanent damages to public and private capital, cause temporary losses in productivity during the reconstruction process, and damage to the sovereign's creditworthiness.

[9] See a recent IMF (2017) and Acevedo et al. (2020) for recent surveys of the literature examining the relationship between weather shocks and economic activity.

Another channel that can explain a greater susceptibility to fiscal crises by countries more prone to floods can be derived from the results reported in Castells-Quitana et al. (2022). These authors have documented that exposure to floods is linked to an increased intensity of urban social disorder. Since tax policies can potentially lead to social unrest (Lax-Martinez and Saia, 2022), governments in countries vulnerable to floods and other disasters may be tempted to lower taxes in order to counteract this impact. This can erode revenue and harm institutional quality, raising the risk of experiencing fiscal distress episodes.

7. Concluding remarks

The urgency of climate change adaptation has become a critical concern for policymakers, particularly in emerging and low-income developing countries, which are the most susceptible and inadequately prepared for future climate hazards. One of the major concerns facing these countries is the limited fiscal space, given the current historical high levels of debt in both emerging and non-emerging economies. This raises the question of the apparent trade-off between fiscal stability and climate change preparedness.

We show that there is no inherent trade-off, as the same factors that determine fiscal stability determine preparedness for climate change. Specifically, we highlight the importance of governance as a crucial determinant in both domains. Thus, advancing in this direction is highly recommended. Another dimension that promises to be a low-hanging-fruit for adaptation and reducing fiscal concerns is an improvement in the human habitat of countries, which include reducing vulnerability to factors such as population aging and urban concentration, while pushing forward aspects like quality of trade and transport, related to infrastructure, and the number of paved roads. This, in conjunction with closely monitoring climate hazards related to floods and excessively prolonged warm periods.

Our recommendations are based on a comprehensive battery of duration proportional hazard models, which take into account not only the climate vulnerability indicators and the readiness indicators of ND-Gain but also traditional macroeconomic and debt-related determinants of fiscal crises. Our models are informed by the existing literature on fiscal crises and by recent methodological literature on causal inference that warns against over controlling or using “bad controls”, which is a common problem in macroeconomic and development economics research.

Improving human habitat is a key ingredient indirectly pointed out by the recent literature in development economics. We provide a new perspective to this set of studies, as we show that improving human habitat also reduces the probability of experiencing a fiscal crisis. Interestingly, we find that it is the combination of the exposure, sensitivity and climate adaptive dimensions in human habitat that impact fiscal outcomes, rather than any of the individual components of the indicator.

Additionally, our findings are consistent with recent literature which indicates that the interest paid is more significant than debt levels in determining the probability of a fiscal crisis. Therefore, global coordination should focus on keeping interest payments constant during the ecological transition of low-income and emerging economies to break the causal relationship between debt to GDP and fiscal crises, as interest paid seems to play a mediating role between the two.

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Appendix

Table A1. Country list and classification

Advanced	Emerging Markets		Low Income Developing Countries
Australia	Albania	Pakistan	Afghanistan
Austria	Algeria	Panama	Bangladesh
Belgium	Angola	Paraguay	Benin
Canada	Antigua and Barbuda	Peru	Bhutan
Cyprus	Argentina	Philippines	Burkina Faso
Czech Republic	Armenia	Poland	Burundi
Denmark	Azerbaijan	Qatar	Cambodia
Estonia	Barbados	Romania	Cameroon
Finland	Belarus	Russia	Central African Republic
France	Belize	Samoa	Chad
Germany	Bolivia	Saudi Arabia	Comoros
Greece	Bosnia and Herzegovina	Seychelles	Congo, Democratic Republic of the
Iceland	Botswana	South Africa	Côte d'Ivoire
Ireland	Brazil	Sri Lanka	Djibouti
Israel	Bulgaria	St. Kitts and Nevis	Eritrea
Italy	Cabo Verde	St. Lucia	Ethiopia
Japan	Chile	St. Vincent and the Grenadines	Ghana
Korea	China	Suriname	Guinea
Latvia	Colombia	Syria	Guinea-Bissau
Lithuania	Costa Rica	Thailand	Haiti
Netherlands	Croatia	The Bahamas	Honduras
New Zealand	Dominica	Tonga	Kenya
Norway	Dominican Republic	Trinidad and Tobago	Kiribati
Portugal	Ecuador	Tunisia	Kyrgyz Republic
Singapore	Egypt	Turkey	Lao P.D.R.
Slovak Republic	El Salvador	Turkmenistan	Lesotho
Slovenia	Eswatini	Ukraine	Liberia
Spain	Fiji	United Arab Emirates	Madagascar
Sweden	Gabon	Uruguay	Malawi
Switzerland	Georgia	Vanuatu	Mali
United Kingdom	Grenada	Venezuela	Mauritania
United States	Guatemala		Moldova
	Guyana		Mozambique
	Hungary		Myanmar
	India		Nepal
	Indonesia		Nicaragua
	Iran		Niger
	Iraq		Papua New Guinea
	Jamaica		Republic of Congo
	Jordan		Rwanda
	Kazakhstan		Senegal
	Kuwait		Sierra Leone
	Lebanon		Solomon Islands
	Libya		Sudan
	Malaysia		São Tomé and Príncipe
	Maldives		Tajikistan
	Mauritius		Tanzania
	Mexico		The Gambia
	Mongolia		Togo
	Morocco		Uganda
	Namibia		Vietnam
	Nigeria		Yemen
	North Macedonia		Zambia
	Oman		Zimbabwe

Note: The table shows the countries included in our main sample. There are 32 advanced economies, 85 emerging market economies and 54 low-income developing countries.

Table A2. Cox model of fiscal crises including rqe

	1	2	3	4	5	6	7	8	9	10
Predictors	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*
debt	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 ** (0.00 – 0.02)	0.01 ** (0.00 – 0.02)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 ** (0.00 – 0.02)
growth	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.06 (-0.13 – 0.01)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.04 (-0.11 – 0.04)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.04 (-0.12 – 0.03)
cda	-0.23 ** (-0.38 – -0.09)	-0.24 ** (-0.39 – -0.09)	-0.23 ** (-0.37 – -0.08)	-0.24 ** (-0.39 – -0.10)	-0.19 * (-0.34 – -0.04)	-0.29 *** (-0.44 – -0.14)	-0.21 ** (-0.36 – -0.06)	-0.25 *** (-0.39 – -0.10)	-0.23 ** (-0.38 – -0.07)	-0.25 ** (-0.43 – -0.08)
inf avg	-0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.02)	0.00 (-0.02 – 0.02)	-0.00 (-0.02 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.02 – 0.02)	0.00 (-0.02 – 0.02)
tot	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	0.00 (-0.01 – 0.01)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)
rents	-0.02 * (-0.04 – -0.00)	-0.02 * (-0.04 – -0.00)	-0.02 (-0.04 – 0.00)	-0.02 * (-0.04 – -0.00)	-0.04 ** (-0.06 – -0.01)	-0.03 ** (-0.05 – -0.01)	-0.02 * (-0.04 – -0.00)	-0.02 (-0.03 – 0.00)	-0.02 * (-0.04 – -0.00)	-0.04 ** (-0.06 – -0.01)
rqe	-1.00 *** (-1.39 – -0.61)	-1.06 *** (-1.40 – -0.73)	-0.93 *** (-1.32 – -0.54)	-1.06 *** (-1.42 – -0.70)	-0.92 *** (-1.26 – -0.59)	-1.12 *** (-1.45 – -0.78)	-1.03 *** (-1.36 – -0.69)	0.03 (-0.72 – 0.78)	-1.02 *** (-1.37 – -0.68)	0.01 (-0.79 – 0.82)
food	0.06 (-0.16 – 0.27)									0.05 (-0.28 – 0.39)
water		-0.02 (-0.23 – 0.20)								-0.05 (-0.28 – 0.19)
health			0.11 (-0.07 – 0.29)							0.12 (-0.16 – 0.40)
ecosystems				-0.01 (-0.29 – 0.27)						-0.13 (-0.47 – 0.21)
habitat					0.48 ** (0.18 – 0.77)					0.40 * (0.08 – 0.73)
infrastructure						-0.25 * (-0.49 – -0.01)				-0.17 (-0.44 – 0.09)
economic							-0.15 (-0.35 – 0.05)			-0.02 (-0.22 – 0.19)
governance								-0.62 ** (-1.00 – -0.23)		-0.56 ** (-0.96 – -0.15)
social									-0.05 (-0.25 – 0.15)	0.14 (-0.11 – 0.40)
Observations	204	204	204	204	204	204	204	204	204	204
R^2 Nagelkerke	0.291	0.290	0.295	0.290	0.327	0.305	0.298	0.326	0.291	0.367
AIC	660.822	661.062	659.640	661.083	650.513	656.756	658.847	650.985	660.839	654.719
log-Likelihood	-322.411	-322.531	-321.820	-322.542	-317.257	-320.378	-321.424	-317.493	-322.419	-311.359

** p<0.05   ** p<0.01   *** p<0.001*

Note: results of a Cox model for the probability of fiscal crises including climate vulnerability and readiness indicators from ND-Gain, alongside institutions. The variables are defined in tables 1 and 2.

Table A3. Cox model of fiscal crises including vae

	1	2	3	4	5	6	7	8	9	10
Predictors	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*
debt	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 ** (0.00 – 0.02)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 ** (0.00 – 0.02)
growth	-0.05 (-0.13 – 0.02)	-0.05 (-0.12 – 0.02)	-0.07 (-0.14 – 0.00)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.04 (-0.11 – 0.03)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.04 (-0.12 – 0.03)
cda	-0.21 ** (-0.36 – -0.06)	-0.25 *** (-0.40 – -0.10)	-0.21 ** (-0.36 – -0.06)	-0.23 ** (-0.38 – -0.09)	-0.17 * (-0.32 – -0.02)	-0.29 *** (-0.45 – -0.14)	-0.21 ** (-0.36 – -0.06)	-0.25 *** (-0.39 – -0.10)	-0.20 * (-0.36 – -0.05)	-0.25 ** (-0.43 – -0.07)
inf avg	0.01 (-0.01 – 0.02)	0.01 (-0.01 – 0.02)	0.01 (-0.01 – 0.02)	0.01 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.01 (-0.01 – 0.02)	0.01 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.01 (-0.01 – 0.02)	0.00 (-0.02 – 0.02)
tot	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	-0.00 (-0.01 – 0.00)	0.00 (-0.00 – 0.01)	-0.00 (-0.01 – 0.00)
rents	-0.02 (-0.04 – 0.00)	-0.02 * (-0.04 – -0.00)	-0.02 (-0.04 – 0.00)	-0.02 * (-0.04 – -0.00)	-0.05 *** (-0.07 – -0.02)	-0.03 ** (-0.05 – -0.01)	-0.02 * (-0.04 – -0.00)	-0.01 (-0.03 – 0.01)	-0.02 * (-0.04 – -0.00)	-0.04 ** (-0.06 – -0.01)
vae	-0.58 *** (-0.90 – -0.25)	-0.73 *** (-1.02 – -0.44)	-0.56 *** (-0.87 – -0.25)	-0.69 *** (-0.98 – -0.40)	-0.76 *** (-1.05 – -0.46)	-0.79 *** (-1.07 – -0.51)	-0.70 *** (-0.99 – -0.41)	0.22 (-0.27 – 0.71)	-0.68 *** (-0.97 – -0.39)	-0.01 (-0.54 – 0.53)
food	0.21 * (0.00 – 0.41)									0.05 (-0.28 – 0.38)
water		0.03 (-0.18 – 0.24)								-0.04 (-0.28 – 0.19)
health			0.24 ** (0.08 – 0.41)							0.11 (-0.16 – 0.39)
ecosystems				0.18 (-0.09 – 0.45)						-0.13 (-0.47 – 0.21)
habitat					0.67 *** (0.39 – 0.96)					0.41 * (0.06 – 0.75)
infrastructure						-0.22 (-0.44 – 0.01)				-0.17 (-0.44 – 0.09)
economic							-0.21 * (-0.42 – -0.00)			-0.02 (-0.22 – 0.19)
governance								-0.69 *** (-0.96 – -0.42)		-0.55 *** (-0.86 – -0.23)
social									-0.14 (-0.33 – 0.05)	0.14 (-0.10 – 0.39)
Observations	204	204	204	204	204	204	204	204	204	204
R^2 Nagelkerke	0.242	0.226	0.258	0.233	0.311	0.240	0.243	0.328	0.234	0.367
AIC	673.911	677.864	669.618	676.191	655.095	674.328	673.684	650.193	675.885	654.720
log-Likelihood	-328.956	-330.932	-326.809	-330.095	-319.548	-329.164	-328.842	-317.096	-329.943	-311.360

** p<0.05   ** p<0.01   *** p<0.001*

Note: results of a Cox model for the probability of fiscal crises including climate vulnerability and readiness indicators from ND-Gain, alongside institutions. The variables are defined in tables 1 and 2.

Table A4. Cox model of fiscal crises including pve

	1	2	3	4	5	6	7	8	9	10
Predictors	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*
debt	0.01 * (0.00 – 0.01)	0.01 (-0.00 – 0.01)	0.01 (-0.00 – 0.01)	0.01 (-0.00 – 0.01)	0.01 ** (0.00 – 0.02)	0.01 * (0.00 – 0.01)	0.01 (-0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 (-0.00 – 0.01)	0.01 ** (0.00 – 0.02)
growth	-0.05 (-0.13 – 0.02)	-0.05 (-0.12 – 0.02)	-0.06 (-0.14 – 0.01)	-0.05 (-0.12 – 0.02)	-0.04 (-0.12 – 0.03)	-0.04 (-0.11 – 0.03)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.05 (-0.12 – 0.02)	-0.04 (-0.12 – 0.03)
cda	-0.32 *** (-0.47 – -0.16)	-0.34 *** (-0.49 – -0.18)	-0.31 *** (-0.46 – -0.15)	-0.33 *** (-0.48 – -0.18)	-0.28 *** (-0.44 – -0.13)	-0.37 *** (-0.53 – -0.21)	-0.31 *** (-0.46 – -0.15)	-0.26 ** (-0.41 – -0.10)	-0.33 *** (-0.50 – -0.17)	-0.26 ** (-0.45 – -0.07)
inf avg	0.01 (-0.01 – 0.02)	0.01 (-0.01 – 0.03)	0.01 (-0.01 – 0.02)	0.01 (-0.01 – 0.02)	0.01 (-0.01 – 0.02)	0.01 (-0.01 – 0.03)	0.01 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.01 (-0.01 – 0.03)	0.00 (-0.02 – 0.02)
tot	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	0.00 (-0.00 – 0.01)	-0.00 (-0.01 – 0.00)	0.00 (-0.00 – 0.01)	-0.00 (-0.01 – 0.01)
rents	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.02 * (-0.05 – -0.00)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.02 (-0.03 – 0.00)	-0.01 (-0.03 – 0.01)	-0.04 ** (-0.06 – -0.01)
pve	-0.72 *** (-1.00 – -0.44)	-0.85 *** (-1.12 – -0.58)	-0.68 *** (-0.96 – -0.40)	-0.77 *** (-1.03 – -0.52)	-0.69 *** (-0.94 – -0.44)	-0.80 *** (-1.04 – -0.56)	-0.77 *** (-1.01 – -0.52)	-0.09 (-0.58 – 0.40)	-0.79 *** (-1.06 – -0.52)	-0.07 (-0.62 – 0.48)
food	0.12 (-0.09 – 0.32)									0.06 (-0.27 – 0.39)
water		-0.10 (-0.32 – 0.12)								-0.06 (-0.31 – 0.19)
health			0.15 (-0.02 – 0.33)							0.11 (-0.17 – 0.39)
ecosystems				0.10 (-0.18 – 0.38)						-0.13 (-0.47 – 0.22)
habitat					0.48 ** (0.19 – 0.77)					0.41 * (0.08 – 0.73)
infrastructure						-0.13 (-0.36 – 0.10)				-0.17 (-0.44 – 0.10)
economic							-0.17 (-0.38 – 0.03)			-0.02 (-0.23 – 0.19)
governance								-0.55 ** (-0.88 – -0.21)		-0.51 ** (-0.88 – -0.14)
social									-0.02 (-0.23 – 0.18)	0.15 (-0.10 – 0.40)
Observations	204	204	204	204	204	204	204	204	204	204
R^2 Nagelkerke	0.292	0.291	0.299	0.290	0.326	0.293	0.298	0.326	0.288	0.367
AIC	660.372	660.820	658.664	661.070	650.826	660.276	658.687	650.862	661.536	654.658
log-Likelihood	-322.186	-322.410	-321.332	-322.535	-317.413	-322.138	-321.343	-317.431	-322.768	-311.329

** p<0.05 ** p<0.01 *** p<0.001*

Note: results of a Cox model for the probability of fiscal crises including climate vulnerability and readiness indicators from ND-Gain, alongside institutions. The variables are defined in tables 1 and 2.

Table A5. Cox model of fiscal crises including cce

	1	2	3	4	5	6	7	8	9	10
Predictors	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*	*Effect*
debt	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 ** (0.00 – 0.02)	0.01 ** (0.00 – 0.02)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 * (0.00 – 0.01)	0.01 ** (0.00 – 0.02)
growth	-0.04 (-0.11 – 0.03)	-0.04 (-0.11 – 0.03)	-0.06 (-0.13 – 0.02)	-0.04 (-0.11 – 0.03)	-0.04 (-0.11 – 0.03)	-0.03 (-0.10 – 0.04)	-0.04 (-0.11 – 0.03)	-0.05 (-0.12 – 0.02)	-0.04 (-0.11 – 0.03)	-0.04 (-0.12 – 0.03)
cda	-0.20 ** (-0.34 – -0.05)	-0.21 ** (-0.35 – -0.06)	-0.19 ** (-0.34 – -0.05)	-0.20 ** (-0.35 – -0.06)	-0.15 * (-0.30 – -0.01)	-0.24 ** (-0.39 – -0.09)	-0.18 * (-0.33 – -0.03)	-0.26 *** (-0.41 – -0.11)	-0.19 * (-0.34 – -0.04)	-0.26 ** (-0.44 – -0.08)
inf avg	0.00 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.01 – 0.02)	0.00 (-0.02 – 0.02)
tot	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.01)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.00)	-0.00 (-0.01 – 0.01)
rents	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.01 (-0.03 – 0.01)	-0.03 * (-0.05 – -0.01)	-0.02 (-0.04 – 0.00)	-0.01 (-0.03 – 0.01)	-0.02 (-0.04 – 0.00)	-0.01 (-0.03 – 0.01)	-0.04 ** (-0.06 – -0.01)
cce	-0.90 *** (-1.28 – -0.53)	-0.98 *** (-1.32 – -0.65)	-0.84 *** (-1.20 – -0.48)	-0.98 *** (-1.33 – -0.63)	-0.87 *** (-1.21 – -0.54)	-1.01 *** (-1.34 – -0.68)	-0.95 *** (-1.29 – -0.61)	0.51 (-0.41 – 1.42)	-0.96 *** (-1.31 – -0.61)	0.31 (-0.67 – 1.28)
food	0.10 (-0.11 – 0.31)									0.06 (-0.27 – 0.40)
water		0.03 (-0.18 – 0.23)								-0.06 (-0.30 – 0.18)
health			0.16 (-0.01 – 0.33)							0.10 (-0.19 – 0.38)
ecosystems				0.04 (-0.24 – 0.32)						-0.12 (-0.46 – 0.22)
habitat					0.50 *** (0.21 – 0.80)					0.39 * (0.06 – 0.72)
infrastructure						-0.19 (-0.43 – 0.05)				-0.17 (-0.43 – 0.09)
economic							-0.13 (-0.33 – 0.07)			-0.02 (-0.23 – 0.19)
governance								-0.86 *** (-1.36 – -0.36)		-0.71 * (-1.28 – -0.15)
social									-0.05 (-0.25 – 0.15)	0.14 (-0.10 – 0.39)
Observations	204	204	204	204	204	204	204	204	204	204
R^2 Nagelkerke	0.291	0.288	0.301	0.288	0.330	0.298	0.294	0.330	0.289	0.368
AIC	660.664	661.472	657.955	661.477	649.581	658.932	659.799	649.809	661.313	654.336
log-Likelihood	-322.332	-322.736	-320.977	-322.738	-316.790	-321.466	-321.899	-316.904	-322.657	-311.168

** p<0.05 ** p<0.01 *** p<0.001*

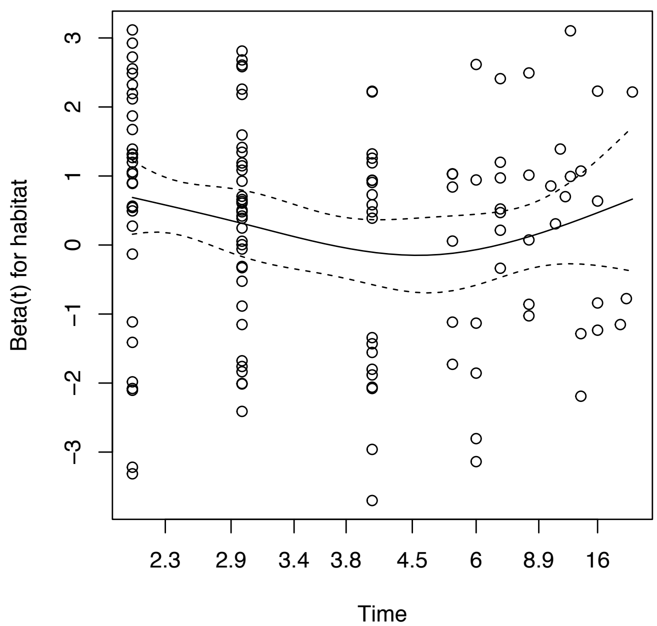
Note: results of a Cox model for the probability of fiscal crises including climate vulnerability and readiness indicators from ND-Gain, alongside institutions. The variables are defined in tables 1 and 2.

Table A6

Row	*Estimate*	*Lower.bound*	*Upper.bound*	*p.value*
interest	0.14	0.07	0.18	0.00
growth	-0.04	-0.09	0.03	0.23
cda	-0.22	-0.35	-0.05	0.01
inf_avg	-0.00	-0.01	0.03	1.00
tot	-0.00	-0.01	0.00	0.76
rents	-0.02	-0.04	-0.00	0.02
habitat	0.36	0.07	0.61	0.02
governance	-0.56	-0.69	-0.37	0.00

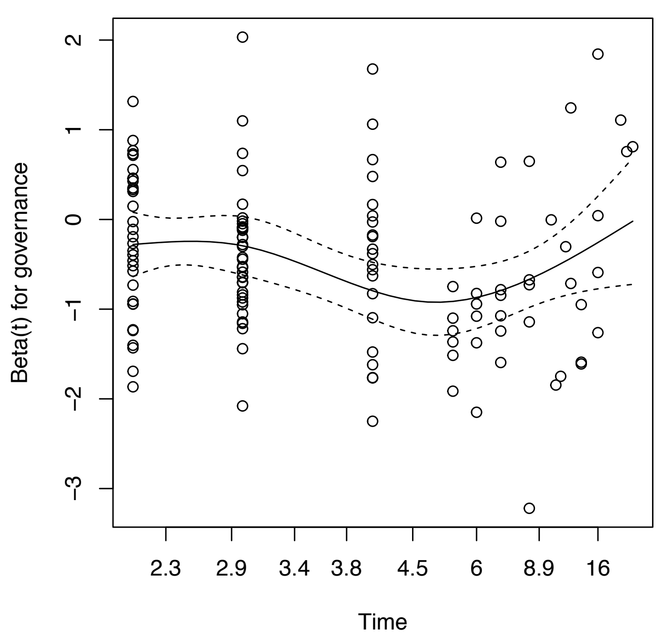
The table shows the confidence intervals by bootstrapping of our base line mode, with 1,000 simulations.

Figure A1. Graphical Test of Proportional Hazards: Habitat



Note: The Chi squared statistic for testing the proportional hazard assumption in habitat is equal to 0.3986 and p.value 0.5278

Figure A2. Graphical Test of Proportional Hazards: Governance



Note: The Chi square statistic for testing the proportional hazard assumption in habitat is equal to 1.5336 and p.value 0.2156

UBIREA
Institut de Recerca en Economia Aplicada Regional i Pública
Research Institute of Applied Economics
Universitat de Barcelona
Av. Diagonal, 690 • 08034 Barcelona

WEBSITE: www.ub.edu/irea • **CONTACT:** irea@ub.edu