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Trade openness and vulnerability to climate change: empirical evidence from 156 countries

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Abstract

The objective of this article is to analyse the effect of trade openness on vulnerability to climate change (CC). An econometric analysis based on panel fixed effects regressions is carried out across 156 countries for the period 1995-2019. Empirical evidence, shows that: (i) trade openness evaluated from the Squalli and Wilson index reduces vulnerability to CC based on the "Global Adaptation Index 2020"; (ii) The underlying effect is more pronounced in low-income countries, compared to middle and high income countries. The results are robust to traditional measures of trade openness (trade openness rate, export and import) and to alternative estimation methods such as Tobit regressions, dynamic fixed effects, quantile regression and the generalized moments method. Policy implications are discussed, including the need for developing countries to strengthen their economic, social, and governance systems to enhance their resilience facing CC through trade.

Keywords: Climate change; Vulnerability; Trade openness; Econometrics; Adaptation; Resilience.

JEL Classification : Q50, Q54, F1, Q59

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1 Introduction

The account for climate change (CC) in macro-economics is increasing (Ahmed and Long, 2012; Agliardi and Xepapadeas, 2019; Tinta, 2022). The impacts of CC on human systems as well as the design of public policies coping with CC depend not only on the level of greenhouse gas (GHG) emissions worldwide, but also on the vulnerability of these systems to climate. For this purpose, the Intergovernmental Panel on Climate Change (IPCC) distinguishes between mitigation and adaptation mechanisms and policies facing CC. Mitigation consists in anthropogenic interventions to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2001). Adaptation refers to adjustments in natural or human systems in response to current or expected climatic effects, uncertainties, shocks and/or adverse events, which potentially moderates damages, vulnerabilities and risks or exploits beneficial opportunities (IPCC, 2001). The general purpose of this article is to analyse the effect of trade openness on vulnerability to CC at the international scale.

The climate issue is now tied to the economy, trade and markets at different scales (Copeland and Taylor, 2004; Ahmed and Long, 2012; Dallmann, 2019; Sorgho and Tharakan, 2022). In particular, to limit the increase in temperature on the macro and international scale, the COP 21 and the Paris Agreement stressed the need to limit and reduce greenhouse gas (GHG) emissions induced by economic activities, including transport activities, sectors, and markets (Antweiler et al., 2001; Managi et al., 2009). A more direct link between CC, markets and trade recently emerged with 'carbon' markets such as the European carbon emissions market, a policy-driven regulatory instrument designed to facilitate the achievement of greenhouse gas emission reduction targets at the EU international scale. Other examples of the interplay between the climate issue, the economy, markets and trade include carbon taxes, which incorporate a carbon component into domestic taxes on the consumption of energy products, with the aim of reducing these emissions to curb global warming. Such carbon taxes can strongly affect international trade. Such public policies mainly relate to the GHG mitigation issue. By contrast, the role of international trade on the vulnerability and adaptation to CC (VCC) can be questioned. Identifying the degree of trade openness of particular vulnerable nations or regions (i.e. those least equipped to deal with the impacts of CC) can serve to understand and address the processes that cause and exacerbate vulnerability (Awan et al., 2018) and, symmetrically, to propose policies fostering the resilience facing CC (Béné and Doyen, 2018; Grafton et al., 2019). Specifically, our research evaluates the effects of trade openness on the vulnerability of countries to CC impacts and their adaptive capacities around the world. Such a research aims at promoting the design and implementation of development policies differentiated according to the regions and sustainably balancing economic and environmental goals.

To our knowledge, no study has empirically examined the importance of trade openness in resilience-based strategies in the face of climate shocks. Our hypothesis is that trade openness reduces VCC. In other words, we wonder to what extent trade openness helps economies coping with potential future climate shocks and adverse events. To assess the VCC, we rely on the Global Adaptation Index 2020 database explained in Chen et al. (2015) and illustrated in Figure 1. Our VCC evaluation is here carried out across 156 countries from 1995 to 2019. Regarding the metric of trade openness, our work focuses on the Squalli and Wilson index (Squalli and Wilson, 2011). This choice differs from other openness indicators relating to distortions caused by trade barriers which include the relative price distortion index (Dollar, 1992), the trade restriction index (Anderson and Neary, 1994; Feenstra, 1995), the indicator based on effective tariffs (Pritchett and Sethi, 1994), as well as the commonly used traditional aperture ratio. In contrast, Squalli and Wilson (2011), describing an open economy as an economy that has a relatively high share of trade in relation to overall economic activity, and a significant level of interaction and interconnection with the rest of the world, have constructed the composite trade share (CTS) index as a measure that takes into account these two dimensions of trade openness.

Beyond the analysis of the impact of trade openness on VCC, our work also pays attention to the role of the development and income level of countries on this vulnerability. The underlying intuition is that countries with low-income are characterized by more vulnerability to CC than countries with high-income through stronger environmental concerns and regulations (Muhammad et al., 2022). For example, the year 2022 was marked by many catastrophic events induced by CC strongly affecting poor countries. It includes devastating floods in Pakistan which caused numerous losses of human life (at least 1,700 dead), which destroyed nearly 250,000 homes and 1.8 million farmlands; a historic drought in East Africa that caused 731,747 deaths and economic losses of US$38.5 billion; as well as series of cyclones in southern Africa, particularly in Madagascar. Thus the poorest countries are often the most exposed countries, the most vulnerable to CC as exempli-

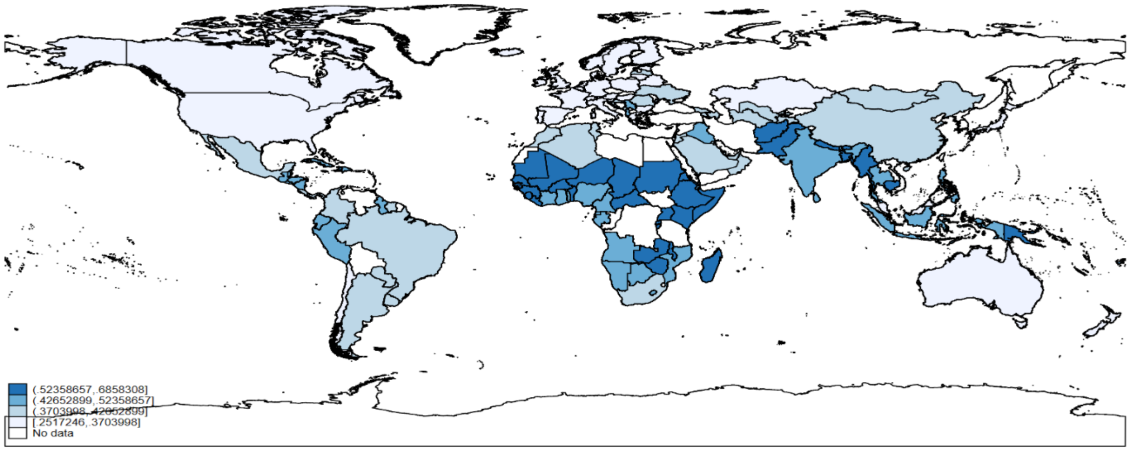

Figure 1: CC vulnerability at the world scale. **Source**: authors using data from Notre Dame Global Adaptation index.

fied globally by Figure 1. Our paper thus also investigates the ties between income level and trade openness in terms of vulnerability to CC. We also examine the role of governance capacity on VCC in line with findings of Tennant and Gilmore (2020); Ngouhouo and Nchofoung (2021).

The structure of the article is as follows: Section 2 presents the model and the data; Section 3 presents the empirical results while Section 4 discusses these results; The last section concludes.

2 Methodology

2.1 Data

The empirical analysis of the effect of trade openness on VCC is carried out throughout 156 countries from 1995 to 2019. This study period is justified by the availability of data. The countries involved in the sample are listed in Table 9 of the appendix. The data set constitutes a panel which offers the possibility of exploiting the temporal and spatial dimensions of the data. The dependent variable is the VCC which measures the propensity or predisposition of human societies to suffer damages in the event of climatic shocks. The data for this variable comes from the "Global Adaptation Index 2020" database previously proposed by Chen et al. (2015) and illustrated in Figure 1. This variable varies between "0 and 100". Modality 0 reflects the absence of vulnerability, while modality "100" expresses a maximal VCC. Details for the computation of this vulnerability index are provided in section A.1 of the Appendix and online in Global Adaptation Index 2020. The variable of interest is represented by the CTS (country trade share) index proposed by Squalli and Wilson (2011) to evaluate trade openness and defined mathematically below in equation (3).

Moreover, the study uses a set of control variables to account for the adaptive capacity of countries. These variables have been already empirically tested by Sarkodie and Strezov (2019). These variables include the adaptive preparation of the social framework (SOC) which measures the level of social inequalities, the quality of the infrastructures, the educational framework and the capacity to innovate. It captures the social conditions of a country to ensure safe and efficient economic activities. It integrates the social conditions favorable to the productivity of the investments and allows an efficient and equitable use of the profits. It also potentially contributes to the resilience of the social framework in the face of a climatic shock. Control variables also include governance readiness (Gov) which combines indicators of political stability, control of corruption, rule of law and regulatory quality. It assesses a government's ability to react when a climate shock occurs. We also account for the adaptation of the economic framework (Eco). This other control variable Eco measures the various economic operations favorable to the business necessary for the mobilization of capital in the private sector. The composite index of these three preceding control variables provides the indicator relating to an overall adaptation of a country's environment. All of these control variables are also obtained from the database of Notre Dame University's "Global Adaptation Index (2020)". The descriptive statistics and the correlation matrix of the variables are provided in the appendix with Tables 10 and 11.

2.2 Trade openness metric

Squalli and Wilson (2011) start from the definition of the ratio of the share of trade and the weight of country $i = 1, 2, 3, \ldots, n$ in world trade. Let X_i, M_i and GDP_i be the exports, imports and gross domestic product of country i respectively. The TS_i trade openness of country i is then defined by:

$$TS_i = \frac{(X + M)_i}{PIB_i}. \quad (1)$$

The second dimension of trade openness involves the relative contribution WTS_i that a country makes to total world trade, namely:

$$WTS_i = \frac{(M+X)_i}{\sum_{j=1}^{n}(M+X)_j}. \tag{2}$$

The larger is WTS_i, the greater the country's weight in world trade. Hereafter we focus on the proportion CTS of a country's level of trade relative to the average world trade as follows

$$CTS_i = n * WTS_i * TS_i. \tag{3}$$

Substituting (1) and (2) into (3), we write equivalently:

$$CTS_i = \frac{(M+X)_i}{\frac{1}{n}\sum_{j=1}^{n}(M+X)_j}\frac{(M+X)_i}{PIB_i}. \tag{4}$$

Intuitively, CTS represents TS adjusted by the proportion of a country's level of trade relative to the average world trade (Mignamissi et al., 2024; Mignamissi and Nguekeng, 2022; Gandjon Fankem and Feyom, 2023). The export, import and GDP data needed to construct the CTS indicator by country are obtained from the WDIs.

2.3 Econometric approach

The empirical analysis of the effect of CTS on VCC is performed using an econometric model inspired by Sarkodie and Strezov (2019). Thus we assume that the VCC is a function of the CTS together with the adaptive capacity of the socio-economic environment as follows:

$$VCC = f(CTS, adaptation). \tag{5}$$

More specifically, we consider the regression

$$VCC_{it} = \varphi_k CTS_{it} + \alpha Soc_{it} + \beta Gov_{it} + \gamma Eco_{it} + \mu_i + \tau_t + \varepsilon_{it}, \tag{6}$$

where VCC_{it} represents the vulnerability to CC in country i for year t , with $i = 1, 2, \ldots, 156$ and $t = 1995, 1996 \ldots, 2019$. Similarly CTS_{it}, Eco_{it}, Soc_{it}, and Gov_{it} stand for trade openness, economic, social, and governance metrics, respectively, in country i at year t while φ_k, α, β and γ are the parameters to be estimated. The values μ_i express the country-specific effect while τ_t represents the time constant. They make it possible to control for unobservable, time-invariant and country-specific characteristics. The variable ε_{it} denotes the error term composed of the individual fixed effects and the time effect common to all countries. These effects are assumed not to be observed.

In order to estimate the equation (6), we adopt a sequential econometric approach depending on the difficulties encountered for each estimation technique. We start with ordinary least squares (OLS) estimates. The sequential approach allows the study to use all available information related to individual and temporal dimensions. Moreover, it increase the possibility of obtaining unbiased and consistent estimators under the assumption of exogeneity of the regressors. Given that several economies in our sample present heterogeneities, it is difficult to claim that the results are not biased. This therefore motivates the choice of a fixed effects (FE) model. The FE model produces unbiased estimators, but at the cost of a loss of information. An alternative to the FE estimator is the use of a random effects (RE) model which produces efficient estimators in the absence of biases related to omit variables. One of the limitations of the RE model is that it is based on overly restrictive assumptions. For example, it is assumed that the individual effect is rather random and uncorrelated with the explanatory variables. The choice between FE and RE models is based on the type of Lagrange multiplier (LM) and Hausman tests.

3 Empirical results

3.1 Basic results

The basic results are presented in Tables 1 and 2. Table 1 presents the effect of the overall CTS index on the VCC in 6 columns. The first two columns (1 and 2) are obtained by OLS. The first column is an estimate made with only CTS as the only explanatory variable. The second column is a redone estimate by adding other explanatory variables. The relevance of this differentiation comes from the fact that the CTS is the best explanatory variable of the VCC despite the consideration of other factors. The other four columns are divided between the FE and RE models. However, the Hausman test shows that the FE model is better than the RE model.

The main lesson from the results in Table 1 is that any increase in the overall CTS index leads to a decrease in VCC worldwide. Columns 1 and 2 obtained from OLS show a significant effect of

	1	2	3	4	5	6
	OLS	OLS	RE	RE	FE	FE
VARIABLES			VCC			
ln(CTS)	-0.0320***	-0.0176***	-0.0117***	-0.00634***	-0.0107***	-0.00549***
	(0.000528)	(0.000585)	(0.000532)	(0.000486)	(0.000539)	(0.000483)
Eco		-0.00951		0.00220		0.00253
		(0.00952)		(0.00213)		(0.00208)
Gov		-0.166***		0.0101*		0.0217***
		(0.00758)		(0.00540)		(0.00537)
Soc		-0.142***		-0.124***		-0.122***
		(0.00768)		(0.00353)		(0.00346)
Constant	0.514***	0.610***	0.462***	0.480***	0.456***	0.468***
	(0.00189)	(0.00363)	(0.00551)	(0.00538)	(0.00148)	(0.00310)
Observations	3,133	3,056	3,133	3,056	3,133	3,056
R-squared	0.548	0.706			0.116	0.398
R2 overall			0.548	0.622	0.548	0.587
R2 between			0.552	0.640	0.552	0.609
R2 within			0.116	0.396	0.116	0.398
Hausman-test			0.000	0.000		
Region fixed effects	Yes	Yes	No	No	No	No

Table 1: Reference model of VCC versus CTS. 1: Ordinary least squares (OLS) without control variables ; 2: OLS with control variables ; 3 : Fixed effects (FE) without control variables ; 4 : FE with control variables ; 5 : Random effects (RE) without control variables ; 6 : RE with control variables. Standard errors are in parentheses. ***p<0.01, **p<0.05, *p<0.1.

around 3% and 1% of trade openness on VCC in 156 countries. The corresponding coefficient of determination R2 of the first specification (or column 1) is approximately 54%. The integration of control variables in column 2 where the second specification shows the same significant effect with an R2 of around 70%.

Table 2 analyses the effect on VCC of other ingredients of trade openness namely key components of CTS including the imports X, exports M and trade TS introduced in equation (1). The analysis is here exclusively performed using FE regressions. Table 2 shows that regardless of the indicators chosen to measure trade openness, the basic result still holds true, i.e. that trade openness reduces the vulnerability of countries worldwide to climate change. Table 2 thus confirms the results obtained in Table 1.

3.2 Test sensitivity

Two sensitivity tests are performed on our results. Drawing on the statistics of the Development Index of the World Bank in 2021, Table 3 contrasts high-income countries, middle-income countries, and low-income countries. Table 4 also distinguishes countries according to their continental origin. These sensitivity tests are inspired by the work of Feindouno and Guillaumont (2019); Guillaumont and Simonet (2011). According to them, the level of income, the geographical location, and the size of a country influence its VCC. Ignoring these aspects in this work would thus lead to biased results.

Interpretation of the results in Table 3 shows that even when distinguishing between countries in terms of income levels, the negative link between trade openness and VCC is confirmed. Furthermore, the magnitude of the link is most apparent in high-income countries, followed by low-income countries, then middle-income countries. This result could be justified by the fact that these countries are more effective in terms of governance. In addition, the involved countries could also have a comparative advantage in the channels through which CTS reduces VCC namely socio-economic adaptation and governmental adaptation. We elaborate on these findings in the discussion below.

The geographical analysis of Table 4 shows that in Africa (column 1), CTS is significantly reduced by about 1%. The same effect in terms of the sign of the estimated coefficient is observed in Asia (column 2); in Europe (column 3); in Latin America. In other words, despite the disaggregation of the sample by geographic area, the negative influence of CTS on VCC stands up to empirical scrutiny. However, in Asian countries (column 2) and in Latin American and Caribbean countries (column 4), the effect of trade openness is higher. The trade openness and effective governance that characterise these countries could explain this result. In addition, the involved countries could also have a comparative advantage in the channels through which CTS reduces VCC.

	1	2	3
	FE		
VARIABLES		VCC	
Ln(TS)	**-0.00236*** **		
	(0.000568)		
ECO	0.00182	0.00162	0.00208
	(0.00206)	(0.00206)	(0.00205)
GOV	-0.0233***	-0.0239***	-0.0224***
	(0.00460)	(0.00461)	(0.00458)
SOC	-0.134***	-0.135***	-0.133***
	(0.00331)	(0.00331)	(0.00329)
Ln(M)		**-0.00131** **	
		(0.000578)	
Ln(X)			**-0.00294*** **
			(0.000487)
Constant	0.494***	0.489***	0.493***
	(0.00341)	(0.00326)	(0.00293)
Observations	3,4	3,4	3,401
R-squared	0.363	0.361	0.367
R2 overall	0.363	0.361	0.367
R2 between	0.569	0.560	0.579
R2 within	0.589	0.579	0.600

Table 2: Basic model with components of trade openness: Trade TS, Export X and Import M. Standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1. Source: authors.

3.3 Robustness tests

Four robustness tests are presented in this subsection: a Tobit test, a dynamic estimator with fixed effects (DFE) , quantile regressions (QR) and the generalized method of moments (GMM). The

	1	2	3
	high- income	low- income	middle- income
VARIABLES		VCC	
Ln CTS	**-0.00990*** **	**-0.00385** **	**-0.00172*** **
	(0.00139)	**(0.00167)**	**(0.000603)**
Constant	0.425***	0.661***	0.497***
	(0.00866)	(0.00781)	(0.00365)
Observations	1,094	451	1,586
R-squared	0.434	0.324	0.439
R2 overall	0.434	0.324	0.439
R2 between	0.351	0.0253	0.336
R2 within	0.376	0.0589	0.331
Control variables	Yes	Yes	Yes

Table 3: Results by income bracket: high-income, low- income and middle- income. Standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1. Source authors

additional robustness tests are motivated by the fact that the results presented above have some shortcomings which we investigate below.

Tobit estimator: Among the shortcomings of the (OLS) empirical analysis proposed in the previous section, we first point out that the approach does not take into account some features of the outcome variable, such as its limited range. First, in terms of the bounded range, the fact that the outcome variable is set in the specific range between 0 and 100 implies that it is censored, and therefore that a double-censored estimation approach such as the Tobit model is useful (Asongu et al., 2020b,a). Also, our dependent variable is a continuous random variable over an interval, and so with this apparent censoring, the OLS provides biased and inconvergent estimators due to the distribution of the model which is a mixture of a discrete distribution and a continuous law. The Tobit model is therefore appropriate to address this shortcoming. The application of the Tobit

	1	2	3	4	5
	Africa	Asia	Europe	Latina America	Oceania
VARIABLES			VCC		
Ln CTS	**-0.00425*** **	**-0.00916*** **	**-0.00276** **	**-0.00929*** **	**0.00156**
	(0.000927)	**(0.00106)**	**(0.00111)**	**(0.00137)**	**(0.00549)**
Constant	0.557***	0.485***	0.390***	0.463***	0.472***
	(0.00582)	(0.00552)	(0.00709)	(0.00717)	(0.0169)
Observations	711	694	728	513	140
R-squared	0.393	0.450	0.434	0.514	0.390
R2 overall	0.393	0.450	0.434	0.514	0.390
R2 between	0.122	0.189	0.530	0.370	0.696
R2 within	0.136	0.190	0.560	0.328	0.796
Control variables	Yes	Yes	Yes	Yes	Yes

Table 4: Results by geographical distribution: Africa, Asia, Europe, Latin America, and Oceania. Standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1. Source authors

estimator are shown in Table 5. It can be seen that a percentage change of the order of 1% of the CTS leads to a marginal attenuation of the VCC of about 1% to to 4% respectively (column 2 and 3). Such results confirm that countries promoting trade openness indirectly improve their resilience to CC.

Dynamic estimator with fixed effects (DFE) : The second robustness check relates to the use of DFE. This technique has the advantage of potentially treating the long-term determinants of the VCC separately from the short-term adjustments. This estimator imposes the identity of all the slope coefficients and the variances of the error terms and only tolerates differences in individual effects between countries. Column 4 of Table 5 details the outcomes of the dynamic estimator with fixed effects. Similarly to the Tobit results, the negative effect of the long-term impact of CTS in reducing VCC is confirmed. The estimated average coefficient associated with the error correction term is negative, significant, and located within an interval of 0 and -1, which again shows the stability of the model.

Quantile regressions: Due to the fact that the OLS estimator only focuses on the average effect and does not capture the CTS effect on different VCC intervals, we use the regression approach quantiles (QR) introduced by Koenker and Bassett Jr (1978). QR has the particularity of taking into account the effect of one variable on another at different points in its distribution. This approach is more robust than OLS for several reasons. For example, it is appropriate when errors are not normally distributed as well as in front of outliers. Moreover, when the distribution of the dependent is wide, the mean can be highly variable in the presence of high heterogeneity in the sample (Cade and Noon, 2003). Thus, QR provides a more accurate description of the distribution of a variable of interest conditional on its determinants than a simple linear regression that focuses on the conditional mean. In line with Binder and Coad (2011), the quantile regression model can be written as follows:

$$y_{it} = x'_{it}\beta_\theta + u_{\theta it} \text{ with } Quant_\theta\left(y_{it}|x_{it}\right) = x'_{it}\beta_\theta, \tag{7}$$

where y_{it} is the VCC index of the country i at date t, β is the vector of parameters to be estimated, x_{it} is a vector of regressors and u is the vector of residuals. $Quant_\theta\left(y_{it}|x_{it}\right)$ represents the conditional quantile of y_{it} for a x_{it} given. The quantile estimator is obtained by solving the following optimization problem for the quantile $(0 < \theta < 1)$

$$\min_{\beta \in R^K}\left[\sum_{i \in \{i: y_i \geq x'\beta\}} \theta\left|y_i - x'_i\,\beta\right| + \sum_{i \in \{i: y_i \prec x'\beta\}} (1-\theta)\left|y_i - x'_i\,\beta\right|\right]$$

The results of the estimation by quantiles compared to that of the OLS are presented in Table 6. Column (1) displays the results of the estimation of the OLS which remain faithful to those obtained previously. Columns (2) to (6) describes estimates for the 10th, 25th, 50th, 75th and 95th quantiles. We observe that the negative and more apparent effect of leaving one quantile has an increasing effect on another. More precisely, the effect is statistically significant on all quantile distributions with highly varying amplitudes. These results are confirmed in Figure 2, which illustrates how the negative effects on CC vulnerability vary across quantiles, and how the magnitude of the effects at different quantiles differ significantly from the OLS coefficients (horizontal line). Indeed, the effect

	(1)	(2)	(3)	(4)
	FE	TOBIT	CENSORED	DFE
VARIABLES		VCC		
L.lnCTS				**-0.00762*****
				(0.00154)
ECO	0.00253	-0.00951	-0.0242	0.0173***
	(0.00208)	(0.00853)	(0.257)	(0.00659)
GOV	0.0217***	-0.166***	-0.409*	0.0126
	(0.00537)	(0.00749)	(0.226)	(0.0170)
SOC	-0.122***	-0.142***	-0.430*	-0.104***
	(0.00346)	(0.00837)	(0.260)	(0.0110)
Ec				**-0.188*****
				(0.0107)
D.lnCTS				**-0.00100***
				(0.000562)
D.ECO				-0.000416
				(0.00217)
D.GOV				0.00838
				(0.00649)
D.SOC				0.00345
				(0.00694)
ln CTS	**-0.00549*****	**-0.0176*****	**-0.0393****	
	(0.000483)	**(0.000574)**	**(0.0170)**	
Constant	0.468***	0.610***	-0.403***	0.0868***
	(0.00310)	(0.00333)	(0.101)	(0.00532)
Observations	3,056	3,056	3,056	3,056
R-squared	0.398			

Table 5: Robustness tests through Tobit and DFE results. Standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1. Source authors.

	1	2	3	4	5	6
	OLS	Q10	Q25	Q50	Q75	Q95
VARIABLES			VCC			
lnCTS	**-0.0176***** **(0.000585)**	**-0.00995***** **(0.000707)**	**-0.0152***** **(0.000544)**	**-0.0160***** **(0.000756)**	**-0.0202***** **(0.000999)**	**-0.0180***** **(0.00243)**
ECO	-0.00951 (0.00952)	0.0210** (0.0105)	-0.00415 (0.00809)	0.00102 (0.0112)	-0.0175 (0.0149)	-0.0120 (0.0362)
GOV	-0.166*** (0.00758)	-0.128*** (0.00923)	-0.135*** (0.00710)	-0.178*** (0.00988)	-0.241*** (0.0131)	-0.237*** (0.0318)
SOC	-0.142*** (0.00768)	-0.174*** (0.0103)	-0.168*** (0.00794)	-0.141*** (0.0110)	-0.0907*** (0.0146)	-0.0628* (0.0355)
Constant	0.610*** (0.00363)	0.507*** (0.00410)	0.556*** (0.00316)	0.600*** (0.00439)	0.677*** (0.00580)	0.714*** (0.0141)
Observations	3,056	3,056	3,056	3,056	3,056	3,056
R- squared	0.706					
Pseudo R2		0.498	0.499	0.482	0.471	0.386

Table 6: Robustness tests through quantile regressions. Standard errors in parentheses; ***p<0.01, **p<0.05, *p<0.1; Source: authors.

seems greater for the intermediate quantiles (Q75, Q95, Q50) than for the extreme quantiles (Q10 and Q25).

Estimation by the generalised method of moments: The generalised method of moments (GMM) opposes two competing estimators, namely a difference and a system estimator. The difference GMM estimator, introduced by Holtz-Eakin et al. (1988) and popularized by Arellano and Bond (1991) consists in transforming the above model in difference to solve the problem of the correlation between VCC_{it-1} and CTS_{it}. This transformation also eliminates the country-specific effect such as: $\Delta VCC_{it} = \theta \Delta VCC_{it} + \beta \Delta CTS_{it} + \Delta Z'_{it}\phi + \Delta\lambda_t + \Delta\varepsilon_{it}$.

Following this specification, the OLS estimate of θ and β is biased, as VCC_{it-1} is still a function of ε_{it-1}, and $Cov(VCC_{it-1}, \Delta\varepsilon_{it}) \neq 0$. To solve this problem Arellano and Bond (1991) proposed to estimate the model by instrumenting the differences with their lagged values (difference GMM estimator). But as demonstrated in Blundell and Bond (1998), this estimator is less robust when the dependent variable is persistent over time, as lagged values are extremely poor instruments.

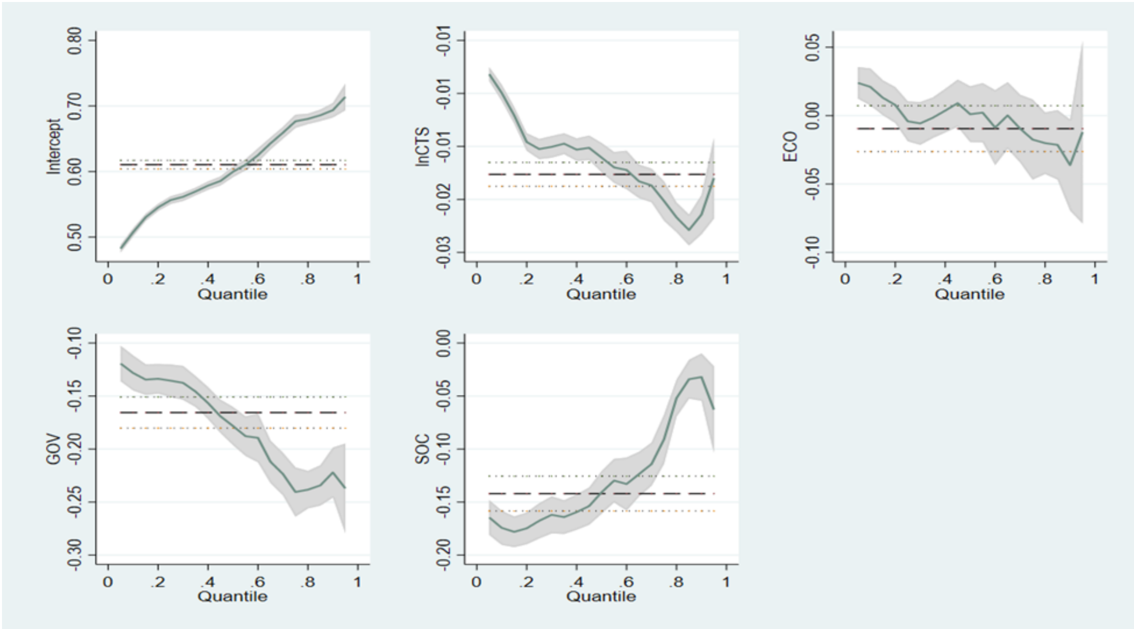

Figure 2: Heterogeneity of the relationship. Source authors.

Thus, following Arellano and Bover (1995); Blundell and Bond (1998) proposed a more robust alternative called a system GMM estimator, obtained from a system of equations, one in level and the other in difference.

$$System - GMM \rightarrow \begin{cases} VCC_{it} = \alpha + \theta VCC_{it-1} + \beta CTS_{it} + Z'_{it}\phi + \mu_i + \lambda_t + \varepsilon_{it} \\ \Delta VCC_{it-1} = \theta \Delta VCC_{it-1} + \beta \Delta CTS_{it} + \Delta Z'_{it}\phi + \Delta\lambda_t + \Delta\varepsilon_{it} \end{cases} \quad (9)$$

The validation of a GMM is cumbersome, as it is based on the consistency of several post-estimation tests. The chosen instruments must be valid, i.e., orthogonal to the error term, but highly correlated with the endogenous variables. It is therefore important to conduct adequate tests for this purpose, one of the most used being Hansen's J test. Furthermore, because of the dynamics induced by the first-order autoregression of the dependent variable, a particular test of autocorrelation of the residuals must be realized. This is the presence/absence of the second-order autocorrelation test of Arellano and Bond (1991). Furthermore, the necessary conditions for the robustness of the GMM results according to Roodman (2009b) are met, as the sample includes 156 countries observed over the period 1995-2019. Lastly, to ensure the asymptotic efficiency of our results (Blundell and Bond, 1998), we prefer the two-step System-GMM estimator over the one-step estimator, with the collapse option used to reduce instrument proliferation (Roodman, 2009a). The results of the system GMM estimator are presented in Table 7 and confirm gain the basic results regarding the negative link between CTS and VCC.

4 Discussion and recommendations

This section discusses the previous results on trade openness and climate vulnerability. In particular, we focus on the underlying roles of, first, technical and composition effects (Grossman and Krueger, 1995; Antweiler et al., 2001; Bekoe and Jalloh, 2023); secondly, transmission channels (mainly governance and income); and thirdly, geography.

Although previous research has argued that trade openness contributes to CC by increasing GHG emissions (Kong et al., 2021; Ahmad and Khattak, 2020; Liu et al., 2021), we find that trade openness reduces climate vulnerability in accordance with Abdelzaher et al. (2020) as shown in Tables 1 and 2 and subsection 3. Adaptation efforts are thus needed at different scales to identify, prevent and reduce risks and minimise ecological, economic and social losses and damages (IPCC, 2001) caused by CC. In particular, adaptation strategies are needed to make communities more resilient in the face of climate changes, uncertainties, and shocks (Alogoskoufis et al., 2021). Adaptation to CC is thus essential for sustainable development. Our article examines to what extent trade can make an important contribution to preventing, reducing and coping with climate risks. This article therefore assesses the impact of international trade on the climate vulnerability of countries around the world using an econometric analysis across 156 countries for the period 1995-2019.

4.1 The role of technical and composition effects

From the economic literature viewpoint (Grossman and Krueger, 1995; Antweiler et al., 2001; Bekoe and Jalloh, 2023), both the technical effect and the composition effect provide important insights into our result. First, the technical effect explains how trade openness reduces vulnerability to CC through knowledge transfer. Open trade facilitates the exchange of resilient and adaptive technologies and strategies between countries. Firms in developed countries can export technologies, knowledge, and strategies to developing countries, enabling them to adopt more sustainable and adaptive

	1	2	3	4
	system GMM			
VARIABLES	**VCC**			
L.VCC	0.946***	0.947***	0.944***	0.986***
	(0.00671)	(0.00296)	(0.00527)	(0.0134)
lnCTS	**-0.00156*** **	**-0.00155*** **	**-0.00172*** **	**-0.00177*** **
	(0.000228)	**(0.000205)**	**(0.000132)**	**(0.000297)**
ECO		0.00397***	0.00281***	-0.000341
		(0.000530)	(0.000840)	(0.00199)
GOV			-0.00619**	-0.00411
			(0.00260)	(0.00424)
SOC				0.0131***
				(0.00327)
Constant	0.0265***	0.0245***	0.0301***	0.00828
	(0.00318)	(0.00185)	(0.00327)	(0.00794)
Observations	3,025	3,025	2,987	2,95
Number of groups	143	143	141	139
Instruments	62	62	62	61
AR (1)	0.000	0.000	0.000	0.000
AR (2)	0.126	0.125	0.125	0.141
Hansen p-value	0.825	0.965	0.922	0.991

Table 7: Estimation by the system GMM estimator. Standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1.

production practices and strengthen their resilience (Ding et al., 2022). In particular transformation strategies of the economy in terms of technology, innovation and scientific knowledge can reduce the vulnerability to CC (Béné and Doyen, 2018; Ay et al., 2014). For example, the development of agroforestry strategies can help combat desertification in Africa. Wildfire management strategies and techniques developed in countries already strongly affected countries (Australia, Mediterranean European countries) can help countries to prevent or mitigate upcoming wildfire damages worldwide. Aquaculture techniques can help countries be more resilient in the face of marine capture fishing fluctuations due to CC such as the northern shift of marine species (Diop et al., 2018). Urban greening techniques can contribute to limit human mortalities during future heat waves in big cities worldwide.

Secondly, the composition effect explains that trade openness reduces vulnerability to CC through the flexibility of supply chains (Strutt and Anderson, 2000; Hoffmann et al., 2005; Parmesan et al., 2022). Trade openness increases global trade in goods and services, which may encourage firms to adopt sustainable and resilient practices throughout their supply chains. In particular, trade can promote diversification strategies across the economy of countries or regions. Keep in mind that an economy specialized in agriculture and targeting food security may be strongly dependent on climate variables such as temperature and rainfall. In line with such diversification strategies, strategies of insurance in the face of climate uncertainties are also relevant to limit vulnerabilities and risks. This insurance is implicitly supported by trade openness through financial markets. More globally, mutualism, coordination and cooperative processes through trade can be of great interest to reinforcing the adaptiveness and resilience (Hardy et al., 2016; Lagarde et al., 2018; Cuilleret et al., 2022) in line with the composition effect. Think also of the European Common Agricultural Policy (CAP) that helps European farming systems to sustain their production and profitability despite the uncertainties, including those induced by CC (drought, flood). The implementation of quota markets (ITQs) for fishing activities as in New-Zealand or Australia can enhance the sustainability and resilience of fisheries altered by CC.

4.2 The role of income and governance channels

In line with the technical and composition effects, our second finding illustrated in Table 3 is that income levels play an important role in the relationship between trade openness and CC. In fact, we find that the effect of trade openness on climate vulnerability strongly depends on income level (Figure 4 in the appendix). The higher the income of a country, the more resilient and less vulnerable it is. The demand for more adaptive strategies including insurance systems or diversification of activities to limit risks increases significantly with income levels. Firms involved in international trade often face more competition and therefore have a greater incentive to cover their risks. The intuition is that domestic firms that do not participate to international trade may be less under pressure from risks (economic, social, and environmental) underlying international competition.

Another finding using explanatory variables complementary to trade openness such as governance quality (Gov) (Tables 5, 6, and 7); is that the quality of governance improves adaptation and flexibility as well as the anticipation of risks (Ngouhouo et al., 2021; Ngouhouo and Nchofoung, 2021). Consequently, developing countries, which are also the most vulnerable to CC (see Figure 1), need to build their capacity in sustainable and resilience-based practices and climate risk management by taking full advantage of training, knowledge transfer and technical cooperation programs offered by open trade. Second, for the common good, developed countries must support developing countries by providing access to finance, technologies and scientific knowledge to help them implement effective adaptation measures putting more emphasis on risks and uncertainties as suggested in Béné and Doyen (2018); Grafton et al. (2019)

4.3 The role of geography

As captured by Table 4, another insight of our work is that the effect of trade openness on climate vulnerability is strongly dependent on geographical location (Topalova, 2010; Dahlke et al., 2020; Zebisch et al., 2021). Countries located in regions with advanced technological industries may be better placed to develop and export reliable technologies and sustainable practices, thereby helping to reduce climate vulnerability. Similarly, regions that already have strong trade links with other regions may be more inclined to reap the benefits of open trade in terms of technology sharing and the sustainable use of capital for CC adaptation projects.

In Africa in particular, trade openness helps reduce dependence on climate-sensitive sectors such as agriculture by allowing African countries to access new markets and diversify their sources of income. In addition, by promoting regional and international trade, trade openness enables African countries to benefit from the transfer of technology and knowledge related to mitigating the effects of climate change. As a continent with diverse natural resources and climates, Africa offers unique opportunities for regional cooperation and intra-African trade. By strengthening trade links between African countries, it is possible to promote a more sustainable use of natural resources and encourage the development of common policies for environmental protection.

5 Conclusion

This study examines the effect of trade openness on VCC. To our knowledge, the empirical literature on the influence of trade openness on climate vulnerability is scarce. Our empirical analysis relies on both the Global Adaptation Index 2020 and the trade openness index proposed by Squalli and Wilson (2011). The empirical evidence in this study is based on a broad panel of 156 countries for the period 1995-2019. The results show that trade openness significantly reduces VCC. When these results are subjected to sensitivity tests, the negative link resists scrutiny based on income brackets, geographic location. The findings also hold out when subjected to further empirical tests using Tobit, dynamic fixed effects, quantile regression (Qreg), and GMM regressions.

The results of this work give directions to research and public policies beyond the positive role of trade openness. In particular, using complementary explanatory variables such as governance quality (Gov), our results suggest that trade openness is a factor of resilience to CC under the condition of a rigorous organisational structure as the quality of governance improves adaptation and flexibility as well as the anticipation of risks (Ngouhouo et al., 2021; Ngouhouo and Nchofoung, 2021). Similarly the role of income and economic performances is put forward as the positive effect of trade openness on the resilience is more pronounced in low-income countries.

The perspectives include the extension of the work to other environmental issues such as vulnerability to biodiversity erosion or water resources (Doyen et al., 2019; Grafton et al., 2019) and the need to promote their sustainability and resilience.

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References

Abdelzaher, D. M., Martynov, A., and Zaher, A. M. A. (2020). Vulnerability to climate change: Are innovative countries in a better position? *Research in International Business and Finance*, 51:101098.

Agliardi, E. and Xepapadeas, A. (2019). Introduction: Special issue on the economics of climate change and sustainability. *Environmental and Resource Economics*, 72:1–4.

Ahmad, M. and Khattak, S. I. (2020). Is aggregate domestic consumption spending (adcs) per capita determining co2 emissions in south africa? a new perspective. *Environmental and Resource Economics*, 75(3):529–552.

Ahmed, K. and Long, W. (2012). Environmental kuznets curve and pakistan: an empirical analysis. *Procedia Economics and Finance*, 1:4–13.

Alogoskoufis, S., Dunz, N., Emambakhsh, T., Hennig, T., Kaijser, M., Kouratzoglou, C., Muñoz, M. A., Parisi, L., and Salleo, C. (2021). *ECB economy-wide climate stress test: Methodology and results*. Number 281. ECB Occasional Paper.

Anderson, J. E. and Neary, J. P. (1994). Measuring the restrictiveness of trade policy. *The World Bank Economic Review*, 8(2):151–169.

Antweiler, W., Copeland, B. R., and Taylor, M. S. (2001). Is free trade good for the environment? *American economic review*, 91(4):877–908.

Arellano, M. and Bond, S. (1991). Some tests of specification for panel data: Monte carlo evidence and an application to employment equations. *The review of economic studies*, 58(2):277–297.

Arellano, M. and Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of econometrics*, 68(1):29–51.

Asongu, S. A., Biekpe, N., and Cassimon, D. (2020a). Understanding the greater diffusion of mobile money innovations in africa. *Telecommunications Policy*, 44(8):102000.

Asongu, S. A., Nnanna, J., and Acha-Anyi, P. N. (2020b). Inequality and gender economic inclusion: The moderating role of financial access in sub-saharan africa. *Economic Analysis and Policy*, 65:173–185.

Awan, S. A., Meo, M. S., Ghimire, A., Wu, R.-Y., and Zhuang, P.-F. (2018). Is trade openness good or bad for environment in pakistan; an ardl bounds testing approach. In *4th Annual International Conference on Management, Economics and Social Development (ICMESD 2018)*, pages 822–827. Atlantis Press.

Ay, J.-S., Chakir, R., Doyen, L., Jiguet, F., and Leadley, P. (2014). Integrated models, scenarios and dynamics of climate, land use and common birds. *Clim. Change*, 126(1-2):13–30.

Bekoe, W. and Jalloh, T. (2023). Assessing the economic implications of free trade on environmental quality: Empirical evidence from africa. *Environmental and Resource Economics*, 84(1):19–36.

Béné, C. and Doyen, L. (2018). From Resistance to Transformation: A Generic Metric of Resilience Through Viability. *Earth's Future*, 6(7):979–996.

Binder, M. and Coad, A. (2011). From average joe's happiness to miserable jane and cheerful john: using quantile regressions to analyze the full subjective well-being distribution. *Journal of Economic Behavior & Organization*, 79(3):275–290.

Blundell, R. and Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of econometrics*, 87(1):115–143.

Cade, B. S. and Noon, B. R. (2003). A gentle introduction to quantile regression for ecologists. *Frontiers in Ecology and the Environment*, 1(8):412–420.

Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M., and Chawla, N. (2015). University of notre dame global adaptation index. *University of Notre Dame.*

Copeland, B. R. and Taylor, M. S. (2004). Trade, growth, and the environment. *Journal of Economic literature*, 42(1):7–71.

Cuilleret, M., Doyen, L., Gomes, H., and Blanchard, F. (2022). Resilience management for coastal fisheries facing with global changes and uncertainties. *Economic Analysis and Policy*, 74:634–656.

Dahlke, F. T., Wohlrab, S., Butzin, M., and Pörtner, H.-O. (2020). Thermal bottlenecks in the life cycle define climate vulnerability of fish. *Science*, 369(6499):65–70.

Dallmann, I. (2019). Weather variations and international trade. *Environmental and resource economics*, 72(1):155–206.

Ding, L., Wu, M., Jiao, Z., and Nie, Y. (2022). The positive role of trade openness in industrial green total factor productivity—provincial evidence from china. *Environmental Science and Pollution Research*, pages 1–14.

Diop, B., Sanz, N., Duplan, Y. J. J., Guene, E. H. M., Blanchard, F., Pereau, J.-C., and Doyen, L. (2018). Maximum economic yield fishery management in the face of global warming. *Ecological Economics*, 154:52–61.

Dollar, D. (1992). Outward-oriented developing economies really do grow more rapidly: evidence from 95 ldcs, 1976-1985. *Economic development and cultural change*, 40(3):523–544.

Doyen, L., Armstrong, C., Baumgärtner, S., Béné, C., Blanchard, F., Cissé, A., Cooper, R., Dutra, L., Eide, A., Freitas, D., and others (2019). From no whinge scenarios to viability tree. *Ecological Economics*, 163:183–188. Publisher: Elsevier.

Feenstra, R. C. (1995). Estimating the effects of trade policy. *Handbook of international economics*, 3:1553–1595.

Feindouno, S. and Guillaumont, P. (2019). Measuring physical vulnerability to climate change: The pvcci, an index to be used for international development policies. Technical report, FERDI Policy Brief.

Gandjon Fankem, G. S. and Feyom, C. (2023). Is trade openness a barrier to industrialization? evidence from sub-saharan africa. *Review of World Economics*, pages 1–47.

Grafton, R. Q., Doyen, L., Béné, C., Borgomeo, E., Brooks, K., Chu, L., Cumming, G. S., Dixon, J., Dovers, S., Garrick, D., Helfgott, A., Jiang, Q., Katic, P., Kompas, T., Little, L. R., Matthews, N., Ringler, C., Squires, D., Steinshamn, S. I., Villasante, S., Wheeler, S., Williams, J., and Wyrwoll, P. R. (2019). Realizing resilience for decision-making. *Nature Sustainability*, 2(10):907–913.

Grossman, G. M. and Krueger, A. B. (1995). Economic growth and the environment. *The quarterly journal of economics*, 110(2):353–377.

Guillaumont, P. and Simonet, C. (2011). Designing an index of physical vulnerability to climate change. Technical report, FERDI Policy Brief.

Hardy, P.-Y., Béné, C., Doyen, L., Pereau, J., and Mills, D. (2016). Viability and resilience of small-scale fisheries through cooperative arrangements. *Environment and Development Economics*, 21(6):713–741.

Hoffmann, R., Lee, C.-G., Ramasamy, B., and Yeung, M. (2005). Fdi and pollution: a granger causality test using panel data. *Journal of International Development: The Journal of the Development Studies Association*, 17(3):311–317.

Holtz-Eakin, D., Newey, W., and Rosen, H. S. (1988). Estimating vector autoregressions with panel data. *Econometrica: Journal of the econometric society*, pages 1371–1395.

IPCC, C. C. (2001). Mitigation–contribution of working group iii to the ipcc. *Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge*.

Koenker, R. and Bassett Jr, G. (1978). Regression quantiles. *Econometrica: journal of the Econometric Society*, pages 33–50.

Kong, Q., Peng, D., Ni, Y., Jiang, X., and Wang, Z. (2021). Trade openness and economic growth quality of china: Empirical analysis using ardl model. *Finance Research Letters*, 38:101488.

Lagarde, A., Doyen, L., Ahad-Cissé, A., Caill-Milly, N., Gourguet, S., Pape, O. L., Macher, C., Morandeau, G., and Thébaud, O. (2018). How Does MMEY Mitigate the Bioeconomic Effects of Climate Change for Mixed Fisheries. *Ecological Economics*, 154:317–332.

Liu, J., Murshed, M., Chen, F., Shahbaz, M., Kirikkaleli, D., and Khan, Z. (2021). An empirical analysis of the household consumption-induced carbon emissions in china. *Sustainable Production and Consumption*, 26:943–957.

Managi, S., Hibiki, A., and Tsurumi, T. (2009). Does trade openness improve environmental quality? *Journal of environmental economics and management*, 58(3):346–363.

Mignamissi, D. and Nguekeng, B. (2022). Trade openness-industrialization nexus revisited in africa. *Economic Change and Restructuring*, 55(4):2547–2575.

Mignamissi, D., Possi Tebeng, E. X., and Momou Tchinda, A. D. (2024). Does trade openness increase co2 emissions in africa? a revaluation using the composite index of squalli and wilson. *Environment Systems and Decisions*, pages 1–29.

Muhammad, I., Ozcan, R., Jain, V., Sharma, P., and Shabbir, M. S. (2022). Does environmental sustainability affect the renewable energy consumption? nexus among trade openness, co2 emissions, income inequality, renewable energy, and economic growth in oecd countries. *Environmental Science and Pollution Research*, 29(60):90147–90157.

Ngouhouo, I., Nchofoung, T., and Njamen Kengdo, A. A. (2021). Determinants of trade openness in sub-saharan africa: do institutions matter? *International Economic Journal*, 35(1):96–119.

Ngouhouo, I. and Nchofoung, T. N. (2021). Economic resilience in sub-saharan africa: Evidence from composite indicators. *Journal of the Knowledge Economy*, pages 1–22.

Parmesan, C., Morecroft, M. D., and Trisurat, Y. (2022). *Climate change 2022: Impacts, adaptation and vulnerability*. PhD thesis, GIEC.

Pritchett, L. and Sethi, G. (1994). Tariff rates, tariff revenue, and tariff reform: some new facts. *The World Bank Economic Review*, 8(1):1–16.

Roodman, D. (2009a). How to do xtabond2: An introduction to difference and system gmm in stata. *The stata journal*, 9(1):86–136.

Roodman, D. (2009b). A note on the theme of too many instruments. *Oxford Bulletin of Economics and statistics*, 71(1):135–158.

Sarkodie, S. A. and Strezov, V. (2019). Economic, social and governance adaptation readiness for mitigation of climate change vulnerability: Evidence from 192 countries. *Science of the total Environment*, 656:150–164.

Sorgho, Z. and Tharakan, J. (2022). Do ptas with environmental provisions reduce ghg emissions? distinguishing the role of climate-related provisions. *Environmental and Resource Economics*, 83(3):709–732.

Squalli, J. and Wilson, K. (2011). A new measure of trade openness. *The World Economy*, 34(10):1745–1770.

Strutt, A. and Anderson, K. (2000). Will trade liberalization harm the environment? the case of indonesia to 2020. *Environmental and Resource Economics*, 17:203–232.

Tennant, E. and Gilmore, E. A. (2020). Government effectiveness and institutions as determinants of tropical cyclone mortality. *Proceedings of the National Academy of Sciences*, 117(46):28692–28699.

Tinta, A. A. (2022). Financial development, ecological transition, and economic growth in sub-saharan african countries: the performing role of the quality of institutions and human capital. *Environmental Science and Pollution Research*, 29(25):37617–37632.

Topalova, P. (2010). Factor immobility and regional impacts of trade liberalization: Evidence on poverty from india. *American Economic Journal: Applied Economics*, 2(4):1–41.

Zebisch, M., Schneiderbauer, S., Fritzsche, K., Bubeck, P., Kienberger, S., Kahlenborn, W., Schwan, S., and Below, T. (2021). The vulnerability sourcebook and climate impact chains–a standardised framework for a climate vulnerability and risk assessment. *International Journal of Climate Change Strategies and Management*, 13(1):35–59.

A Appendix

A.1 Description of the vulnerability index and countries involved in the study

The climate vulnerability data sets for model estimation are taken from ND-GAIN. The construction of the ND-GAIN framework is based on published peer-reviewed material, the IPCC Review process, and feedback from corporate stakeholders, practitioners, and development users. Most of the vulnerability measures are said to be actionable, meaning that these represent actions or the result of actions taken by national governments, communities, Civil Society Organizations, Non-Government Organizations, and other stakeholders. For easier comparison between countries prior to the economic model estimation, the data series are converted into scores ranging from 0 to 1 following the scaling formula by ND-GAIN, expressed as:

$$Score = Direction - \frac{rawdata - referencepoint}{baselinemaximum - baselineminimum}$$

Where the parameter of "direction" has two values, 0 when calculating score of vulnerability indicator; 1 when calculating score of readiness indicators, so that a higher vulnerability score means higher vulnerability (worse) and a higher readiness score means higher readiness (better). Climate Vulnerability is composed of 36 indicators. Each component has 12 indicators crossed with six sectors, such as food, water, health, ecosystem services, human habitat, and infrastructure. Out of the 36 indicators of vulnerability from the six sectors, 12 indicators each were categorizations under; Exposure, Sensitivity and Adaptive Capacity. Table 9 presents the fundamentals and indicators of vulnerability to climate change.

Sector	Food	Water	Health	Ecosystem services	Human Habitat	Infrastructure
Exposure component	Projected change of cereal yields	Projected change of annual runoff	Projected change of deaths from climate change induced diseases	Projected change of biome distribution	Projected change of warm period	Projected change of hydropower generation capacity
Exposure component	Projected population change	Projected change of annual groundwater recharge	Projected Change in Vector Borne Disease	Projected change of marine biodiversity	Projected change of flood hazard	Projected change of sea level rise impacts
Sensitivity component	Food import dependency	Fresh water withdrawal rate	Slum population	Dependency on natural capital	Urban concentration	Dependency on imported energy
Sensitivity component	Rural population	Water dependency ratio	Dependency on external resource for health services	Ecological footprint	Age dependency ratio	Population living under 5m above sea level
Adaptive Capacity component	Agriculture capacity (fertilizer, irrigation, pesticide, tractor use	Access to reliable drinking water	Medical staffs (physicians, nurses, and midwives)	Protected biomes	Quality of trade and transport-related infrastructure	Electricity access
Adaptive Capacity component	Child malnutrition	Dam capacity	Access to improved sanitation facilities	Engagement in international environment conventions	Paved roads	Disaster preparedness

Table 8: Description of the vulnerability index

Table 9 details the 156 countries involved in the empirical study.

				List of Countries
Afghanistan	Croatia	India	mozambique	Singapore
Albania	Cuba	indonesia	myanmar	Slovenia
Algeria	Cyprus	Iraq	namibia	Solomon Islands
Angola	Denmark	Ireland	Nepal	Somalia
Antigua and Barbuda	Djibouti	Israel	netherlands	South Africa
Argentina	Dominica	Italy	New Sealand	Spain
Armenia	Dominican Republic	Jamaica	Nicaragua	Sri Lanka
Australia	Ecuador	Japan	Niger	Sudan
Austria	El Salvador	Jordan	Nigeria	Suriname
Aserbaijan	Equatorial Guinea	Kazakhstan	Norway	Sweden
Bahrain	Eritrea	Kenya	Oman	Switserland
Bangladesh	Estonia	Kuwait	Pakistan	Syrian Arab Republic
Barbados	Ethiopia	Latvia	Panama	Tajikistan
Belarus	Fiji	Lebanon	Papua New Guinea	Thailand
Belgium	Finland	Lesotho	Paraguay	Timor-Leste
Belise	France	Liberia	Peru	Togo
Benin	Gabon	Lithuania	Philippines	Tonga
Bhutan	Georgia	Luxembourg	Poland	Trinidad and Tobago
Bosnia and Hersegovina	Germany	Madagascar	Portugal	Tunisia
Botswana	Ghana	Malawi	Qatar	Turkmenistan
Brazil	Greece	Malaysia	Romania	Uganda
Brunei Darussalam	Grenada	Maldives	Russian Federation	Ukraine
Bulgaria	Guatemala	Mali	Rwanda	United Arab Emirates
Burkina Faso	Guinea	Malta	Samoa	United Kingdom
Burundi	Guinea-Bissau	Mauritania	Sao Tome and Principe	United States
Cambodia	Guyana	Mauritius	Saudi Arabia	Uruguay
Cameroon	Haiti	Mexico	Senegal	Uzbekistan
Canada	Honduras	Mongolia	Serbia	Vanuatu
Central African Republic	Hungary	Montenegro	Seychelles	Zambia
Chad	Iceland	Morocco	Sierra Leone	Zimbabwe
Chile	China	Colombia	Comoros	Costa Rica
Cote d'Ivoire				

Table 9: List of Countries.

A.2 Statistics

Table 10: Variable description and sources.

Variable	Observation	Mean	Std. Dev.	Min	Max	Source
Vulnerability	3,9	.4394579	.0974451	.2411048	.7049342	GAIN 2020
Ln CTS	3,133	2.71494	2.180097	-2.929702	7.61075	Authors
Ln Trade	3,539	4.284969	.5788345	-3.863269	6.08068	WDI
Ln Export	3,54	3.475571	.6929439	-5.225669	5.433695	WDI
Ln Import	3,539	3.652304	.5648361	-4.159045	5.339138	WDI
ECO	3,85	.419184	.1372767	0	.8806359	GAIN 2020
GOV	3,85	.4974957	.1856031	.0014792	.9064161	GAIN 2020
SOC	3,825	.2988525	.1575779	.0788817	.7454727	GAIN 2020

Table 11: Correlation matrix

	vulnerability	Ln CTS	LnTrade	Ln Export	Ln Import	ECO	GOV	SOC
Vulnerability	1.0000							
Ln CTS	-0.7401	1.0000						
Ln Trade	-0.3095	0.2084	1.0000					
Ln Export	-0.4234	0.3754	0.9439	1.0000				
Ln Import	-0.1820	0.0478	0.9545	0.8083	1.0000			
ECO	-0.5260	0.4808	0.1782	0.2639	0.0839	1.0000		
GOV	-0.7130	0.5617	0.3400	0.4185	0.2466	0.5861	1.0000	
SOC	-0.7136	0.6229	0.1162	0.2016	0.0373	0.5412	0.6613	1.0000

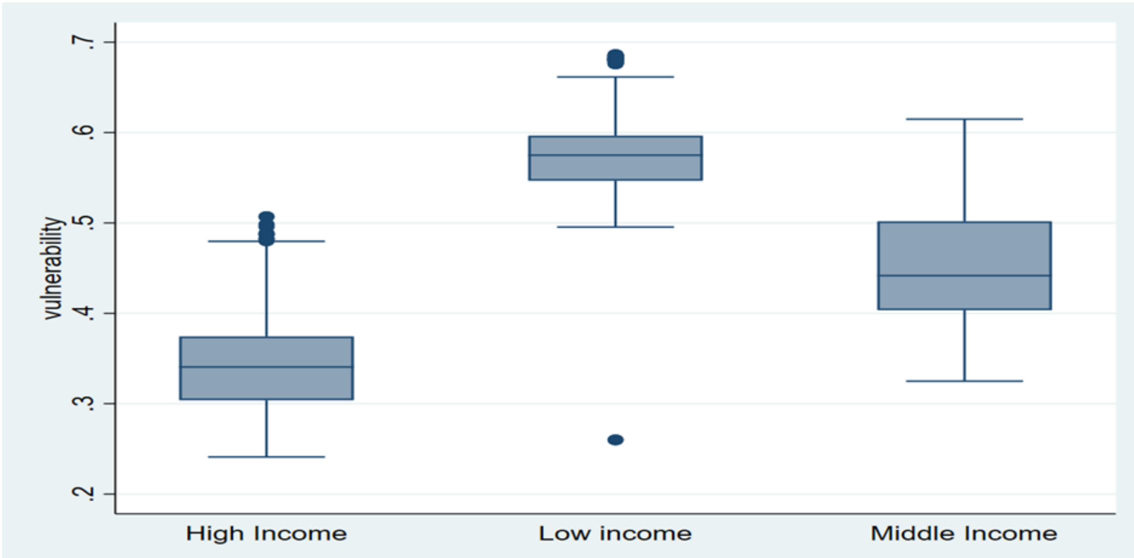

Figure 3: Evolution of vulnerability in countries according to their level of income

Source authors

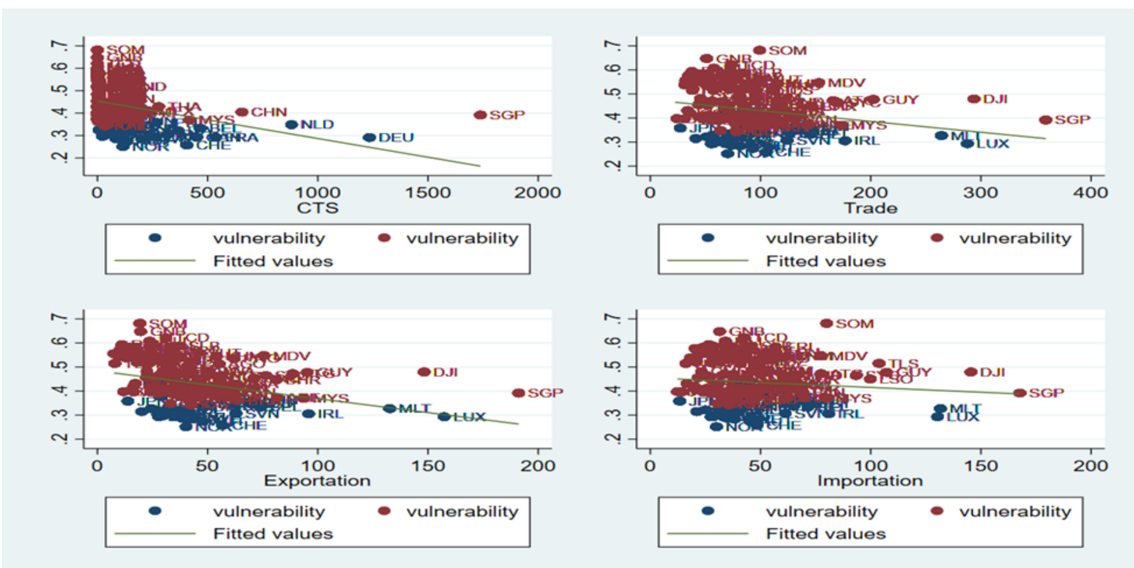

Figure 4: Scatter of the effect of different trade openness measures on vulnerability to CC: a developed country/developing country specification. Source authors.

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