Indian Journal of Finance and Economics
Vol. 5, No. 1, 2024, pp. 17-36
https://DOI:10.47509/IJFE.2024.v05i01.02

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RELATIONSHIP AMONG CLIMATE CHANGE AND ECONOMIC GROWTH IN INDIA: A TIME SERIES INVESTIGATION

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Received: 29 January 2024; Revised: 27 February 2024;
Accepted 09 March 2024; Publication: 29 June 2024

Abstract: In simple term Climate change we mean that an increase of temperature in the atmosphere and or decline in rainfall. Climate change is having an increasingly unprecedented effect on human lives. Economies are affected severely in terms of sovereign risk due to climate change variations influencing the macro economy. Climate Change Variable = Climate Vulnerability Index and Climate Resilience Index where Climate Resilience comprises of Social Readiness Risk Indicators , Economic risk Indicators, Governance risk Indicators. This paper explores the relationship between climate change and economic growth of India. ARDL Bounds Test for Cointegration, Vector Error Correction Models, Diagnostic checking etc techniques are used in this study as research tools. This study finds that both in the short and long run climate vulnerability negatively affects gdp growth in India. Therefore climate change has become a matter of apprehension not only for the government of India alone but for all of us since everyone directly or indirectly affected by lower gdp growth.

Keywords: Climate Change, Climate Vulnerability, Climate Resilience, ARDL Bound Cointegration

INTRODUCTION

For a developing nation like India, climate change is a harsh reality. This is mostly because the backbone of the growth of a developing country is made of conventional methods of generating energy and resources. Despite a huge advancement in technologies, such countries often find themselves in conflicting positions. Economy, development and climate change often

To cite this paper:
Kanchan Datta (2024). Relationship among Climate change and Economic Growth in India: A Time Series Investigation. *Indian Journal of Finance and Economics*. 5(1), 17-36. *https://DOI:10.47509/IJFE.2024.v05i01.02*

cross each other's paths resulting in increased risk and vulnerability (Sharma & Kathuria, 2022).Climatic variations disguised as cyclones and floods have caused massive desolation of crops, property, and infrastructure. This has also caused negative impacts on human health, especially heat stressors. Rural dwellers continue to depend on agriculture for livelihood and food, making them explicitly vulnerable to climate variability and change. All these factors hitch socio-economic development goals(Sadhukhan,2019). Climate change is having an increasingly unprecedented effect on human lives. Economies are affected severely in terms of sovereign risk due to climate change variations influencing the macro economy. Asian countries are highly susceptible to economic downturn due to the consequences of climate change (Jayasooriya,2023). In simple language by the term climate change we mean that an increase of temperature in the atmosphere and or decline in rainfall. But *Notre Dame Global Adaptation Initiative* develops the concept of climate change from multi dimensional perspectives. First they define climate change from two broad perspectives , these are climate vulnerability and the other is climate resilience. Climate vulnerability refers to a country's exposure sensitivity and capacity to adapt to the impacts of climate change. On the other hand resilience estimates a country's capacity to apply economic investments and convert them to adaptation and it covers three areas, economic social readiness and governance. Climate vulnerability again consists of six indicators. These are food, water, health eco system service human habitat and infrastructure. Similarly economic indicator is measured by doing business indicators, social readiness is classified in to social in equality , ICT infrastructure, education and innovation and finally governance indicator is measured by political stability and non violence of the country, control of corruption, regulatory quality and rule of law of the nation concerned. The climate change dimensions and the variables to capture those dimensions and the sources of data are shown in Table A in the Appendix.

LITERATURE REVIEW, RESEARCH GAP AND OBJECTIVES OF THE STUDY

The study of **Jayasooriya S.P,** (2023), *Impact of Climate Change on Sovereign Risk in Asia*, where the researcher uses Government bond spread as the dependent variable which is also an indicator of government's sovereignty and also tries to establish the impact of climate change measured by climate vulnerability, climate resilience, economic risk indicator, social risk indicator , governance

risk indicator and also take some macro economic variables to estimate the variability of sovereign risk through the variability of these variables and of course in a panel data set up. Similar type of work done by **Beirne Renzhi, and Volz** (2020) climate risks and the cost of sovereign borrowing, they have applied structural VAR model to estimate such relationship. Closely related to the above mentioned work done by **Zenios** (2021) titled with climate change on the transparency of sovereign debt. So these are few examples from a balk of research studies related to climate change and government's sovereignty and most of the papers are few nations together that is under panel data perspective. A study done by **Wong K.S, Lee C.& Wong L W., Wang** (2019), titled '*Impact of climate Change and economic factors on Malaysian food price*' the CO2 gas emission is taken as a proxy for the climate changed which effects and the real income was represented by the real gross domestic product. Their findings show that both the climate change variable and real gdp jointly affect the food prices in Malaysia. **M Balasubramanian M. & Dhulasi Birundha V.,(2012**) in their paper explains climate change and its various aspects in Indian context. They opine Climate change is associated with various adverse impacts on agriculture, water resources, forest and biodiversity, health, coastal management and increase in temperature. Decline in agricultural productivity is the main impact of climate change on India. Climate change would represent additional stress on the ecological and socioeconomic systems that are already facing tremendous pressure due to rapid industrialization, urbanization and economic development. This paper analyzes the impact of climate change and its various aspects in the Indian context. An attempt in this paper has been taken to explore the relationship between climate change and economic growth of India. Since climate change has a multidimensional facets say climate vulnerability and climate resilience which can also be covered by social readiness, economic indicators, governance indicators etc, hence this study explores the relationship among all the variables with gdp growth of India. In other words how the climate change indices impacts economic growth in the context of India? From this perspective this study definitely add some values in the existing literature on climate change and GDP growth nexus in India.

METHODOLOGY OF THE STUDY

As usual in time series econometric studies 1st task of any researcher is to go for unit root test here also first we have applied ADF Unit root test for each variables of the study. The results are shown in Table-1.

The generalised ARDL (p,q) model is specified as

$$Y_t = \alpha_{01} + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{t=0}^{q} \theta_i' X_{t-i} + \epsilon_{it} \quad (1)$$

Where Y_t is a vector and the variables X_t are explanatory variables with either I(1) or I(0) or a mixture of I(1) and I(0), that is a combination of both level and first difference stationarity. Now Cointegration test is one of the basic approaches to confirm that estimated time series regression does not produce a spurious regression. We need to apply suitable technique for cointegration or establishing a long run relationship. The use of Johansen's cointegration test is no longer valid. Hence the appropriate test is the **Bounds test proposed by Pesaran Shin and Smith (2001**). The dependent variable of the above equation (Y_t)is a function of its lagged values, the current and lagged values of other variables in the model .p is the lags for dependent variable and q is the number of lags for independent variables. These lags are determined by appropriate technique say AIC or SIC etc.

To perform the bound test for cointegration, the conditional ARDL (p, q1 q2) model with four variables in our case may be specified as follows.

$$\alpha_{01} + \beta_{11}\text{lgdpg}_{t-i} + \beta_{21}\text{lcvul}_{t-i} + \beta_{31}\text{leconomic}_{t-i} + \beta_{41}\text{lgovernance}_{t-i} + \beta_{51}\text{lsocialreadiness}_{t-i} + \sum_{i=1}^{q} \delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q} \delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q} \delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q} \delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q} \delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varepsilon_{1t} - \quad (2)$$

$$\Delta\text{lcvul}_{ti} = \alpha_{02} + \beta_{21}\text{lgdpg}_t + \beta_{22}\text{lcvul}_{t-i} + \beta_{23}\text{leconomic}_{t-i} + \beta_{24}\text{lgovernance}_{t-i} + \beta_{25}\text{lsocialreadiness}_{t-i} + \sum_{i=1}^{q} \delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q} \delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q} \delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q} \delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q} \delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varepsilon_{2t} - \quad (3)$$

$$\Delta\text{leconomic}_{ti} = \alpha_{03} + \beta_{31}\text{lgdpg}_t + \beta_{32}\text{lcvul}_{t-i} + \beta_{33}\text{leconomic}_{t-i} + \beta_{34}\text{lgovernance}_{t-i} + \beta_{35}\text{lsocialreadiness}_{t-i} + \sum_{i=1}^{q} \delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q} \delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q} \delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q} \delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q} \delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varepsilon_{3t} - \quad (4)$$

$$\Delta\text{lgovernance}_{ti} = \alpha_{04} + \beta_{41}\text{lgdpg}_t + \beta_{42}\text{lcvul}_{t-i} + \beta_{43}\text{leconomic}_{t-i} + \beta_{44}\text{lgovernance}_{t-i} + \beta_{45}\text{lsocialreadiness}_{t-i} + \sum_{i=1}^{q} \delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q} \delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q} \delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q} \delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q} \delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varepsilon_{4t} - \quad (5)$$

$$\Delta\text{lsocialreadiness}_{ti} = \alpha_{05} + \beta_{51}\text{lgdpg}_t + \beta_{52}\text{lcvul}_{t-i} + \beta_{53}\text{leconomic}_{t-i} + \beta_{54}\text{lgovernance}_{t-i} + \beta_{55}\text{lsocialreadiness}_{t-i} + \sum_{i=1}^{q}\delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q}\delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q}\delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q}\delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q}\delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varepsilon_{5t} \text{ -} \quad (6)$$

If there is no cointegration, the ARDL(p,q1 q2) model is specified as,

$$\Delta\text{lgdpg}_t = \alpha_{01} + \sum_{i=1}^{q}\delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q}\delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q}\delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q}\delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q}\delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varepsilon_{2t} \quad (7)$$

If there is cointegration, the error correction term (ECT) representation is specified as,

$$\Delta\text{lgdpg}_t = \alpha_{01} + \sum_{i=1}^{q}\delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q}\delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q}\delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q}\delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q}\delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varphi ECT_{t-1} + \varepsilon_t \text{ ----(8), where } \varphi \text{ is the speed of adjustment.}$$

$$\Delta\text{lcvul}_t = \alpha_{01} + \sum_{i=1}^{q}\delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q}\delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q}\delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q}\delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q}\delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varphi ECT_{t-1} + \varepsilon_t \quad (9)$$

$$\Delta\text{leconomic}_t = \alpha_{01} + \sum_{i=1}^{q}\delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q}\delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q}\delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q}\delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q}\delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varphi ECT_{t-1} + \varepsilon_t \quad (10)$$

$$\Delta\text{lgovernance}_t = \alpha_{01} + \sum_{i=1}^{q}\delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q}\delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q}\delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q}\delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q}\delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varphi ECT_{t-1} + \varepsilon_t \quad (11)$$

$$\Delta\text{lsocialreadines}_t = \alpha_{01} + \sum_{i=1}^{q}\delta_{1i}\Delta\text{lgdpg}_{t-i} + \sum_{i=1}^{q}\delta_{2i}\Delta\text{lcvul}_{t-i} + \sum_{i=1}^{q}\delta_{3i}\Delta\text{leconomic}_{t-i} + \sum_{i=1}^{q}\delta_{4i}\Delta\text{lgovernance}_{t-i} + \sum_{i=1}^{q}\delta_{5i}\Delta\text{lsocialreadiness}_{t-i} + \varphi ECT_{t-1} + \varepsilon_t \quad (12)$$

Table 1: Unit Root test results

Variables	*ADF test Statistic(p-value)*		
	Without trend	*With trend*	*Decision*
Climate Vulnerability(lcvul)	-0.541 (0.88)	-2.516 (0.32)	
DCVulnerability(dlvul)	-4.345 (0.00)	-4.25 (0.00)	I(1)
Social readiness(lsocial)	-2.144 (0.23)	-2.087 (0.55)	
DSocial readiness(dlsocial)	-3.483 (0.00)	-3.402 (0.05)	I(1)
Economic Indicators (leconomic)	-2.132 (0.23)	-2.204 (0.49)	
DEconomic Indicators (dleconomic)	-3.707 (0.00)	-3.621 (0.02)	I(1)
Governance Indicators (lgovernance)	-2.255 (0.18)	-2.113 (0.54)	
DGovernance Indicators(dlgovernance)	-2.951 (0.03)	-3.021 (0.11)	I(1)
GDP Growth (lgdpg)	-3.889 (0.00)	-3.996 (0.00)	I(0)

FINDINGS

From the Unit root test results it is clear that there is a combination of integration of the variables. Only gdp growth variable is integrated of order zero that is I(0) variable but other variables of the study are I(1) that is they are (climate vulnerability , social readiness, economic risk indicator, governance risk indicator etc) are non stationary at level but becomes stationary after 1st difference. Since there is a mixture of integration for testing the presence of long run relationship Johansen technique will not be appropriate. In the next section we have applied Pesaran/ Shin/Smith technique of ARDL Bound test for checking the presence of long run relationship among the variables. The results of Bound test is shown in the Table 2.

Table 2: Results Pesaran/Shin/Smith (2001) ARDL Bounds Test for Cointegration

H0: no levels relationship	F = 13.286 t = -6.608
Critical Values (0.1-0.01), F-statistic, Case 3 | [I_0] [I_1] | [I_0] [I_1] | [I_0] [I_1] | [I_0] [I_1] | L_1 L_1 | L_05 L_05 | L_025 L_025 | L_01 L_01	

k_4 | 2.45 3.52 | 2.86 4.01 | 3.25 4.49 | 3.74 5.06
accept if F < critical value for I(0) regressors
reject if F > critical value for I(1) regressors

Critical Values (0.1-0.01), t-statistic, Case 3

	[I_0] [I_1]	[I_0] [I_1]	[I_0] [I_1]	[I_0] [I_1]
	L_1 L_1	L_05 L_05	L_025 L_025	L_01 L_01
k_4	-2.57 -3.66	-2.86 -3.99	-3.13 -4.26	-3.43 -4.60

accept if t > critical value for I(0) regressors
reject if t < critical value for I(1) regressors
k: # of non-deterministic regressors in long-run relationship
Critical values from Pesaran/Shin/Smith (2001)

FINDINGS

Table 2 shows that the F value is 13.286 and no values are there in I(1) regressors which is higher than this value. Hence we have to reject the null hypothesis of no level relationship exists among the variables. So the there exist long run relationship among the variables. Similarly from t value criterion also we see no values are there in I(1) regressors which is lower than t = -6.608. Here again we can say that the variables are cointegrated that implies the long run relationship among the variables. Since in the short run there may have short run deviations so to capture the short run and long run dynamics we run Vector error correction model. The results of VEC model estimation are shown in the table 3.

Table 3: Results of Vector Error Correction Models

Equation no	*Dependent variable*	δ_1	δ_2	δ_3	δ_4	δ_5	φ
8	$\Delta lgdpg_t$	.113 (0.628)	-68.325* (0.003)	-5.304* (0.025)	-5.273 (0.134)	16.787 * (0.017)	-1.214* (0.000)
9	$\Delta lcvul_t$	.0024* (.001)	-.213 (0.183)	-.0401* (0.013	.0367 (0.127)	.0960 (0.047)	-.002 * (.0028)
10	$\Delta leconomic_t$	.117 (0.649)	5.251 (0.838)	-.715 (0.783)	.494 (0.899)	2.631 (0.735)	-.269 (0.474)
11	$\Delta lgovernance_t$	.007 (0.627)	2.681* (0.074)	.442* (0.004)	.749* (0.001)	-1.357* (0.003)	.044* (.001)
12	$\Delta lsocialreadines_t$	.035 (0.699)	1.54 (0.867)	-.118 (0.899)	.434 (0.899)	.476 (0.864)	-.057 (0.670)
Johansen normalization restriction imposed(Long run estimations of the basic equation)							

Dependent variable	*Explanatory Variables*			
lgdpgrowth	*lcvul*	*leconomic*	*lgovernance*	*lsocialreadines*
	-10.09 (0.00)	3.26 (0.00)	3.22 (0.00)	1.26 (0.00)

P value is given in ()

FINDINGS

Short run Impacts

From the above table it is clear that the estimation of equation 8 reveals that ECM term is significant. it implies the long run relation is significant among the variables. Although the estimated coefficient is - 1.21 , it should be less than one. The climate vulnerability is negative and statistically significant. It implies in the short run increase of climate vulnerability in the previous period declines gdp growth in the current period in India. There is predictive causality between climate vulnerability and gdp growth in the short run in India. Economic risk indicator is also negative and statistically significant. It implies increase of economic risk indicator also declines gdp growth in the short run. Governance risk indicator is not significant, although social readiness is positive and significant. In implies with an increase in social readiness indicators to combat the impact of climate change gdp growth increases.

Now coming to another ECM specification reflected by equation 9 that is when we use climate vulnerability as dependent variable. Here the ECM coefficient is negative and less than one and statistically significant. This implies the short run deviations are significant, and the speed of adjustment .0017 that is .02. In other words any deviation in the previous period is automatically corrected by 2% in the next period. Though the speed of adjustment is slow, but still we can say there exist a long run relationship among the variables. Now coming to the short run coefficients. Economic risk indicator is negative and statistically significant. It implies with the increase of economic risk indicator climate vulnerability declines. On the other hand in an increase of social readiness indicator in the previous period also increases climate vulnerability in the current period in the short run. Other variables are not statistically significant in the short run to have any significant impact on climate vulnerability.

Now considering estimation of equation 10, that is when economic risk indicator is the dependent variable, no variable is seen as statistically significant. Now considering equation 11 ,where governance risk indicator is taken as dependent variable except gdp growth all other variables are statically

significant. For example, climate vulnerability is positively affecting governance risk indicator, with an increase of governance risk indicator climate vulnerability is also increases in the short run. So there exist short run granger causal relation between these variables. Similarly economic risk indicator is also positive and statically significant . This implies an increase in economic risk indicator also increases governance risk indicator in India in short run. On the otherhand the soial readiness indicator is negative and significant. It implies with an increase in social readiness indicator the governance risk indicator declines

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Long run Impacts

In the long run the climate vulnerability indicator and gdp growth are inversely related. With an increase of one percentage point of climate vulnerability declines gdp growth by 10 percentage point .

Now after estimation of VEC model it is very important to perform the diagnostic checking . In this study Lagrange Multiplier test for the presence of Auto correlation in the error series, similarly J-B test for normality of the residuals and VEC stability test are performed . The results are shown in the table below respectively.

Diagnostic Checking

Table 4: Test for the presence of Auto correlation and normality

Lagrange-Multiplier test for Auto correlation		
H0: no autocorrelation at lag order		
lag	chi2 statistic	P value
1	16.76	0.89
2	22.24	0.62

Jarque-Bera test for Normality		
	chi2 statistic	
DLGDPgrowth	1.36	0.50
DLVulnerability	0.60	0.74
DLEconomic	144.85	0.00
DLgovernance	0.64	0.72
DLreadiness	1.01	0.60
ALL	148.49	0.00

Table 5: VEC Model stability Checking

Eigenvalue	Modulus
1	1
1	1
1	1
1	1
-.4889068 + .4606849i	.671759
-.4889068 - .4606849i	.671759
.08980358 + .4727468i	.481201
.08980358 - .4727468i	.481201
.3308162 + .02220966i	.331561
.3308162 - .02220966i	.331561

The VECM specification imposes 4 unit moduli.

FINDINGS

Diagnostic checking shows that the Vector error correction models are not suffering from autocorrelation problem upto the lags decided by AIC in this study. This table also shows that individually most of the VEC models (except the model where D_leconomic is used as dependent variable) do not suffer from the normality condition , although overall model suffers from violating the normality conditions. Table -5 shows the stability condition of the VEC model. Hence it shows 4 unit moduli where as we need only one unit moduli for fulfilling the stability condition. Hence our model satisfies the stability condition.

SUMMARY AND CONCLUSION

Although there are plethora of studies related to climate change and its impact on various macro or socio economic indicators but very few or perhaps no studies so far have been tried to explore the relationship with climate change indices which consists of climate vulnerability indices and climate resilience indices on

economic growth in the economy of India. This study uses the data related to climate vulnerability indices and climate resilience indices from Penn-World Table (PWT 10), gdp growth from the World Development Indicators (WDI) of the World Bank, and the time period covers year 1995 to 2020. Applying time series econometric techniques it is clear that there is a combination of integration of the variables. Only gdp growth variable is I(0) variable but other variables of the study are I(1) that is they are (climate vulnerability , social readiness, economic risk indicator, governance risk indicator etc.) are non stationary at level but becomes stationary after 1st difference. Since there is a mixture of integration for testing the presence of long run relationship Johansen technique will not be appropriate. Hence this study need to apply ARDL Bounds Test for Cointegration, Vector Error Correction Models etc. This study finds that both in the short and long run climate vulnerability negatively affects gdp growth in India. Therefore climate change has become a matter of apprehension not only for the government of India alone but for all of us since everyone directly or indirectly affected by lower gdp growth.

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APPENDIX

Table 1

Climate Change Variable = Climate Vulnerability Index and Climate Resilience Index where Climate Resilience comprises of Social Readiness Risk Indicators, Economic risk Indicators, Governance risk Indicators.		
Variables	*Definition*	*Data sources*
Climate Vulnerability Index	Climate vulnerability refers to "a country's exposure, sensitivity, and capacity to adapt to the impacts of climate change" and it comprises indicators of six life-supporting sectors—food, water, health, ecosystem services, human habitat, and infrastructure	Notre Dame Global Adaptation Initiative (ND-GAIN1Penn-World Table (PWT 10),
Climate Resilience Index	Resilience, on the other hand, estimates "a country's capacity to apply economic investments and convert them to adaptation actions" and covers three areas—economic, governance, and social readiness—with nine indicators	
GDP Growth	Annual percentage growth rate of GDP at market prices based on constant local currency. Aggregates are based on constant 2015 prices, expressed in U.S. dollars.	World Bank national accounts data, and OECD National Accounts data files.

Table 2

Climate Vulnerability Indicators	*Indicator*	*Description*
(1) Food	(i)projected change of cereal yields	Projected amount that climate change is predicted to change food supply by mid-century for three staples: rice, wheat and maize. The projections of the yield productions are obtained from five crop models (EPIC, GEPIC, LPJmL, pDSSAT, PEGASUS), and it assumes effect of CO2 fertilization but does not adjust for changes in farming systems or irrigation
	(ii) projected population change	An indication of food demand by the mid-century. The projection data are from the World Bank Health Nutrition and Population Statistics (HNPStats)which provides country-level projection of population up to 2050.
	(iii) food import dependency	Proportion of cereal consumption obtained from imports. The definition of cereal is from FAO referred as "crops harvested for dry grain only", including wheat, rice, barley, maize, popcorn, rye, oats, millets, sorghum, buckwheat, quinoa, fonio, triticale, canary seed, mixed grain, and remaining types (FAO, n.d.). Cereal consumption is equal to production and imports minus exports.
	(iv) rural population	This measure includes all people living in the rural regions of a country.
	(v) agriculture capacity	A combination of four indicators of agricultural technology: capacity to equip agriculture areas with irrigation, N+P205 total fertilizer use on arable and permanent crop area use, pesticide use, and tractor use. The irrigation measure obtained from FAO indicates the proportion of agriculture areas equipped with irrigation, but does not measure the amount of land that is indeed been irrigated in a specific year. Therefore, it is a capacity measure. The fertilizer and pesticide measures are the total consumption of the active ingredients (for both fertilizer and pesticide) as the reported sum divided by hectare. The tractor use measures the number of wheel and crawler tractors used in agriculture. Together, these measures are combined into an indication of the accessibility of agriculture technological inputs.
	(vi) child malnutrition	A measure of malnutrition based on the precent of under-5-year-olds with a low weight for height ratio; usually taken as a good indicator of chronic malnutrition. An assumption is taken for this indicator that OECD countries have a default child malnutrition rate of 0.

(2) Water	(i) projected change of annual runoff	An indication of how climate change will bring changes to annual surface water resources by the mid of the century. Projected surface runoff data, defined as precipitation minus evapotranspiration and change in soil moisture storage, are provided by Aqueduct at World Resource Institute. Aqueduct
	(ii)projected change of annual groundwater recharge	uses the ensemble of six global circulation models (GCMs) from Coupled Model Intercomparison Project Phase 5 (CMIP5) chosen to represent a broad diversity of models that best reproduce the mean and standard deviation of recent stream flow records in 18 large river basins (Alkama et al., 2013). The database covers 14998 catchments derived from the Global Drainage and Basin Database.
	(iii)fresh water withdrawal rate	An indication of how climate change will bring changes on annual groundwater resource by mid-century. GWR data are provided by Goethe University Frankfurt (Portmann et al., 2013).
	(iv)water dependency ratio	The proportion of total actual renewable water resources (including desalinated water) that is withdrawn in a specific year
	(v)dam capacity	The proportion of the total renewable water resources originated outside the country, including the surface water and ground water entering the country or secured by treaties
	(vi)access to reliable drinking water	An indication of the capacity to adjust to the changing (temporal and geographical) distribution of freshwater resources, including changes due to climate change. It is a measure of the per capita dam storage capacities within one country, calculated by the per capita theoretical initial capacities of all dams, which does not allow for changes over time due to siltation. Commonly used indicator of the capacity to deliver reliable domestic water supplies. The drinking water sources are considered reliable if they have a household connection, public standpipe, borehole, protected well or spring, or rainwater collection.

(3) Health	(i)projected change of deaths from climate change induced diseases	An indication of the climate change impacts on several types of diseases. The indicator is a model-based estimate of the quality-adjusted loss of life years under several different climate scenarios. Disability adjusted life year (DALY) due to malaria, an indication of the climate change impacts on vector borne diseases, is excluded because more specific models have been used to project such impacts and it is assessed by another ND-GAIN indicator, the projected change of length of transmission season of vector-borne diseases
	(ii)projected change in vector-borne diseases	This indicator takes the projection of malaria LTS as an indication of the climate change impacts on vector-borne diseases. LTS data were taken from projections (Caminade, et al., 2014) that took the ensemble mean of malaria LTS over four malaria models and five GCMs. However, the incidence of vector-borne diseases is also strongly dependent on the quality of public health systems. In this indicator the WHO estimated number of malarial cases per 1000 population per month of current LTS is used as a measure of these services
	(iii)dependency on external resource for health services	The percentage of external resources (e.g. bilateral payments, NGO operations etc.) in total national health expenditure.
	(iv)slum population	A slum household is defined as a group of individuals living under the same roof lacking one or more of life-supporting facilities: access to improved water, access to improved sanitation, sufficient-living area, or durability of housing. Tenure is included as a 5th element, but insufficient data is available (MDG, n.d.).
	(v)medical staff	Sum of the number of physicians, nurses and midwives per 1000 population in the country. Increases in physicians, nurses, or midwives will have the same effect on the indicator.
	(vi)access to improved sanitation facilities	Commonly used indicator of the capacity to control infectious diseases. The indicator is a proportion of the population with access to excreta disposal facilities that can effectively prevent human, animal, and insect contact with excreta

(4) Environment	(i)projected change of biome distribution	An indication of how climate change will impact the change of terrestrial biome biodiversity within a country by the end of the century. Data were taken from the global version of a dynamic vegetation model (MC1) (Gonzalez et al., 2010).
	(ii)projected change of marine biodiversity	An indication of how climate change will impact the change of marine biodiversity in a country's exclusive economic zones by mid-century. It is a measure based on projected changes in the distribution of 1066 exploited species of marine fish and invertebrates under climate envelope scenarios based on A1B scenarios (Cheung et al., 2009).
	(iii)natural capital dependency	Based on the World Bank's Natural Capital Accounting project. This indicator of the strength of the dependency of social systems on ecosystem goods and services is based on the deployment of natural capital in national accounting, including national income and savings in the form of all assets and capital goods that are inputs to economic well-being (The World Bank, 2011). The natural capital related to ecosystem services includes: crop, pasture, forest (timber), forest (non-timber) and protected areas. Sub-surface capital such as oil, gas and mineral reserves are not included.
	(iv)ecological footprint	The ecological footprint estimates the number of hectares of land and water, both within and outside the country, that are needed to meet the average demand on ecosystems services by the population's lifestyle. This is compared with the estimated capacity of a country's ecosystems to regenerate and maintain
	(v)protected biome	Taken directly from the Yale Environmental Performance Index (EPI), the indicator "assesses the protection of biomes weighted by the proportion of a country's territory the biome occupies." EPI defines the indicator as follows: "It measures the degree to which a country achieves the target of protecting 17% of each terrestrial biome within its borders, weighted by the domestic contribution of each terrestrial biome… All biome protection percentages were capped at 17% so that higher protection in one biome cannot be used to offset lower protection in another."
	(vi)engagement in international environmental conventions	An indicator based on the country's participation in international forums, which is an indicator of its capacity to engage in multilateral negotiations and to reach agreement on appropriate actions internally

(5) Habitat	(i)projected change of warm periods	An indication of the probability of extreme heat under climate change by mid-century. This indicator uses the Warm Spell Duration Index (WSDI), which defines periods of excessive warmth using a percentile-based threshold calculated for a calendar 5-day window in the base period 1961-1990. WSDI counts the number of days in a year when daily maximum of near surface temperature exceeds the 90th percentile threshold for 6 consecutive days or longer (Alexander, et al., 2006; Sillmann, et al., 2013b).
	(ii)projected change of flood hazard	Flood hazard is measured by the predicted, monthly maximum precipitation in 5 consecutive days (rx5day). Rx5day is defined as monthly maximum consecutive 5-day precipitation. It is a measure of precipitation extreme under climate change, a risk factor for flood hazard (Kundzewicz & Schellnhuber, 2004).
	(iii)urban concentration	Urban concentration measures both concentration of a country's population within cities (i.e. the degree of urbanization in general) and concentration of the urban population within a small number of large population (cities of 750,000 inhabitants or more) centers via the Herfindahl Index (Henderson, 2000; Van Eck &Koomen, 2008).
	(iv)age dependency ratio	An indication of the size of the vulnerable population in terms of ages. This indicator considers the population under 14 or above 65 as the vulnerable group.
	(v)quality of trade and transport infrastructure	Logistics professionals' perception of country's quality of trade and transport related infrastructure (e.g. ports, railroads, roads, information technology), on a rating ranging from 1 (very low) to 5 (very high). Scores are averaged across all respondents.
	(vi)paved roads	Proportion of the total length of the roads that are paved. Paved roads are those finished with macadamized crushed stone, bitumen or equivalent, concrete or cobblestones and expressed as a percentage of the stated length of the public road system.

(6) Infrastructure	(i)projected change of hydropower generation capacity	An indication of the potential risk of hydropower generation capacity weighted by the importance of hydropower to one country, i.e. the proportion of the electricity production from hydroelectric sources. The data of the projected change are available at the sub-continental level, drawn from (Hamududu & Killingtveit, 2012).
	(ii)projected change of sea level rise impacts	An indication of how coastal infrastructure will be impacted by the combined effect of sea level rise and potential storm surge by the end of the century. The indicator considers the proportion of land areas, adjacent to the ocean, that are lower than the projected sea level rise and the average height of storm surge.
	(iii)dependency on imported energy	A measure of the percentage of total energy use that is imported and thus not fully within a country's control. Energy use refers to the use of primary energy before transformation to other end-use fuels, according to WDI, equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport.
	(iv)population living under 5m above sea level	The proportion of the population living in the area where elevation is 5 m or less. It is a simple measure of the population sensitive to coastal risks.
	(v)electricity access	The proportion of the population with access to grid-power.
	(vi)disaster preparedness	An indication of capacities to deal with climate-related nature disasters. This indicator uses monitoring from the Hyogo Framework Action (HFA). The HFA outlined an action plan from 2005 to 2015 to establish five priorities for disaster preparedness. Countries are monitored in two-year intervals against the five priorities by self-reported data.
Climate Resilience Indicators		
Economic risk indicators	(i)doing business	The indicator took the World Bank Doing Business (DB) indicators as an indication of how countries are capable of attracting adaptation investment. The index assesses the investment climate in 10 topics using 40 indicators. The 10 topics are: starting a business, dealing with construction permits, getting electricity, registering property, getting credit, protecting investors, paying taxes, trading across borders, enforcing contracts, and resolving insolvency.

Governance risk indicators	(i)political stability and non-violence	An indicator directly from the World Governance Indicators (WGI), "capturing perceptions of the likelihood of political instability and / or politically motivated violence , including terrorism
	(ii)control of corruption	An indicator directly from the World Governance Indicators (WGI), "capturing perceptions from firms and households survey respondents and public, private, and NGO sector experts worldwide of public power exercised for private gain, including both petty and grand forms of corruption, as well as 'capture' of the state by elites and private interests."
	(iii)regulatory quality	An indicator directly from the World Governance Indicators (WGI), "capturing perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development."
	(iv)rule of law	An indicator directly from the World Governance Indicators (WGI), "capturing perceptions from firms and households survey respondents and public, private, and NGO sector experts worldwide of confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence."
Social readiness indicators	(i)social inequality	The country's poorest quintile's share in national income or consumption
	(ii)ICT infrastructure	A composite indicator from 4 sub-indicators that consider both the access to and the use of ICT infrastructure: mobile phone subscription per 100 persons, fixed phone subscription per 100 persons, fixed broad-band subscription per 100 persons, and percent of individuals using internet. Data for all four are available from the annual ICT Development Index (IDI) database. The mobile phone subscription measures the subscription to public mobile services including the post-paid and prepaid subscriptions (World Development Indicators, 2014). The fixed phone subscription is assumed to measure of the active number of analog fixed telephone lines, ISDN channels, fixed wireless (WLL), public payphones and VoIP subscription (International Telecommunication Union, 2010). The fixed broad-band subscription refers to the number of broadband subscribers with a digital subscriber line, cable modem, or other high-speed technology (World Development Indicators, 2014). The individual internet use measures the proportion of internet users with access to the worldwide network (World Development Indicators, 2014).
	(iii)education	A measure of enrolment in tertiary education to represent the education level of a country. It is approximated by the ratio of the enrollment in tertiary education (regardless of age) to the population of the age group that officially corresponds to tertiary education attendance.
	(iv)innovation	A measure of the number of patent applications, filed through the Patent Cooperation Treaty procedure or with a national patent office, by residents per capita.

Source: Notre Dame Global Adaptation Initiatives, Country Index Code Book

2. ARDL(2, 2, 2, 0,2) model estimation results

ARDL(2,2,2,0,2) regression

Sample: 1997 thru 2019 Number of obs = 23
R-squared = 0.9053
Adj R-squared = 0.7916
Log likelihood = 32.820788 Root MSE = 0.0881

D.lgdpgrowth	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
ADJ						
lgdpgrowth						
L1.	-2.005916	.3035507	-6.61	0.000	-2.682269	-1.329563
LR						
lvulnerability	6.824076	3.549983	1.92	0.083	-1.08578	14.73393
leconomic	-2.34613	.8583209	-2.73	0.021	-4.258588	-.4336716
lgovernance	-3.025361	1.404283	-2.15	0.057	-6.154299	.1035761
lreadiness	4.589709	2.075588	2.21	0.051	-.0349898	9.214408
SR						
lgdpgrowth						
LD.	.5599279	.1904359	2.94	0.015	.1356103	.9842456
lvulnerability						
D1.	-94.41831	29.45779	-3.21	0.009	-160.0544	-28.78226
LD.	-44.61889	19.10066	-2.34	0.042	-87.17782	-2.059956
leconomic						
D1.	-2.148764	1.458391	-1.47	0.171	-5.398262	1.100735
LD.	-8.071426	1.855059	-4.35	0.001	-12.20476	-3.938096
lreadiness						
D1.	9.444663	4.248956	2.22	0.050	-.0225999	18.91193
LD.	23.85595	4.916886	4.85	0.001	12.90044	34.81146
_cons	5.01562	2.724357	1.84	0.095	-1.054626	11.08587