Long run macroeconomic impact of climate change on total factor productivity - Evidence from CS-ARDL model

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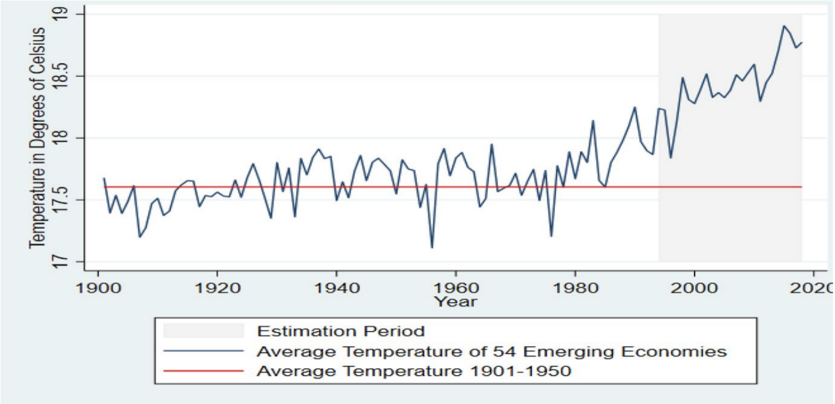
Motivation

- The surface temperature has been rising gradually, triggered by carbon emission, thereby making it difficult for the quality of life and livelihood of human beings.
- It necessitates effective adaptation and mitigation strategies.
- EMEs often ignore to meet their development challenges
- This paper attempts to show that they cannot sustain growth by ignoring this.
- The rising temperature may dampen TFP by affecting (1) labour productivity, (2) capital productivity and (3) ecological services.
- Contribution
  - Capital productivity
  - three sources of productivity damage
  - Methodological improvement

Trends in the rise of temperature in emerging market economies

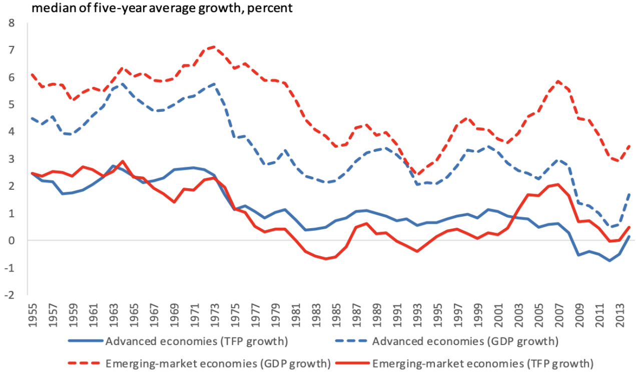


ig. 1 Average annual temperature of panel countries (54 emerging economies) from 1901 to 2018 and verall 1901–1950 temperature average. Source: Climatic Research Unit

Figure (1) Trends in the rise of temperature in emerging market economies

Declining productivity in emerging markets

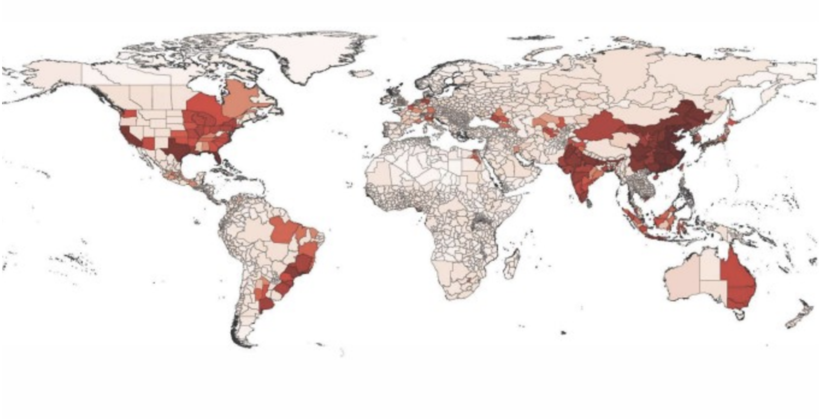
Figure 2 Total factor productivity (TFP) and GDP growth in emerging-market and advanced economies, 1955–2014



Source: Penn World Tables 9.0.

Figure (2) Declining productivity in emerging markets

Emerging markets are more exposed to climate risk



XDI Gross Domestic Climate Risk analysis: Global heat map showing comparison of aggregated damage risk in 2050.

Figure (3) Emerging markets are more exposed to climate risk

Literature

- **Relatively overlooked area is the impact of climate change on TFP**
  - Early theoretical Studies
    1. Dietz and Stern [2015]: TFP fall and rapid increase in the social cost of carbon if the global mean temperature is above the industrial level
    2. Moore and Diaz [2015] : Climate change affects economic growth via the impact on TFP and investment.
  - Empirical Literature
    1. Agriculture TFP (micro studies)-Ortiz-Bobea et al. [2018] , Chancellor et al. [2021]
    2. Total factor productivity growth - Letta and Tol [2019]
    3. Production efficiency - Kumar and Khanna [2019]

In this Paper

- Simple Ramsay Model to show the loss of ecological services, capital and labour productivity due to climate change damping TFP.
- Earlier Studies have mainly used reduced-form econometric methods [Dell et al., 2012; Letta and Tol, 2019, Hsiang et al., 2013].
- Earlier Studies have assumed
  1. Temperature is an exogenous indicator that rules out reverse causality. e.g. economic growth in the past could have feedback effects on future temperature [Kahn et al., 2021]
  2. Schultz and Mankin [2019] emphasised political and economic factor influences temperature measurement.
  3. These methods rule out the potential presence of unit roots in the form of stochastic trends.
  4. Ignore the potential presence of cross-sectional dependence.

In this Paper

- Penn World Table [Feenstra et al., 2015b] TFP data with weather indicators of 21 Emerging markets and estimate the the long-run relationship between TFP and annual variation in temperature.
- We use the cross-sectional augmented autoregressive distributed lag model(CS-ARDL) [Chudik and Pesaran, 2015] [Ditzen, 2021], which accounts for the heterogeneous effect of temperature on TFP across countries, allows us to test for weak exogeneity and get consistent parameter in the presence of feedback effect from TFP to temperature.
- This paper shows the potential mechanism by which labour productivity, capital productivity and reduction in ecosystem services can affect TFP

Household

Each household wants to maximise lifetime utility as given by

$$U = \int_0^{\infty} u[c_t]e^{-\rho t}dt; \quad u'(c) > 0, u''(c) < 0 \tag{1}$$

where, ρ is the discount factor and $c(t)$ represents per capita consumption. The instantaneous utility function as follows:

$$u(c_t) = \frac{c_t^{1-\theta} - 1}{1 - \theta} \tag{2}$$

If the amount of capital (K) is assumed as assets and C is the consumption, the motion of capital can be expressed as (by ignoring t subscript):

$$\dot{K} = (r - \delta).K + w.L - C \tag{3}$$

Labour (L) is fixed in an economy. Dividing both sides by L, this expression can be represented in terms of per capita as follows:

$$\dot{k} = (r - \delta).k + w - c \tag{4}$$

Where, $k = K/L$ and $c = C/L$. This would serve as the budget constraint for the household. So, the household would maximise lifetime utility (U) subject to this constraint.

Firms

N identical countries worldwide, and each possesses one firm only producing Y_{it} intermediate output in i-th period. The world output can be expressed as

$$X_t = \left[\sum_{i=1}^{N} Y_{it}^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)} \tag{5}$$

Where, Y_{it} is the quantity of input variety $i = 1, .., N$. $\sigma > 1$, so it is meaningful to consider changes in the number of inputs.
If inputs are all equally priced, then $Y_{it} = Y_t$: $X_t = N^{\sigma/(\sigma-1)} Y_t$.
$N^{\sigma/(\sigma-1)} > 1$, capturing the productivity gain. It may also apply to the emission level.

Emission and temperature

The global emission function: $E_t = X_t^{\phi}; \phi > 0$.

The global temperature: $T_t = \ln E_t$.

$$T_t = \phi \ln X_t \tag{6}$$

The production function country can be specified as follows:

$$Y_{it} = A(T_{it}) \left[A_K(T_{it})K_{it}\right)^{\alpha} \left(A_L(T_{it})L_{it}\right]^{1-\alpha} = B_{it} K_{it}^{\alpha} L_{it}^{1-\alpha} \tag{7}$$

Where, $B_{it} = A(T_{it})A_K(T_{it})^{\alpha} A_L(T_{it})^{1-\alpha}$, which denotes the aggregate productivity term (CRS).

Emission and temperature

Damage functions:
$A(T_t) = A(1 - \mu_A T_t)$, where $\mu_A > 0$.
$A_K(T_t) = A_K(1 - \mu_K T_t)$
$A_L(T_t) = A_L(1 - \mu_L T_t)$; $\mu_K, \mu_L > 0$.
The production function can be simplified as follows:

$$Y_t = BDY_t^{-\Omega} K_t^{\alpha} L_t^{1-\alpha} \tag{8}$$

Where, $B = AA_K^{\alpha} A_L^{1-\alpha}$; $\Omega = [\mu_A + \alpha\mu_K + (1-\alpha)\mu_L]\phi$; $D = N^{-\Omega\sigma/(\sigma-1)}$.
Rearranging the Y_t term, we find

$$Y_t = (BD)^{\frac{1}{1+\Omega}} K_t^{\frac{\alpha}{1+\Omega}} L_t^{\frac{1-\alpha}{1+\Omega}} \tag{9}$$

In per capita terms (in the lower letters) as follows:

$$y_t = (BD)^{\frac{1}{1+\Omega}} k_t^{\frac{\alpha}{1+\Omega}} L^{\frac{-\Omega}{1+\Omega}} \tag{10}$$

Note that the output per capita, y_t, contains the term of productivity loss, D, due to the damage.

Conceptual Framework

If the marginal productivity of capital is defined as the rental rate, we get the rental rate (r_t) as follows:

$$r_t = \left(\frac{\alpha}{1+\Omega}\right)(BD)^{\frac{1}{1+\Omega}} k_t^{-1+\frac{\alpha}{1+\Omega}} L^{-\frac{\Omega}{1+\Omega}} - \delta \tag{11}$$

Since $\frac{\alpha}{1+\Omega}$ is fraction, r_t will be falling with the rise of k_t. Applying the Hamiltonian optimisation method, we find the growth rate of the economy as follows:

$$\frac{\dot{c}}{c} = \frac{1}{\theta}\left[\frac{\alpha}{1+\Omega}(BD)^{\frac{1}{1+\Omega}} k_t^{\frac{\alpha-\Omega-1}{1+\Omega}} L^{\frac{-\Omega}{1+\Omega}} - (\delta+\rho)\right] \tag{12}$$

The first of the third bracket declines with capital accumulation. It will converge to $\delta + \rho$. At steady state, $k_t = k^*$. Therefore, we find:

$$k^* = \left[\left(\frac{(\delta+\rho)(1+\Omega)}{\alpha}\right)^{1+\Omega} \frac{L^{\Omega}}{BD}\right]^{-\frac{1}{1+\Omega-\alpha}} \tag{13}$$

If we substitute k^* in the production function (10), we find the steady state output per capita as follows:

$$y^* = (BD)^{\frac{1}{1+\Omega}} L^{\frac{-\Omega}{1+\Omega}} k^{*\frac{\alpha}{1+\Omega}} \tag{14}$$

The average productivity of capital and total factor productivity are defined in terms of y_t/k_t and y_t/k_t^{α} and found as follows (for $\Omega > 0$):

$$\frac{y_t}{k_t} = (BD)^{\frac{1}{1+\Omega}} L^{\frac{-\Omega}{1+\Omega}} k_t^{\frac{\alpha-\Omega-1}{1+\Omega}} \tag{15}$$

Conceptual Framework

Note that when $\Omega = 0$, we find that $TFP_t|_{\Omega=0} = B$.
The higher the value of D, the lower the TFP.
$\Delta \log TFP_t = \log TFP_t|_{\Omega>0} - \log TFP_t|_{\Omega=0}$

$$\Delta \log TFP_t = -\frac{1}{1+\Omega}[\Omega \log B + \log D] - \frac{\Omega}{1+\Omega} \log L - \frac{\alpha\Omega}{1+\Omega} \log k_t \qquad (17)$$

The first term of the right-hand side captures the loss of productivity due to ecological damage
The second and third terms contain the loss of productivity with respective to the damage in labour and capital efficiencies, respectively.
At $k_t = k^*$, TFP would be fixed at TFP^*, much smaller than B for $\Omega > 0$. Moreover, for a positive value of either μ_A, μ_K, μ_L or ϕ, we find that $\Omega > 0$ and the TFP will be lower.

Climatic Indicators

Climate Indicators

1. Rainfall - Climate Change Knowledge Portal (World Bank)
2. Maximum Temperature - Climate Change Knowledge Portal (World Bank)
3. Average Temperature - Climate Change Knowledge Portal (World Bank)

Data and Descriptive Statistics

Economic Indicators

1. Secondary schl. enrollment rate, secondary (% gross) -World Development Indicators(WDI, 2016)
2. Exports of goods and services (current US$) - World Development Indicators(WDI, 2016)
3. Imports of goods and services (current US$) - World Development Indicators(WDI, 2016)
4. General government final consumption expenditure (% of GDP) -World Development Indicators(WDI, 2016)
5. Foreign direct investment, net inflows (% of GDP) - World Development Indicators(WDI, 2016)
6. Labor force, total - World Development Indicators(WDI, 2016)
7. GDP (current US$) - World Development Indicators(WDI, 2016)
8. Number Of Persons engaged (in millions) - Penn World Table Productivity Data Sheet
9. Capital Stock at Constant 2017 Rational Prices (in mil. 2017 US) - Penn World Table Productivity Data Sheet
10. TFP at constant national price (2017=1) - Penn World Table Productivity Data Sheet

Projection Data

- Together with climate Indicators and economic variables, we get complete balanced panel data of 21 Emerging markets .
- Time span - 1990-2018
- Used World Bank Climate projected temperature data for projecting future impact.
- We used four RCP Scenarios.
- RCP includes stringent mitigation scenarios (RCP 2.6), two intermediate scenarios (RCP 4.5 and RCP 6.0) and one with very high emissions (RCP 8.5). RCP 8.5 is also called a business-as-usual scenario.

Stationarity

- Three panel unit root test Im, Pesaran, and Shin [2003b] Levin, Lin, and James Chu [2002] and Pesaran [2007a] CADF test.
- In Pesaran [2007a] we use lags of order 0 , 1 and 2 to compute statistics of unit roots.
- In the first set of economic variable log(TFP) is difference stationary and thus integrated of order 1. Other control variables Trade openness and Human capital is integrated and Foreign direct investment , Institutional quality and Inflation is level stationary.
- In second set of variables , All climate indicators are integrated of order zero. Annual variation in mean temperature , annual variation in maximum temperature and precipitation is level stationary.
- **We got mix of both stationary and integrated series.**

Stationarity

Table A.2: Panel unit root test result

Variables	First generation unit root test IPS (c) p-value	IPS (c,t) p-value	LLC (c) -p-value	LLC (c,t)	Second generation unit root test CADF lag(0)	CADF lag(1)	CADF lag(2)
Total factor productivity	2.1151	-1.9127**	-0.91734	-0.62722	1.981	1.657	0.778
	(0.9828)	(0.0279)	0.1795	0.2653	0.976	0.951	0.782
Δ Total factor productivity	10.8564***	-11.3223***	-7.60693***	-7.02190***	-11.929***	-6.105***	-4.092***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Mean Temperature	-7.1131***	-12.6674***	-6.95561***	-12.1421***	-13.500***	-7.351 ***	-7.566***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Maximum Temperature	-7.9070***	-11.7831***	-5.3834***	-12.1421***	-11.870**	-5.841 ***	-5.006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Heat Degree Days	-9.4135***	-12.6674***	-6.6075***	-8.0920***	-14.151**	-8.535 ***	-6.068***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Precipitation	-11.6903***	-12.6324***	-6.7655***	-5.8694***	-15.680**	-5.628 ***	-2.927***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)
Trade openness	-1.1591	-3.8235***	-2.4651*	-2.1807*	-0.887	-1.009	-1.148
	(0.1232)	(0.001)	(0.006)	(0.014)	(0.188)	(0.156)	(0.875)
Δ Trade openness	-12.4207***	-12.7212***			-10.857***	-2.766***	-2.134
	(0.000)	(0.000)			(0.000)	(0.003)	(0.984)
Human Capital	-3.6227	-2.1873*	-1.3937**	-1.9033*	0.328	-1.009	1.148
	(0.9999)	(0.0144)	(0.0068)	(0.0146)	(0.188)	(0.156)	(0.875)
Δ Human Capital	-8.5126***	-8.6833***			-10.857***	-2.766***	2.134***
	(0.000)	(0.000)			(0.000)	(0.000)	(0.001)
Inflation	-8.4137***	-9.0884***	119.997	188.511	-11.238***	-10.024***	-7.111***
	(0.000)	(0.000)	(1.000)	(0.999)	(0.000)	(0.000)	(0.000)
Institutional quality	-1.7083*	-3.3161***	-2.8265*	-0.9507	-0.919	-2.196	-2.382***
	(0.0438)	(0.000)	(0.002)	(0.170)	(0.179)	(0.014)	(0.000)
Foreign Direct Investment	-5.7878***	-6.6931 ***	-3.9650***	-2.7652*	-7.236**	-4.658***	-1.829*
	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.034)

Notes: c indicates unit root test without intercept and c(t) indicates that we allow for different intercepts (and time trends) for each country. Large negative values lead to rejection of a unit root in favor of (trend) stationarity. We tested for both first generation unit root test which assumes cross sectional Independence and second generation unit root test which assumes cross sectional dependence. **(***)(*) (**)Indicate rejection of the null hypothesis of a unit root at the(1%) (5%) level (10%) level**

Figure (4) Panel unit root result

Main Result

- Long run estimate of annual variation of mean temperature is negative and significant
- increase in one degree temperature decrease **3.22 percentage** of log(TFP) in long run
- Our results confirmed the previous studies of Kumar and Khanna [2019] and Letta and Tol [2019]. Letta and Tol [2019] concluded that increase in one degree celcius decreases total factor productivity growth by 0.49 percentage
- Pesaran [2021] CD test rejects null of the presence of cross sectional dependence and we conclude that estimated model has no cross sectional dependence.
- We compute Pesaran [2007a] CIPS panel unit root test for the residual as test for cointegration.[Holly et al., 2010] [Baltagi and Griffin, 1997] implying presence of non-spirious estimate.
- Found presence of cointegration- suggesting long-run relationship.

Main Result

Table (1) Estimates of the long-run relationship between temperature and TFP

Variables	(1) CS-ARDL p-value	(2) CS-ARDL p-value	(3) PMG-ARDL -p-value	(4) PMG- ARDL	(5) NSYC-IV	(6) NSYC-IV
Mean Temperature	-.0322*		-0.0457**		-.00791**	
	(0. 0145)		(.0533)		(.00472)	
Maximum Temperature		-.0222*		-0.0387*		-.00837**
		(.0099)		(0.003)		(.00494)
CIPS Statistics	-7.236***	-7.377***	-3.8352***	-3.4814***	NA	NA
Cointegration	Yes	- Yes	Yes	Yes	NA	NA
CD Statistics	-0.19	-0.45	10.674***	10.366***	NA	NA
Number of observation	609	609	609	609	609	609
Number of Countries	21	21	21	21	21	21

Notes: The dependent variable is log (Total factor productivity) CS-ARDL: Cross sectional autoregressive distributed lag of Chudik and Pesaran [2015]Ditzen [2021] PMG :Pooled mean Group NSYC-IV :Defactored instrument variable estimation Norkut e et al. [2021] . CD: Cross sectional dependance test of Pesaran [2021] - The CD statistics has null hypothesis of no cross sectional independance in the residual of estimated model. CIPS is cross sectionally augmented IPS of the residuls of long run relationship . NA- For defactored instrument varible estimation we used Stata module xtivreghdfe which do not report error term. **(***)(*) (**)Indicate rejection of the null hypothesis at the(1%) (5%) level (10%) level**

Robustness

Variables	(1) CS-ARDL Log(TFP)	(2) CS-ARDL Log(TFP)	(3) CS-ARDL Log(TFP)	(4) CS-ARDL Log(TFP)	(5) CS-ARDL Log(TFP)
Mean Temperature	-0.0361*	-0.0379***	-0.03637*	-0.05538*	-0.039822*
	(0.0162)	(0.0121)	(0.01427)	(0.02779)	(0.01557)
Precipitation	-0.00004	-0.000047	-0.00009	-0.00018	-0.00009
	(0.000054)	(0.00004)	(0.000083)	(0.00011)	(0.00008)
Human Capital		0.00145*	0.00122	0.00173	0.00180
		(0.00066)	(0.00119)	(0.00158)	(0.00144)
Trade openness			0.09976*	0.00821	0.10322*
			(0.04430)	(0.05467)	(0.04990)
Institutional quality				-0.00547*	
				(.00251)	(.00472)
Foreign direct investment					-0.00198
					(0.00199)
Error correction term	-.9866***	-1.0825***	-1.28988***	-1.2123***	-1.4116***
CIPS Statistics	-7.140 ***	-7.698 ***	-10.952***	-9.429***	-10.009
Cointegration	Yes	- Yes	Yes	Yes	Yes
CD Statistics	-0.72	0.11	-0.11	-0.54	-0.73
Number of observation	609	474	426	389	426
Number of Countries	21	21	18	16	18

Table (2) Estimates of the long-run relationship between temperature and TFP with control variables

Causality

Table 3: Causality tests between log(TFP) and Temperature shock

Judodis, Karavias and Sarafidis (2021) Granger non-causality test				
		HPJ Wald Statistics	Number of Lags	
H0- average temperature do not granger cause Log (TFP)		5.0259**	1	
H0- Log (TFP) do not granger cause average temperature		4.8071**	1	
Granger causality test based on PVECM				
	Chi square statistics	Coefficient on lagged TEMP	coefficient of lagged TEMP	Number of Lags
H0- average temperature do not granger cause Log (TFP)				
Weak exogeneity test	66.881			2
$a_1 = 0$	[0.000]			2
Short-run Granger non-causality test	4.7973	0.0010	0.00605	2
$\phi_{12j} = 0$	[0.0908]	(0.0029)	(0.0028)	2
Strong exogenity test	71.61			2
$\phi_{12j} = a_1 = 0$	[0.000]			2
Number of observations	609			
Number of countries	21			
	Chi square statistics	Coefficient on lagged LTFP	coefficient of lagged LTFP	Number of Lags
H0- Log (TFP)do not granger average temperature				
Weak exogeneity test	0.03744			2
$a_1 = 0$	[0.846]			2
Short-run Granger non-causality test	0.379	-0.09438	0.3339	2
$\phi_{12j} = 0$	[0.8272]	(0.5363)	(0.5441)	2
Strong exogenity test	0.4180			2
$\phi_{12j} = a_1\ 0$	[0.9635]			2
Number of observations	609			
Number of countries	21			

Notes: [] contains p values of wald statistics and () contains standard error of the individual coefficient.
(*)(*) (**)Indicate rejection of the null hypothesis at the(1%) (5%) level (10%) level**

Heterogeneity

Table (3) Estimates of the long-run relationship between temperature and TFP

	(1) Cold CS-ARDL	(2) Moderate Hot CS-ARDL	(3) Very Hot CS-ARDL	(4) less-developed EMEs CS- ARDL	(5) Developed EMEs CS-ARDL
Mean Temperature	-0.0273*	-0.0144*	-0.0269	-0.0586*	-0.0056
	(0.0087)	(0.0067)	(0.0197)	(0.0307)	(0.0080)
CIPS Statistics	-3.639***	-2.561**	-5.743***	-3.132***	-6.288***
Cointegration	Yes	Yes	Yes	Yes	Yes
R-squared (Mean Group)	0.43	0.35	0.42	0.29	0.38
Number of observation	112	189	270	189	370
Number of Countries	4	7	10	7	14

The dependent variable is log (Total factor productivity) CS-ARDL: Cross sectional autoregressive distributed lag of Chudik and Pesaran [2015]Ditzen [2021] CD: Cross sectional dependance test of Pesaran [2021] - The CD statistics has null hypothesis of no cross sectional independance in the residual of estimated model. CIPS is cross sectionally augmented IPS of the residuls of long run relationship .() contains standard error() contains standard error. Cold - Temperature Bin(0-10 C) , Moderate Hot - Temperature Bin(10-20 C) and Very Hot - Temperature Bin(20-30 C)

(*)(*) (**)Indicate rejection of the null hypothesis at the(1%) (5%) level (10%) level**

Non-Linear impact of temperature

Table (4) Estimates of the Assymetric Panel CS-ARDL

	(1) Assymetric CS-ARDL Log(TFP)	(2) CS-ARDL with quadratic temperature indicator Log(TFP)
Error correction term	-0.8049***	-1.1618***
Long run coefficient		
Temperature(-ve)	.00002	
	(.00679)	
Temperature(+ve)	-.00135	
	(.00595)	
Temperature		0.683
		(0.2870)
Temperature2		-0.0167**
		(0.00864)
Short run coefficient		
Temperature(-ve)	-.00345	
	(.00473)	
Temperature(+ve)	-.00400	
	(-.00345)	
Temperature		0.7379**
		(0.2855)
Temperature2		-0.0190**
		(0.0074)

Mechanism

Table (5) Temperature shocks and mechanism

Regressor	Labour CS-ARDL	Capital CS-ARDL	LP CS-ARDL Productivity measure	CP CS-ARDL	Forest cover CS-ARDL Ecosystem service
Mean Temperature	-0.8059**	-.1374**	-449.28**	-0.005**	-0.0083
	(0.4327)	(0.0822)	(265.49)	(0.0028)	(0.0085)
Error correction term	-0.8948***	-0.9952***	-0.9740***	-0.9550***	-0.2794***
CIPS Statistics	-8.954 ***	-9.741***	-7.457***	-8.778***	-8.338
Cointegration	Yes	- Yes	Yes	Yes	Yes
CD Statistics	-0.45	-0.03	-0.97	-2.27*	0.99
Number of observation	609	609	609	609	609
Number of Countries	21	21	21	21	21

(*)(*) (**)Indicate rejection of the null hypothesis at the(1%) (5%) level (10%) level**

Labour -Number Of Persons engaged (in millions) , Capital-Capital Stock at Constant 2017 Rational Prices (in mil. 2017 US $) , Labour productivity - GDP per unit of labour , Capital productivity- GDP per unit of capital. Forest cover- Forest Area (sq. km) Cereal yield-Cereal Yield (kg per hectare) Manufacturing -Manufacturing value-added as % of GDP Agriculture -Agricultural value-added as % of GDP Natural resources rent-Total natural resources rents (% of GDP)

Temperature shocks and mechanism

- uncertainty induced by extreme weather events - choosing an incorrect input mix by farmers and investors. Investors cut their investments, leading negative impact of temperature on labour productivity [Adhvaryu et al., 2018, Letta and Tol, 2019], labour supply [Somanathan et al., 2021], and cognitive abilities [Hancock et al., 2007].
- greater temperatures limit lubricants' ability to reduce surface friction between mechanical components [Mortier et al., 2010], increase the failure rates by raising the volume of input materials requirements [Collins, 1963], and slow down computer processing speed. Climate change-induced natural disasters can increase physical risk.
- Another channel of impact can be thought of as a reduction in ecosystem services, which leads to the reallocation of resources away from research and development to climate change mitigations. This may also reduce the productivity of factors such as agricultural land and labour

Adaptation

Table (6) Temperature shocks and Adaptation

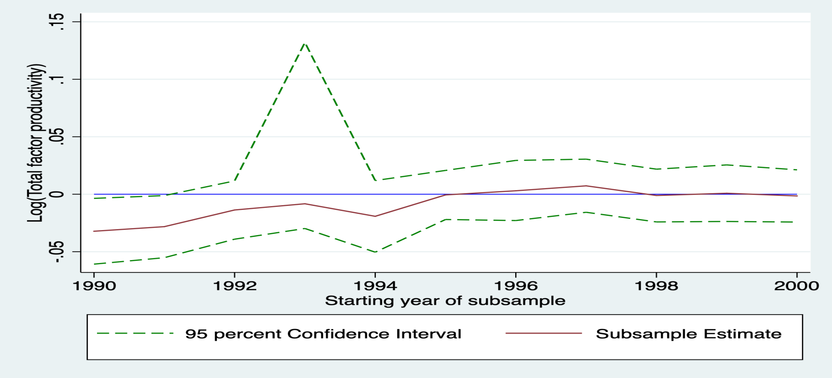
Regressor	Manufacturing CS-ARDL	Agriculture CS-ARDL Sector level impact	Natural Resource rent CS-ARDL	Cereal yield CS-ARDL Prices
Mean Temperature	-0.2010	-0.2056	0.3257	-128.30***
	(0.3960)	(0.2742)	(0.3137)	(39.71))
Error correction term	-0.9225***	-1.155***	-0.9899***	-1.3060***
CIPS Statistics	-5.466	-7.182	-9.849***	-9.877***
Cointegration	Yes	Yes	Yes	Yes
CD Statistics	-2.08*	-2.12**	4.12***	-2.27**
Number of observation	609	609	609	609
Number of Countries	21	21	21	21

(*)(*) (**)Indicate rejection of the null hypothesis at the(1%) (5%) level (10%) level**

Labour -Number Of Persons engaged (in millions) , Capital-Capital Stock at Constant 2017 Rational Prices (in mil. 2017 US $) , Labour productivity - GDP per unit of labour , Capital productivity- GDP per unit of capital. Forest cover-Forest Area (sq. km) Cereal yield-Cereal Yield (kg per hectare) Manufacturing -Manufacturing value-added as % of GDP Agriculture -Agricultural value-added as % of GDP Natural resources rent-Total natural resources rents (% of GDP)

Adaptation

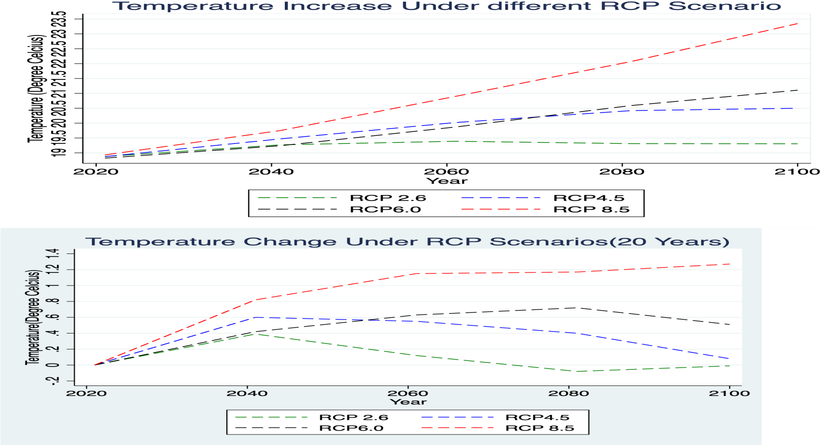
Figure (5) Long-Run Effects of Climate Change on Log(TFP) with different subsample based on Starting year



Notes: Figures show the long-run effect (and their 95% standard error bands) of climate change on log(TFP) on the subsample of different windows, using the CS-ARDL specification. We start the estimation with the full sample and then drop one year at a time.

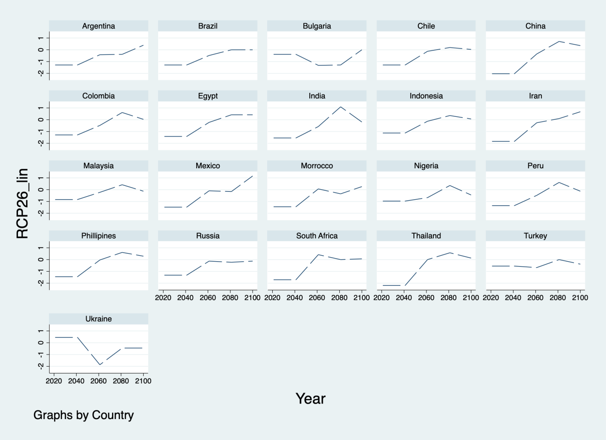
Projected Impact of temperature on TFP

Figure (6) Temperature under RCP Scenarios over 2021-2100



Projected Impact of temperature on TFP

Figure (7) TFP projections (in percentage) over the period 2020–2099 (Linear Projection Estimate)

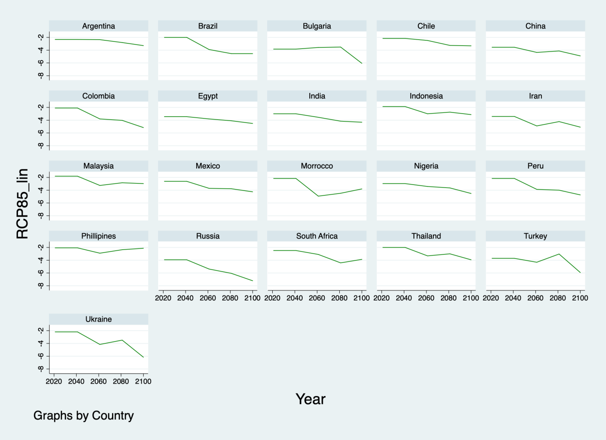


(a) RCP 2.6 Low Emission Scenario

Source: Authors' calculation based on data drawn from the World Bank

Projected Impact of temperature on TFP

Figure (8) TFP projections (in percentage) over the period 2020–2099 (Linear Projection Estimate)



(a) RCP 8.5 Business as usual scenario

Source: Authors' calculation based on data drawn from the World Bank Climate

Projected Impact of temperature on TFP

Table (7) Level of TFP projections over the period 2020–2099

Scenario Level of log(TFP)	2021-2041	2041-2061	2061-2081	2081-2100
RCP 2.6	-1.255	-0.386	+0.2576	+0.032
RCP 4.5	-1.932	-1.771	-1.288	-0.2576
RCP 6.0	-1.3524	-2.02	- 2.32	-1.642
RCP 8.5	-2.6404	- 3.70	-3.77	-4.089

Notes: Positive (+) and Negative(-) sign indicates the magnitude of increase or decrease of the level of TFP in 2021-2100. RCP 2.6 - Low Emission Scenario, RCP 4.5 RCP 6.0- Intermediate emission scenario, RCP 8.5- Business as usual scenario

Climate Change , Economic Dynamics and Adaptation Pathways- A panel analysis of Indian States

Climate Change , Economic Dynamics and Adaptation Pathways- A panel analysis of Indian States

Table (8) MAIN RESULTS: EFFECTS OF ANNUAL AND SEASONAL TEMPERATURES ON GDP GROWTH

Variables	(1) CS-ARDL Annual	(2) CS-ARDL Summer	(3) CS-ARDL Monsoon	(4) CS-ARDL Autumn	(5) CS-ARDL Winter
GSDP Growth	-0.0235**	-0.0074	-0.0057	-0.0128*	-0.0363
	(0.0089)	(0.0095)	(0.0058)	(0..0069)	(0.0434)
CIPS Statistics	-15.411***	-12.324***	-13.605***	-11.169***	-14.091***
Cointegration	Yes	Yes	Yes	Yes	Yes
CD Statistics	-1.80*	-2.34*	-1.51	0.12	- -2.07**
Rainfall	Yes	Yes	Yes	Yes	Yes
Population	Yes	Yes	Yes	Yes	Yes
R Squared	0.73	0.61	0.61	0.58	0.73
Number of observation	1143	964	964	964	964
Number of States	31	31	31	31	31

Notes: The dependent variable is GSDP Growth. Independent variable is annual variation in mean temperature.The first column reports the estimated coefficients on average annual temperature from a regression of the economic growth rate. The four columns on the right report the estimated coefficients for each of the four seasonal temperature averages (regressions (2) and (5)). In the panel regressions, all 31 states and Union territories of India are included Temperatures are in degrees Celcius. The sample is 1980–2019 for annual regression and 1981-2014 for seasonal. Summer (Average of month of March , April and May) Monsoon(Average of June, July, August and September) Autumn(October and November) and Winter(Average of December , January and February).ERA weather data is used. Standard errors are in parentheses. **(***)(**) (*) indicate the level of**

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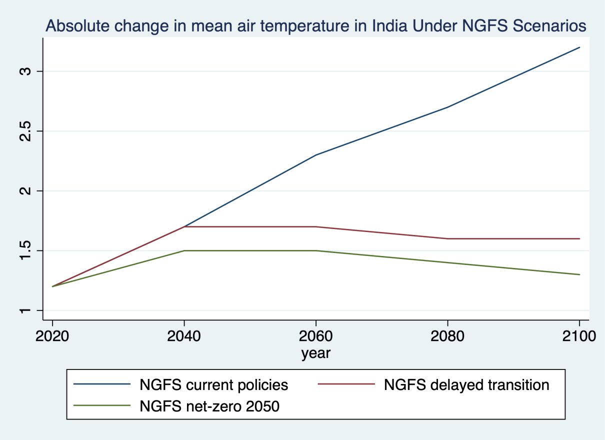

Figure (9) NGFS Scenario temperature rise 2021-2100

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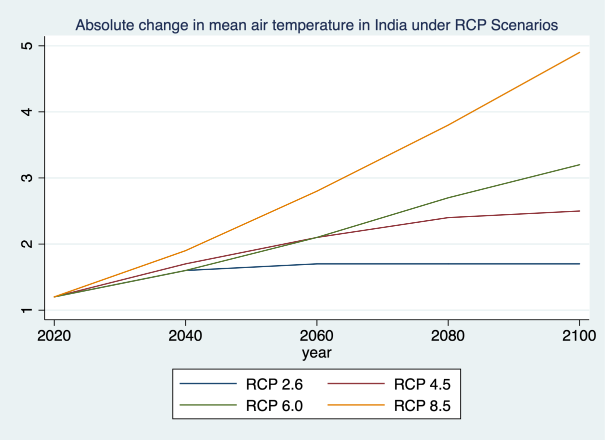

Figure (10) RCP Scenario temperature rise 2021-2100

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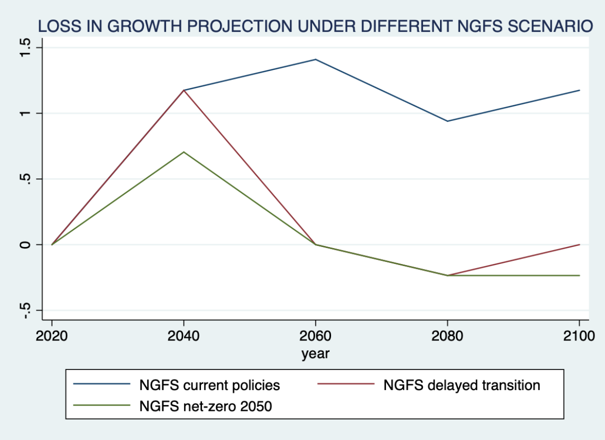

Figure (11) Future Growth Loss and Temperature Rise Projections under different RCP and NGFS Scenario 2020-2100

Climate Change, Economic Dynamics and Adaptation Pathways- A panel analysis of Indian States

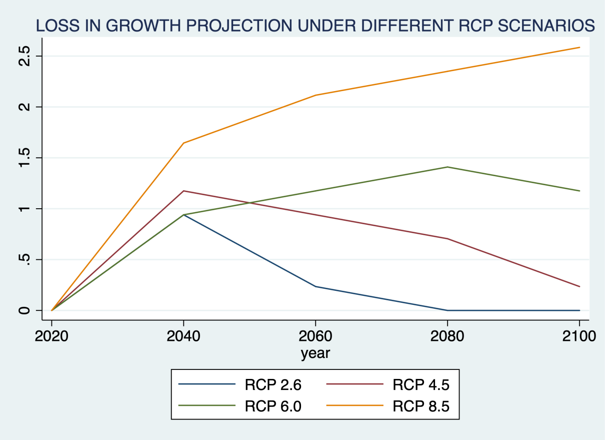

Figure (12) Future Growth loss and Temperature rise Projections under differnet RCP and NGFS Scenario 2020-2100

Summary

- A significant negative effect of temperature on the level of TFP.
- A 1 degree Celcius increase in the mean temperature reduces the level of TFP by 3.22%.
- A non-linear relationship between the temperature and TFP. Extreme climatic zones are expected to experience a greater impact than others.
- Unidirectional long-run causality runs from temperature to TFP.

Summary

- Climate change influences the level of TFP by damaging labour productivity, capital productivity and the ecosystem.
- Under the High emission scenario, the level of TFP decline was in the range of 2.6% to 4.0%.

Thank You