The long-term impact of climate change on growth: Evidence from Chinese provinces

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2. Data and methodology
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Trends

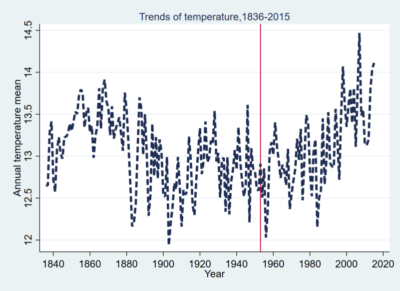


Figure 1. Annual temperature means in China, 1836-2015

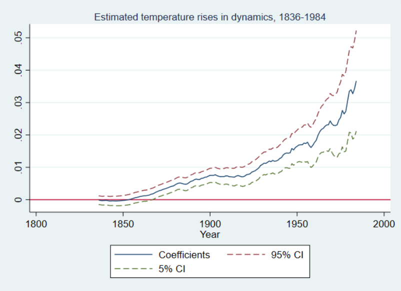


Figure 2.Temperature trends in China, 1836-1984

Measuring the economic losses due to climate change

- Non-linearity of climate values and their stochasticity and sensitivity (Mann et al, 1998; Palmer, 2019; Anderson et al, 2023)
- Direct and indirect economic damages/losses due to climate change in the long term (Nordhaus, 1994, 2006; Dell et al, 2009; 2012; Jones and Olken, 2010; Welch, 2010; Mendelsohn et al 1994; Mendelsohn, 2016; Thakkar et al, 2023)
- The impact of El Niño and La Niña and temperature deviations (McPhaden, et al, 2006; Cashin et al, 2017; Li et al, 2020; Tol, 2021; Kahn et al, 2021; Mohaddes et al, 2022)
- The negative impact of temperature extremes on crops, manufacturing production and diseases (Zhang, et al, 2017; Ponticelli et al, 2019; Chen et al, 2020; Zhang et al, 2023)

Measuring the economic losses due to climate change

- Scholars are mainly focused on GDP-temperature interactions in the long-term and undertaking a risk analysis of temperature extremes on macroeconomic stability (Kalkuhl and Wenz, 2020; Newell *et al*, 2021; Linsenmeier 2023; Ben *et al*; 2023; Kotz,*et al*, 2024; Bilal and Känzig, 2024)
- The mechanisms by which climate change causes damage and possible mitigation/adaptation strategies are also commonly investigated, especially in the agriculture sectors (Burke and Emerick, 2016; Cui and Xie, 2022; Chen *et al*, 2023; Cui and Zhong, 2024)

Data collection and processing

- We collect and deflate provincial level GDP per capita, GDP and other series of economic indicators from 1952 to 2015
- We use 6-hourly climate data (20CRv3) from 1836 to 2015 to calculate the population-weighted climate values. We focus on the temperature and precipitation to calculate the difference between annual means and the 20/30/40-year historical norms to capture $\hat{T}_{it}(m)^{+}$ and $\hat{T}_{it}(m)^{-}$
- To predict and estimate economic losses, we use CMIP6 climate projections combined with the population distribution data to calculate the population-weighted annual temperature mean, temperature deviations and corresponding impacts on economic growth

Data

Table 1: Summary Descriptions

Panel A. Population-weighted Climate Change, 1836-1952					
Variable name	Obs	Mean	Std. Dev.	Min	Max
Annual temperature mean (°C)	3,510	12.664	5.323	-1.392	22.759
Annual precipitation mean (t/m^{-2})	3,510	1.141	0.662	0.064	3.991
$T_{it}(m)^+$	2,760	1.587	2.771	0.000	20.634
$T_{it}(m)^-$	2,760	1.717	2.463	0.000	14.812
$P_{it}(m)^+$	2,760	4.606	11.045	0.000	140.519
$P_{it}(m)^-$	2,760	5.204	7.932	0.000	51.594
Panel B. Population-weighted Climate Change, 1953-2015					
Variable name	Obs	Mean	Std. dev.	Min	Max
Annual temperature mean (°C)	1,890	12.750	5.344	-0.871	22.984
Annual precipitation mean (t/m^{-2})	1,890	1.035	0.615	0.093	3.147
$T_{it}(m)^+$	1,890	2.093	2.537	0.000	12.961
$T_{it}(m)^-$	1,890	0.939	1.729	0.000	12.417
$P_{it}(m)^-$	1,890	3.454	6.277	0.000	61.408
$P_{it}(m)^-$	1,890	3.718	5.727	0.000	38.466
Panel C. National Economic Growth, 1953-2015					
Variable name	Obs	Mean	Std. Dev.	Min	Max
GRP per capita growth	63	0.033	0.079	-0.161	0.242
GRP growth	63	0.033	0.081	-0.176	0.260

Data

Panel D. Provincial Economic Growth, 1953-2015					
Variable name	Obs	Mean	Std. Dev.	Min	Max
GRP per capita growth	1,890	0.028	0.051	-0.251	0.358
GRP growth	1,890	0.028	0.052	-0.377	0.382
GRP growth (primary sector)	1,890	0.041	0.078	-0.385	0.436
GRP growth (secondary sector)	1,890	0.013	0.072	-0.547	0.718
GRP growth (tertiary sector)	1,890	0.032	0.074	-0.693	0.730
GRP growth (agriculture sector)	1,795	0.044	0.086	-0.551	0.841
GRP growth (industry sector)	1,860	0.017	0.077	-0.788	1.024
GRP growth (construction sector)	1,864	0.030	0.111	-0.693	1.589
GRP per employed growth	1,751	-0.008	0.128	-0.965	0.653
Employment growth	1,751	0.037	0.113	-0.552	0.952
Salary growth	1,407	0.036	0.108	-2.287	2.294
Deposit growth	1,827	0.074	0.166	-0.947	1.259
Loans growth	1,827	0.082	0.208	-0.646	2.302
Inflation(CPI)	1,568	0.037	0.058	-0.121	0.355
Inflation(RPI)	1,782	0.027	0.054	-0.163	0.380
Intra trade growth	1,730	0.085	0.093	-0.543	0.700
Export growth	1,532	0.110	0.385	-2.431	4.437
Import growth	1,330	0.141	0.515	-4.415	4.005
Government income growth	1,765	0.029	0.222	-2.465	1.693
Government expenditure growth	1,830	0.048	0.196	-1.352	1.438
Panel F. Growth of economic output quantity, 1952-2015					
Variable name	Obs	Mean	Std. Dev.	Min	Max
Grain growth	1,857	0.020	0.117	-0.494	0.557
Oil growth	1,858	0.028	0.283	-2.225	1.473

Methodology

Our auto-regressive distributed lag (ARDL) model follows Dhaene & Jochmans(2015) and Chudik *et al.* (2018) and uses the maximum likelihood fixed effects estimation (SPJK-FE) or the half-panel Jackknife FE (HPJ-FE) with weakly exogenous regressors to reduce the estimation bias when N is larger than T given by:

$$\Delta y_{i,t} = a_i + \sum_{l=1}^{p} \psi_l \Delta y_{i,t-l} + \sum_{l=0}^{p} \beta_l' \Delta \bar{x}_{i,t-l} + \varepsilon_{i,t} \quad (1)$$

- $\Delta y_{i,t}$ is the annual economic growth rate of province i in year t
- $\Delta \bar{x}_{it}(m) = [\tilde{T}_{it}(m)^{+}, \tilde{T}_{it}(m)^{-}, \tilde{P}_{it}(m)^{+}, \tilde{P}_{it}(m)^{-}]'$ includes all climate change variables and their optimal lags
- $\tilde{T}_{it}(m) = [T_{it} - T*_{i,t-1}(m)]$ and $\tilde{P}\_it(m) = [P_{it} - P^{*}_{i,t-1}(m)]$ measures the temperature or rainfall deviations compared to their historical norms from year $t-1$ to t

Baseline regression

Table 7: Long-Run Effects of Climate Change on the Growth Rate of GRP per capita using population-weighted Climate Values, 1953-2015

	GRP per capita I								
Specification I	20-Year Moving-Average			30-Year Moving-Average			40-Year Moving-Average		
	FE	HPJKFE	SPJKFE	FE	HPJKFE	SPJKFE	FE	HPJKFE	SPJKFE
$\hat{\theta}_\delta \hat{T}_{it}(m)^+$	−1.043***	−3.319***	−3.812***	−1.295***	−4.028***	−4.603***	−1.674***	−5.171***	−5.933***
	(0.254)	(0.904)	(0.991)	(0.308)	(1.139)	(1.289)	(0.369)	(1.464)	(1.673)
$\hat{\theta}_\delta \hat{T}_{it}(m)^-$	−1.670***	−3.900**	−4.737***	−2.812***	−6.175**	−7.391***	−3.591***	−8.437**	−10.16***
	(0.427)	(1.210)	(1.264)	(0.648)	(1.887)	(1.878)	(0.849)	(2.602)	(2.515)
$\hat{\theta}_\delta \hat{P}_{it}(m)^+$	−0.291**	−0.561*	−0.586	−0.376**	−0.841*	−0.899*	−0.427**	−1.033*	−1.133
	(0.0946)	(0.276)	(0.304)	(0.137)	(0.404)	(0.447)	(0.156)	(0.505)	(0.610)
$\hat{\theta}_\delta \hat{P}_{it}(m)^-$	−0.224*	−0.243	−0.403	−0.366*	−0.498	−0.750	−0.209	−0.137	−0.417
	(0.114)	(0.258)	(0.314)	(0.182)	(0.384)	(0.475)	(0.259)	(0.526)	(0.607)
$\hat{\phi}$	0.550***	0.253***	0.228***	0.553***	0.257***	0.230***	0.550***	0.253***	0.228***
	(0.0312)	(0.0534)	(0.0353)	(0.0316)	(0.0536)	(0.0354)	(0.0315)	(0.0538)	(0.0353)
Specification II	20 Year Moving-Average			30 Year Moving-Average			40 Year Moving-Average		
	FE	HPJKFE	SPJKFE	FE	HPJKFE	SPJKFE	FE	HPJKFE	SPJKFE
$\hat{\theta}_{\Delta\|\tilde{T}_{it}(m)\|}$	−1.147***	−2.817***	−3.361***	−1.535***	−3.794***	−4.387***	−2.023***	−4.674***	−5.543***
	(0.258)	(0.806)	(0.909)	(0.335)	(1.096)	(1.226)	(0.422)	(1.402)	(1.573)
$\hat{\theta}_{\Delta\|\tilde{P}_{it}(m)\|}$	−0.295***	−0.481*	−0.578*	−0.436***	−0.814*	−0.943*	−0.408**	−0.659	−0.883
	(0.0703)	(0.217)	(0.258)	(0.109)	(0.335)	(0.385)	(0.149)	(0.399)	(0.506)
$\hat{\phi}$	0.548***	0.254***	0.229***	0.548***	0.255***	0.230***	0.547***	0.251***	0.228***
	(0.0317)	(0.0537)	(0.0350)	(0.0318)	(0.0538)	(0.0351)	(0.0317)	(0.0540)	(0.0351)
N	30	30	30	30	30	30	30	30	30
T	58	58	58	58	58	58	58	58	58
N × T	1,770	1,740	1,770	1,770	1,740	1,770	1,770	1,740	1,770

Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Estimation in dynamics

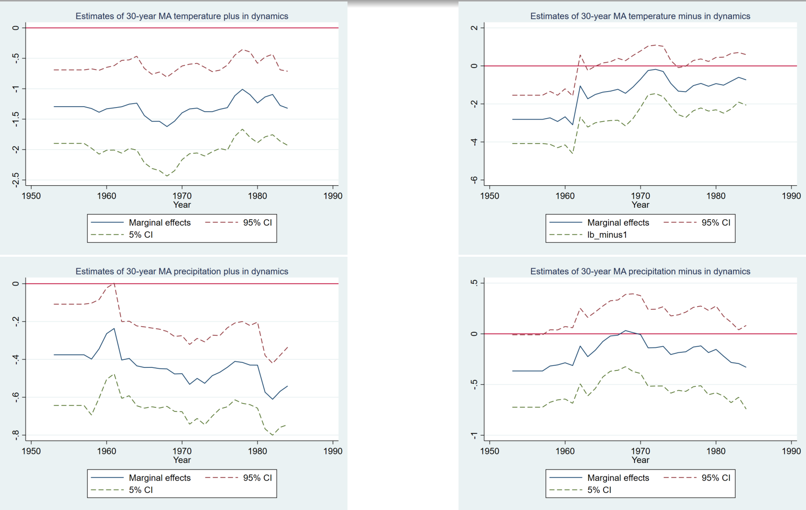


Figure 1. Coefficients of HPJ regression on temperature and precipitation in dynamics, 1953-1985

Meta-analysis

Table 9: Long-run effects of climate change on the growth rate of the major economic indicators for China using population-weighted 30-year moving average climate values, 1953-2015

	Agriculture	Industry	Construction	Deposit	Loans	Salary	Government revenue	Government spending	CPI	RPI
Half Panel Jackknife-FE										
$\hat{\theta}_\delta \hat{T}_{it}(m)^+$	-2.036***	-1.395**	-1.081	-0.310	-1.286*	-1.357*	-0.826	0.944	-7.314**	-6.610***
	(0.555)	(0.512)	(0.622)	(0.495)	(0.571)	(0.603)	(0.933)	(0.571)	(2.643)	(1.527)
$\hat{\theta}_\delta \hat{T}_{it}(m)^-$	-3.251**	-0.479	-2.974*	-5.300***	-5.082***	-3.188***	3.429	4.125**	-8.599*	-5.983**
	(1.054)	(1.071)	(1.468)	(1.286)	(1.313)	(0.917)	(2.140)	(1.393)	(3.555)	(1.873)
$\hat{\theta}_\delta \hat{P}_{it}(m)^+$	-0.329	-0.529	-0.603	-0.159	-0.286	-0.628*	-1.165**	-0.477	-2.829*	-2.034***
	(0.252)	(0.289)	(0.318)	(0.273)	(0.268)	(0.269)	(0.400)	(0.267)	(1.153)	(0.578)
$\hat{\theta}_\delta \hat{P}_{it}(m)^-$	-0.418	-0.204	-0.0536	-0.284	0.255	-1.184***	0.247	0.782*	-1.322	-0.801
	(0.258)	(0.209)	(0.482)	(0.288)	(0.308)	(0.284)	(0.453)	(0.332)	(0.906)	(0.455)
$\hat{\phi}$	0.676***	0.704***	0.665***	1.145***	0.893***	0.834***	0.996***	1.274***	0.142**	0.211***
	(0.0572)	(0.154)	(0.107)	(0.0625)	(0.0556)	(0.138)	(0.118)	(0.0712)	(0.0442)	(0.0400)
No. of province (N)	30	30	30	30	30	30	30	30	30	30
T min	26	32	32	32	32	20	16	26	20	20
T max	58	58	58	58	58	58	58	58	60	60
N × T	1,646	1,710	1,714	1,678	1,678	1,264	1,614	1,682	1,452	1,682

Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

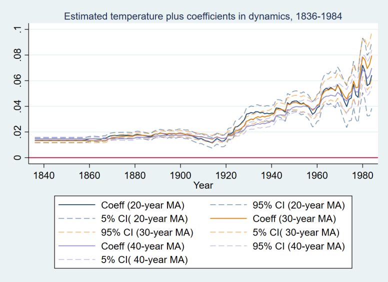
Meta-analysis

Table 10: The climate adaptation strategies for China using population-weighted 30-year moving average climate values

	Grain	Oil	Employment	GRP per employed	Intra-trade (1953-1984)	Intra-trade (1985-2015)	Exports (1953-1984)	Exports (1985-2015)	Imports (1953-1984)	Imports (1985-2015)
HPJ-FE regression										
$\hat{\theta}_\delta \hat{T}_{it}(m)^+$	0.437	1.527	-1.012	0.0664	-0.547	1.135	-5.370	-5.090*	0.408	-6.076***
	(0.403)	(1.007)	(0.621)	(0.789)	(0.824)	(2.119)	(5.237)	(1.978)	(3.906)	(1.730)
$\hat{\theta}_\delta \hat{T}_{it}(m)^-$	2.442***	11.44***	10.06***	-17.90***	7.441***	43.57**	2.351	9.815**	11.07	2.941
	(0.689)	(2.011)	(1.787)	(3.083)	(1.320)	(16.08)	(6.177)	(3.319)	(6.044)	(4.232)
$\hat{\theta}_\delta \hat{P}_{it}(m)^+$	0.391**	0.334	-0.193	-0.184	-0.591	2.331	-0.229	-1.292**	1.613	-2.477***
	(0.147)	(0.364)	(0.243)	(0.364)	(0.343)	(1.324)	(1.521)	(0.499)	(1.524)	(0.649)
$\hat{\theta}_\delta \hat{P}_{it}(m)^-$	0.00069	1.353**	1.757***	-2.769***	0.955**	-0.381	2.498	1.334*	-0.000261	0.491
	(0.169)	(0.461)	(0.371)	(0.585)	(0.353)	(0.906)	(1.371)	(0.595)	(1.785)	(0.728)
$\hat{\phi}$	1.330***	1.338***	0.686***	0.519***	0.859***	0.227*	0.970***	1.065***	1.630***	1.283***
	(0.0866)	(0.0729)	(0.0750)	(0.0700)	(0.0776)	(0.0913)	(0.212)	(0.135)	(0.192)	(0.133)
N	30	30	30	30	29	30	27	30	21	30
T min	32	32	30	30	2	20	2	24	2	18
T max	58	58	58	58	28	30	28	30	28	30
N × T	1,708	1,708	1,602	1,602	686	890	482	892	306	876

Standard errors in parentheses, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Trends of temperature deviations



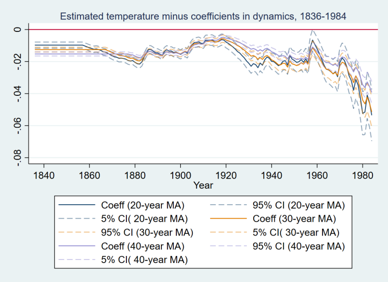


Figure 2. Trends of temperature deviations in dynamics, 1953-1985

Predictions and sustainability

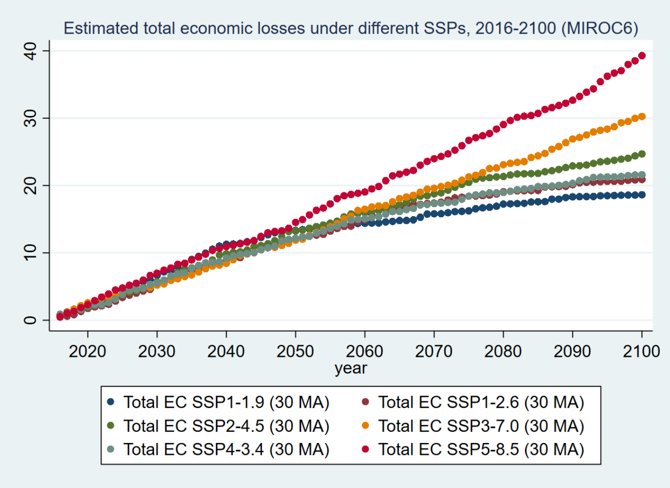
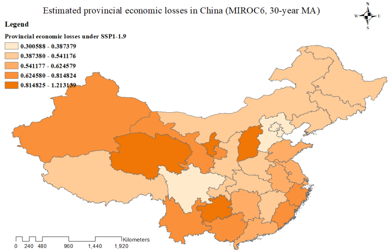
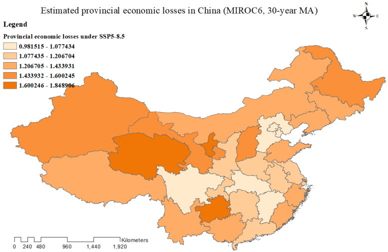


Figure 3. Estimated total economic losses under different SSP scenarios, 2016-2100

Spatial heterogeneity



Total Economic losses by 2100 under SSP1



Total Economic losses by 2100 under SSP5

Main findings

- Temperature plus will drive economic losses by 2100, while the impacts of temperature minus are mitigated by a series of adaptation strategies. There is no difference in using temperature rising or temperature deviations to make the GDP-temperature interaction analyses
- Using the half-panel jackknife econometric approaches, we estimate that 1-degree temperature above/below its 30-year historical norms will reduce GDP per capita growth by 0.2665/0.417 percentage points on average
- The economic losses due to temperature minus ($\hat{T}_{it}(m)^{-}$) were mitigated by a series of adaptation strategies

Main findings

- Western regions, northeastern regions and some of the rich coastal provinces will suffer more economic losses due to temperature rises by the end of this century
- Our estimated total losses are 10.87 to 18.24 (38.90 to 54.74) annual GDP per capita growth percentage point under the Representative Concentration Pathways 1.9 (8.5) by 2100, which is approximately 2.67-2.82 times higher than applying adaptation policies
- Assuming the provincial yearly GDP per capita growth equals five percentage points on average, the total economic losses without applying any carbon neutrality policies will be 9.15% to 12.88% of the economic losses by 2100

Q&A

Thank you for your attention!