UNIVERSITÉ PARIS 1 PANTHÉON - SORBONNE

U.F.R. DE SCIENCES ÉCONOMIQUES

Centre d'économie de la Sorbonne

THÈSE

Pour l'obtention du titre de Docteur en Sciences Économiques

Présentée et soutenue publiquement le 23 janvier 2023 par

Thibault LEMAIRE

<TITRE DE LA THÈSE>

Sous la co-direction de :

Rémi BAZILLIER	Jean-Bernard CHATELAIN
Professeur des Universités	Professeur des Universités
Université Paris 1 Panthéon-Sorbonne	Université Paris 1 Panthéon-Sorbonne

Membres du jury :

Katrin MILLOCK	Professeure des Universités, Directrice de recherche CNRS
	Université Paris 1 Panthéon - Sorbonne (Présidente)
Olivier DAMETTE	Professeure des Universités
	Université de Lorraine (Rapporteur)
Stéphane GOUTTE	Professeur des Universités
	University Paris-Saclay (Rapporteur)
Kamiar MOHADDES	Associate Professor in Economics & Policy
	University of Cambridge (Examinateur)

UNIVERSITÉ PARIS 1 PANTHÉON - SORBONNE
U.F.R. DE SCIENCES ÉCONOMIQUES
Centre d'économie de la Sorbonne

PHD THESIS
for the degree of Doctor of Philosophy in Economics
Prepared and publicly defended on January 23, 2023 by

Thibault LEMAIRE

<DISSERTATION TITLE>

Under the supervision of:

Rémi BAZILLIER	Jean-Bernard CHATELAIN
Professor	Professor
Université Paris 1 Panthéon-Sorbonne	Université Paris 1 Panthéon-Sorbonne

Members of the Committee:

Katrin MILLOCK	Professor, Director of Research at CNRS
	Université Paris 1 Panthéon - Sorbonne (President)
Olivier DAMETTE	Professor
	Université de Lorraine (Reviewer)
Stéphane GOUTTE	Professor
	University Paris-Saclay (Reviewer)
Kamiar MOHADDES	Associate Professor in Economics & Policy
	University of Cambridge (Examiner)

Table of Contents

List of Figures

List of Tables

Part I

Macroeconomic Effects of Climate Change

Chapter 1

Climate Change in Developing Countries: Global Warming Effects, Transmission Channels and Adaptation Policies[1]

Abstract

We show that global warming has negative macroeconomic consequences in developing countries. Using panel data covering 126 low- and middle-income countries between 1960 and 2017, we find that sustained positive temperature deviations from their historical norms have a non-linear negative effect on per capita real output growth: our main estimate indicates that in the median country, a sustained 1°C increase in temperature lowers real GDP per capita annual growth rate by 1.25 percentage points (0.82–1.69 p.p., 90% confidence interval). Examining transmission mechanisms, we find that temperature rise affects the households' intertemporal trade-off between consumption and investment, since the share of private consumption in total value-added increases while the share of investment declines. A sectoral decomposition shows that the share of industrial value-added also declines. While the share of agricultural value-added increases, agricultural output and productivity declines as investments are substituted by fertilizers and livestock. Taken together, our results suggest that global warming will reinforce development traps, hindering further adaptation to climate change in developing countries.

[1]joint work with Olivier de Bandt and Luc Jacolin.

1 Introduction

Climate change, *i.e.* the changing patterns of temperatures and precipitations, is increasingly recognized as one of the global challenges of our time. Its growing and global environmental and socio-economic impacts weigh significantly on the current international agenda and on national policymaking. Its impact may however vary significantly according to the level of economic development, with low- and middle-income countries bearing a disproportionate cost, even though their low carbon emissions have contributed only marginally to temperature rises, and, in some cases, help mitigate it. This combination of high impact of and low historical contribution to climate change may imply different priorities between mitigation and adaptation policies in developing countries, in particular using policy toolkits focusing on providing rapid economic growth to ensure economic convergence with developed countries and to reach the Sustainable Development Goals. These policy dilemmas for developing countries between increasing living standards and limiting greenhouse gases (GHG) emissions, and the risk of collective action failures arising from differences in development levels, were recognized by the 2015 Paris Climate Agreement which includes annual transfer commitments from advanced economies to developing countries amounting to 100 billion US dollars.

In this article, we examine the macroeconomic consequences of climate change in developing countries. The recent and rapidly growing literature that links temperatures and precipitations to output growth already points to a negative effect on economic growth in the vast majority of both developed and developing countries (Dell et al., 2012, 2014), with possible accelerating and cumulative non-linear effects (Burke et al., 2015c). Using the local projections method with a quadratic specification, Acevedo et al. (2020) also find that temperature hikes reduce output growth. Kahn et al. (2021) use an autoregressive distributed lag (ARDL) approach, without quadratic term, but assess the macroeconomic effect of temperature deviations from their historical norms, instead of temperature levels. Because of the distinct characteristics of low- and middle-income countries (higher demographic growth, lower levels of development and resilience, lower institutional quality), the impact of climate on economic growth (or development, proxied by GDP per capita) may however differ markedly from that in high-income countries both in terms of scope and transmission mechanisms.

To address these issues, we chose to focus on assessing the effect of global warming, defined as sustained positive temperature deviations from their historical norms, on real GDP and real GDP per capita growth, combining economic and climate data to obtain a panel of 126 low- and middle-income countries over the period 1960–2017. We control for sustained precipitations deviations from their historical norms to assess whether climate change effects on output mostly stem from global warming or precipitations.

To complement our analysis, we shed light on the transmission channels by decomposing the GDP into its demand and sectoral components. Finally, we test the impact of policy variables of particular interest for developing countries to assess how they could be effective in attenuating the macroeconomic effect of global warming on output.

This article contributes to the existing literature by introducing significant methodological innovations. First, we depart from earlier studies whose central estimates are obtained from samples that include countries from all income levels. These may underestimate the impact on developing countries, deeply exposed to climate change risks. To address the crucial financial policy and international aid issues to achieve the Sustainable Development Goals, we focus exclusively on low- and middle-income countries.

Second, we abandon the hypothesis that labour productivity is the main transmission channel and consider the possibility of transmission through land productivity. Therefore, we construct the country-year climate observations adopting an agnostic approach and we compute them as the unweighted average of gridded climate observations within land boundaries.

Third, we depart from the use of weather shocks and adopt a variant of the local projections method introduced in Ramey and Zubairy (2018) to capture the effects of sustained temperature and precipitations deviations from their historical norms on per capita output growth over different horizons. In addition to being closer to the policy question of interest, *i.e.* assessing the effects of climate change instead of weather shocks, this strategy may reduce the bias introduced by the use of the contemporary shock while controlling for the forward values of the independent variable within the horizon (Ramey and Zubairy, 2018).

Fourth, we complement this analysis by inspecting the underlying transmission mechanisms, both on the demand and the supply sides, before discussing the role of policy variables. Our results provide additional insights on how climate change affects economic growth in developing countries

In a first exercise, we find that global warming has a substantial and sustained negative impact on GDP (and GDP per capita) growth in developing countries. In the median country, a sustained 1°C increase in temperature lowers real GDP per capita annual growth rate in 1.25 percentage points (0.82–1.69 p.p., 90% confidence interval), while the effect of precipitation deviations is not economically significant, in line with recent studies. We then confirm the robustness of this result by presenting a series of tests that consist in excluding China, Russia and India, three countries which have had a non-negligible contribution to climate change and which could introduce an issue of reverse causality, using real GDP instead of real GDP per capita as a dependent variable, controlling for the occurrence of natural disasters, the levels of temperatures and precipitations and the effects of terms of trade movements, using Driscoll and Kraay standard errors, and adding country-specific linear and quadratic time trends to control for gradual changes to countries' growth rates that may be due to country-specific time-varying factors.

In the second exercise on transmission mechanisms using both demand and sectoral components, we find that global warming increases the relative share of private consumption and decreases that of investment, possibly reflecting more binding subsistence requirements in a context of a declining output and income. We also find that global warming leads to an increase of the share of the agricultural value-added in GDP at the expense of industrial value-added, despite a decline in agricultural output growth, leading to a potential reinforcement of the "food problem": because of subsistence requirements, developing countries tend to devote a higher share of their relatively scarce resources to food production and consumption. Both the sectoral and the demand decomposition of GDP indicate a shift towards short-term gains at the cost of investment, economic diversification and future prosperity.

In a third exercise, we discuss the role of several potential adaptation policies, such as electrification, deforestation, coal consumption, exchange rate regime or institutional quality, to attenuate the negative effect of global warming on output growth in developing countries. We do not consider the effects of such policies on climate change itself through increased greenhouse gases emissions, *i.e.* whether they are compatible or not with mitigation efforts. Some of these policies could therefore be considered as maladaptation policies. Causal inference from this exercise is more difficult, but the results seem to indicate that a higher level of development is associated with a smaller effect of global warming on per capita output growth.

In sum, since our results also indicate that development becomes more difficult to achieve as temperatures rise, we find that global warming reinforces development traps, threatens the gains in living standards, particularly since the beginning of the 21st Century, and will hinder further adaptation to climate change in developing countries.

The remainder of the article is organized as follows. Section 2 reviews the literature and Section 3 describes the data and introduces some stylized facts on climate change.

Section 4 details the empirical strategy. Section 5 presents the results of the global warming effects on output as well as robustness checks, Section 7 analyses the transmission mechanisms and Section 7 discusses the effects of adaptation policies. Finally, Section 8 concludes.

2 Review of the Literature

An early topic of interest (Ibn Khaldun, 1377; Montesquieu, 1748), the climate-economic growth nexus has become a research topic of paramount importance with increasing global concerns about climate change. Some literature strings highlight the role played by geography and climate conditions for economic development (Diamond, 1997; Sachs, 2003), while others, such as Acemoglu et al. (2002) and Rodrik et al. (2004), argue that institutions are the ultimate determinant of development, at least within the historical human climate niche (Xu et al., 2020). Easterly and Levine (2003) point out that the impact of geography on development can be explained by how climate conditions and disease environments affect the institutions that are built. These authors, as well as observation, indicate that there is no simple and deterministic relation between climate and economic growth, and a rapidly growing string of theoretical and empirical research has uncovered a large scale of micro and macro transmission channels between climate and economic activity. This ample literature on the relation between economic activity and the main variables of climate change, temperatures and precipitations, is reviewed in Dell et al. (2014), Carleton and Hsiang (2016), Heal (2017) and Auffhammer (2018), among others.

2.1 Structural Macroeconomic Models

The main theoretical approach to analyze the relation between the economy and the climate, pioneered by Nordhaus (1977), is to build comprehensive, partial or general equilibrium, quantitative models (Integrated Assessment Models - IAMs). These models include the DICE model (Nordhaus, 1992, 2008), as well as a great number of other specifications introduced in Rezai et al. (2012), Kompas et al. (2018), Barnett et al. (2020) and Alestra et al. (2022). In these models, economic activity interacts with the climate through GHG emissions from production and a climate damage function. Such approaches are well-suited to capture cross-country or cross-region heterogeneity (Bretschger and Valente, 2011) but are highly sensitive to underlying assumptions on the discount factor (Dietz et al., 2020, as already stressed in the earlier Nordhaus/Stern debate), the exclusion of the financial sector (Lamperti et al., 2019) or risk incorporation (Cai et al., 2013). They are more likely to underestimate damages than empirical alternative approaches (Lancesseur et al., 2020), leading to potentially significant underestimations of the optimal carbon price. This has led authors to question their relevance (Pindyck, 2013) or find agents-based alternatives with stochastic individual weather shocks (Lamperti et al., 2018). The specification and calibration of the damage function, which captures the economy's response to rising temperatures, are critical (Weitzman, 2010) and entail high uncertainty (Tol, 2002).

2.2 Calibration of the Damage Function

Recent empirical literature has therefore sought to provide more robust calibrations of the damage function. Such studies aim at estimating economic damages arising from high frequency or annual weather shocks over a large palette of transmission channels. The relevance of such transmission channels may vary from region to region and according to economic development.

The agricultural sector is both highly sensitive and vulnerable to climate change. In developed countries, Deschênes and Greenstone (2007) project a modest positive effect of increased temperatures and precipitations on agricultural output in the US. Using Californian data and an instrumental variable approach, Hagerty (2020) finds a decline in crop production when water is scarce and inefficient adaptation strategies to raise revenues. Burke and Emerick (2016) also find little effects of adaptation in the U.S. agricultural sector, with strong negative impacts of temperature hikes on crop yields.

The impact of climate change on the agricultural sector is crucial in developing countries, where this sector represents a larger share of output and employment and the key to subsistence for the most vulnerable populations exposed to both poverty, malnutrition and the direct effects of climate change. Taraz (2018) finds evidence of farmers adaptation in India, but with limited success in the face of extreme heat rises. Aragón et al. (2021) find that farmers in Peru adapt to climate change through increased land use to cope with lower production from increased temperatures, but at the cost of future productivity. Auffhammer and Kahn (2018) review more extensively the challenges that farmers in developing countries may need to tackle in order to adapt to climate change, which include higher income volatility, bad harvests, animal malnutrition and crop choice, among others.

Climate change may also affect human capital and hence labour productivity. Using U.S. data, Barreca et al. (2015) find that abnormally high temperatures are associated with lower fertility rates 9 months later, while Barreca and Schaller (2019) find that hot weather increases the risk of shorter gestation. Kim et al. (2019) also evidence a negative relation between extreme temperatures and maternal and infant health, and Ranson (2014) finds a positive relation between temperatures and criminal acts. Sun et al. (2019) show that climate change will induce an increase in health heat stress that will primarily affect developing countries.

Another strand of the literature focuses on the relation between weather shocks and conflicts. In a historical perspective, Christian and Elbourne (2018) find that lower precipitations increased the likelihood of Roman emperors assassination because of military agitation at the frontiers due to starvation, and Fenske and Kala (2015) argue that the African slave trade increased in cold years due to cost reductions stemming from lower mortality and higher yields. For more recent periods, Burke et al. (2009) find strong linkages between civil war and temperature in Africa, with warmer years leading to significant increases in the likelihood of war. McGuirk and Nunn (2020) and Eberle et al. (2020) find a relation between precipitation and temperature shocks, respectively, and conflict between herders and farmers. The mechanisms imply competition for scarce resources, and the results suggest that appropriate institutions help mitigate these negative effects of weather shocks. The literature review by Hsiang and Burke (2014) and the meta-analysis by Hsiang et al. (2013) conclude that the magnitude of climate's influence on modern conflict is both substantial and highly statistically significant, with a vast set of possible transmission mechanisms.

Because of this diversity, the enumerative approach, by summing up sectoral effects, has not been successful in providing better calibrations of the damage functions (Lancesseur et al., 2020). Hence, a recent strand of the literature has focused on various aggregate macroeconomic variables, such as real GDP and real GDP per capita, to disentangle the net economic effects of weather shocks.

2.3 Empirical Macroeconomic Approaches

Macroeconometric vector auto-regressive (VAR) models have evidenced that business cycles in both high-income and developing small island countries are vulnerable to weather shocks and natural disasters (Buckle et al., 2007; Cashin and Sosa, 2013). Building an estimated dynamic stochastic general equilibrium (DSGE) model, Gallic and Vermandel (2020) show that climate matters for New Zealand's business cycle through land productivity, shift in farmers' demand for goods and real exchange rate movements.

Using sub-national data for the U.S. economy, Colacito et al. (2019) find that temperature hikes reduce GDP growth, and Hsiang et al. (2017), by looking at the probable effects of climate change on a wide set of economic outcomes, also conclude that climate change will negatively affect GDP and will increase spatial inequalities. Kalkuhl and Wenz (2020) use global sub-national aggregate data and find that weather conditions, *i.e.* annual changes in temperature levels, only affect real gross regional product growth where temperatures are high and find that an increase in global mean temperature reduces global output level, particularly in tropical regions. Using the precipitation-evapotranspiration index (Vicente-Serrano et al., 2010), Couharde and Généroso (2017) show that hydro-climatic conditions affect economic growth in predominantly agricultural developing countries. Couharde et al. (2019) provide evidence, using the same index, that the effects of El Niño and La Niña episodes on real GDP per capita in low- and middle-income countries depend on local weather conditions and are greater in tropical, humid countries.

In a highly influential paper using cross-country panel data, Dell et al. (2012) find that higher temperatures not only substantially reduce economic growth, but also have wide-ranging effects affecting the agricultural and industrial sectors, as well as political stability. Burke et al. (2015c) point out that these effects on economic activity may be cumulative and nonlinear, necessitating the use of quadratic specifications. The authors find that the effect of higher temperatures on productivity is negative in both developing and high-income countries but dwindles as economies get wealthier, and that impacts increase as temperature rises. They conclude that global income inequality is likely to increase because poorer countries are warmer, a result confirmed in Diffenbaugh and Burke (2019). Newell et al. (2021) find that these models, which incorporate temperature levels, are affected by model uncertainty. The authors conclude that temperature levels affect low-income countries' GDP and agricultural production, but not those of high-income countries.

Using the local projections method with a quadratic specification, Acevedo et al. (2017) and Acevedo et al. (2020) find that in warmer low- and middle-income countries (but not in temperate high-income countries), higher temperatures negatively affect output growth because of reduced agricultural output, suppressed productivity of workers exposed to heat, slower investment and poorer health. Abandoning the quadratic specification, Acevedo et al. (2019) conclude that adaptation policies have had a limited capacity to attenuate the negative effects of higher temperatures on output growth.

After developing a theoretical framework in which labour productivity is the main transmission mechanism, Kahn et al. (2021) use an ARDL approach with a linear specification and consider temperature and precipitation deviations from their historical norms instead of their levels. Contrary to much of the literature (Tol, 2018), the authors find that positive temperature deviations negatively affect real per capita output growth in both developing and high-income countries. Precipitation deviations have no statistically significant effects, confirming the results found in numerous studies. The fact that a large strand of the recent literature finds negative effects of temperature shocks on output growth, and not only on the level of output, increases concerns on the projected economic impacts of climate change due to the compounding effect. Burke et al. (2018), among others, discuss the economic benefits from limiting temperatures rise.

2.4 Distinguishing Climate Change from Weather Shocks

Economic activity may also be affected by natural disasters, a large proportion of which may be sensitive to climate change. Recent research has focused on short-run economic effects of (climate-related) natural disasters (Klomp and Valckx, 2014; Kousky, 2014; Lazzaroni and van Bergeijk, 2014). Skidmore and Toya (2002) find positive effects of disasters on growth, with reduced losses from disasters when the economy develops (Toya and Skidmore, 2007). Building a fictious counterfactual using the synthetic control method, Cavallo et al. (2013) find no effects of large natural disasters on growth once political turmoil is controlled for. Closing important methodological caveats of earlier studies, Strobl (2012) finds that natural disasters weigh on growth in the short-term, and Noy (2009) finds that this is particularly the case in developing countries. To take into account the endogeneity between natural disasters and socio-economic conditions (Kahn, 2005), Felbermayr and Gröschl (2014) advocate using physical measures of disasters and also find that they have negative effects on growth.

The seemingly contradictory findings on the macroeconomic effects of natural disasters may stem from the diversity of these events (Fomby et al., 2013; Loayza et al., 2012) and heterogeneous transmission mechanisms (Mohan et al., 2018). Such effects include the capital stock (Acevedo, 2016), trade flows (El Hadri et al., 2018, 2019), public finances (Lis and Nickel, 2010; Acevedo, 2014; Klomp, 2017), the financial sector (Albuquerque and Rajhi, 2019; Brei et al., 2019; Keerthiratne and Tol, 2017; Klomp, 2014), fiscal and monetary policy (Ouattara and Strobl, 2013; Klomp, 2020), household income and welfare (Carter et al., 2007; Arouri et al., 2015; Keerthiratne and Tol, 2018), aggregate welfare (Cantelmo et al., 2019) or religiosity (Sinding Bentzen, 2019).

Evidence on the effects of natural disasters on economic activity in the long run is however still inconclusive (Noy and duPont IV, 2016). While climate models' predictions about future temperatures and precipitations are uncertain (Burke et al., 2015a), these models are not able yet to predict precisely enough the future changes in the frequency and intensity of extreme natural events Hsiang and Kopp (2018). As shown in

Weitzman (2009), our inability to value the cost of cataclysmic events that occur with an unknown tiny probability might lead us to underestimate the costs of climate change.

As discussed notably in Hsiang (2016), recent research on the economic impact of climate change points to important distinctions to make between natural disasters, weather shocks and climate change. Climate change can be defined as the joint probability distribution describing the state of the multi-dimensional atmosphere, ocean, and freshwater systems (Hsiang and Kopp, 2018) whereas better identified weather shocks are specific draws from this probability distribution (Tol, 2020).

2.5 Contribution to the Literature

To reconcile the two notions of climate change and weather shocks, we first construct a horizon-specific measure of total, cumulative temperature and precipitation deviations from their historical norms. Considering temperature and precipitation deviations from their historical norm retains the advantageous econometric properties of exogenous weather shocks, as discussed in Bento et al. (2020), and taking the cumulative deviations over different horizons allows us to measure one dimension of climate change.

We then use a variant of the local projections method introduced in Ramey and Zubairy (2018) which makes it possible to capture the total response of output to a cumulative shock in temperature and precipitation deviations from their historical norms over different horizons lasting from 1 to 6 years. Specifying such sustained temperature and precipitations deviations, *i.e.* climate change instead of weather shocks, is in our view a better fit to answer the policy question of interest. It also eliminates biases associated with the inclusion of forward values of the independent variables as controls (Ramey and Zubairy, 2018).

Controlling for natural disasters also contributes to disentangle the effects of such large-scale climate-driven events on economic activity from the effects of global warming. Finally, focusing on developing countries helps us tailor our model specifications to their specific characteristics, reduce the risk of under-estimation and assess how these may affect the path to sustainable growth in a more tractable way.

3 Data and Stylized Facts

To assess the effect of global warming on economic activity in low- and middle-income countries (as defined by the 2019 World Bank classification, shown in appendix Figure 1.A.1), we construct a country-level dataset covering 126 countries over the period

1960 - 2017. Sample selection is exclusively based on data availability, and the detailed list of countries is indicated in appendix Table 2.A.1. The dataset covers three dimensions: socio-economic variables, climate-related disaster and climate variables, and carbon emissions and consumption. Appendix Table 2.A.2 lists all the data sources used in this paper.

3.1 Socio-Economic data

The main dependent variables, real GDP per capita and real GDP, are obtained from the International Financial Statistics (IFS) and World Development Indicators (WDI) dataset. The WDI dataset is also the main source for alternative dependent variables: private, public and total consumption, investment and fixed investment, imports, exports and trade balance, as well as the shares of real value added of services, manufacturing and industry. Agricultural data (Total Factor Productivity - TFP, output, inputs, labour, machinery, fertilizers and livestock) are obtained from the United States Department of Agriculture (USDA - ERS, 2019). The Human Development Index is retrieved from the UNDP - HDI (2019), commodity exports value is obtained from Gruss and Kebhaj (2019) and TFP from the Penn World Tables version 9.1 (Feenstra et al., 2015).

The total growth of a variable over a period is computed as the log difference of this variable between the end and the beginning of period.

3.2 Climate data

Monthly land temperature and precipitation data are from the University of Delaware (Matsuura and Willmott, 2019). The global dataset is gridded with a 0.5°latitude $\times$ 0.5°longitude resolution (approximately 55km near the equator) and covers the period 1900–2017. Country-level data are obtained by computing the unweighted average of all the observations within the land boundaries of each countries.

Contrary to the methodology used mostly for developed countries (Dell et al., 2012; Burke et al., 2015c; Acevedo, 2016; Kahn et al., 2021, among others), we do not weight the climate observations by local population density. In addition to endogeneity issues, particularly in long periods (due to climate-induced migration), such a strategy is not optimal in the case of developing countries where economic activity may not coincide with the distribution of population.

First, climate conditions can affect output through capital destruction during extreme events with distant impacts. For instance, El Niño costero strongly impacted the coastal regions of Southern Ecuador and Northern Peru in 2017, but most of it adverse effects, from floods and landslides, or *huaicos*, resulted from heavy rainfalls in the western slope of the Andes mountain range, in addition to the coastal areas.[2] Exceptional floods in western France in May and June 2016 were also due to heavy rainfalls upstream, while global value chains reinforce the economic relevance of remote climatic conditions.[3]

Second, the economic production might not be located where population density is high, particularly in countries that rely heavily on natural resources (e.g oil production in the Sahara desert and population close to the Mediterranean in Algeria, or the strong impact of the melting of the scarcely populated Artic sea ice). Weighting climate data by the population density might impede to capture climate variations that matter for production and economic outcomes.

Third, agricultural production, a major component of GDP in many LICs and MICs, may be determined by upstream as much as local climate conditions, especially when it relies on irrigation. The Egyptian economy, prior to the erection of the Aswan dam, provides a famous example: rainfalls in Ethiopia used to determine the fate of Egyptian farmers and Egypt's economy, while local climatic conditions, *i.e.* variation in local high temperatures and low precipitations, were of relatively little importance. Peru provides another, less extreme example, as its coastal and Andean agriculture (located in relatively highly populated areas) depends on high altitude precipitations originating from the Amazon basin, and therefore partially determined by temperatures, precipitations and winds in the Amazon basin. In this context, weighting local climate variables by population density provides no benefits in terms of identification. More importantly, both irrigated and rainfed agriculture usually occur where population density is relatively low, raising further concerns on the robustness of weighting climate observations by population density.

3.3 Carbon Dioxide Emissions

Historical data on CO_2 country emissions from the beginning of industrialization (1751 in the UK) are retrieved from Boden et al. (2017). Time series were combined (e.g. Yemen) or split (e.g. Czechoslovakia before 1992) to take into account changes or merging of states over time. Historical data from split series are based on the relative weight in the first year of their separation. The historical observations corresponding to colonies are not included.

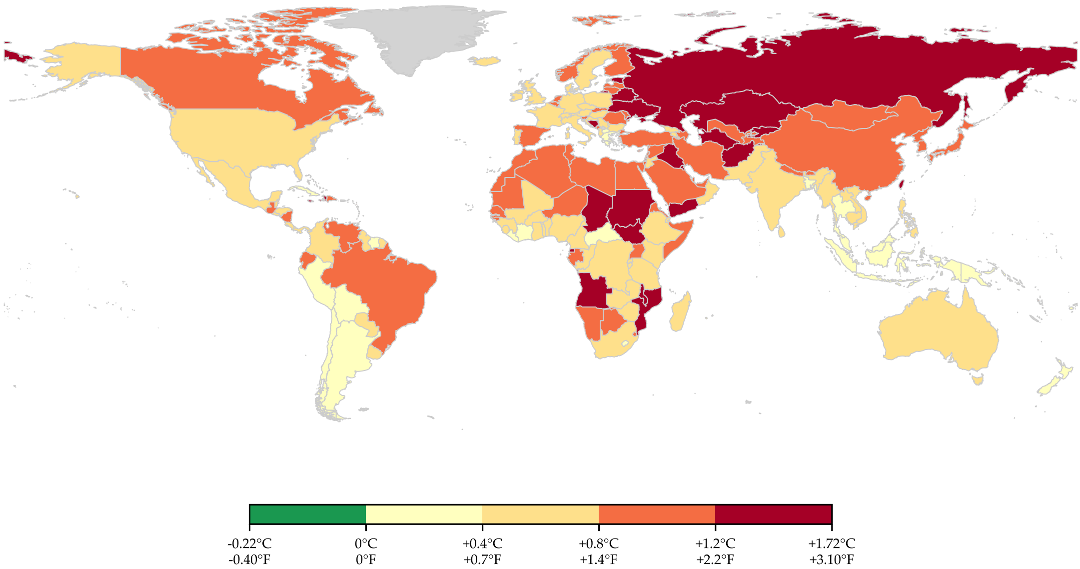
[2] As evidenced in https://www.dhn.mil.pe/Archivos/Oceanografia/ENFEN/nota_tecnica/01-2017.pdf.

[3] Floods in Thailand caused major hikes in hard drive prices globally in 2011.

Country territorial CO_2 emissions and transfers, corresponding to the difference between CO_2 consumption and territorial emissions, are retrieved from Friedlingstein et al. (2019) and allow to expand the time coverage of CO_2 emissions until 2017.

3.4 Climate Change: A Descriptive Analysis

Figure 1.1 – Yearly Temperature difference: 2001-2017 Vs. 1900-1950



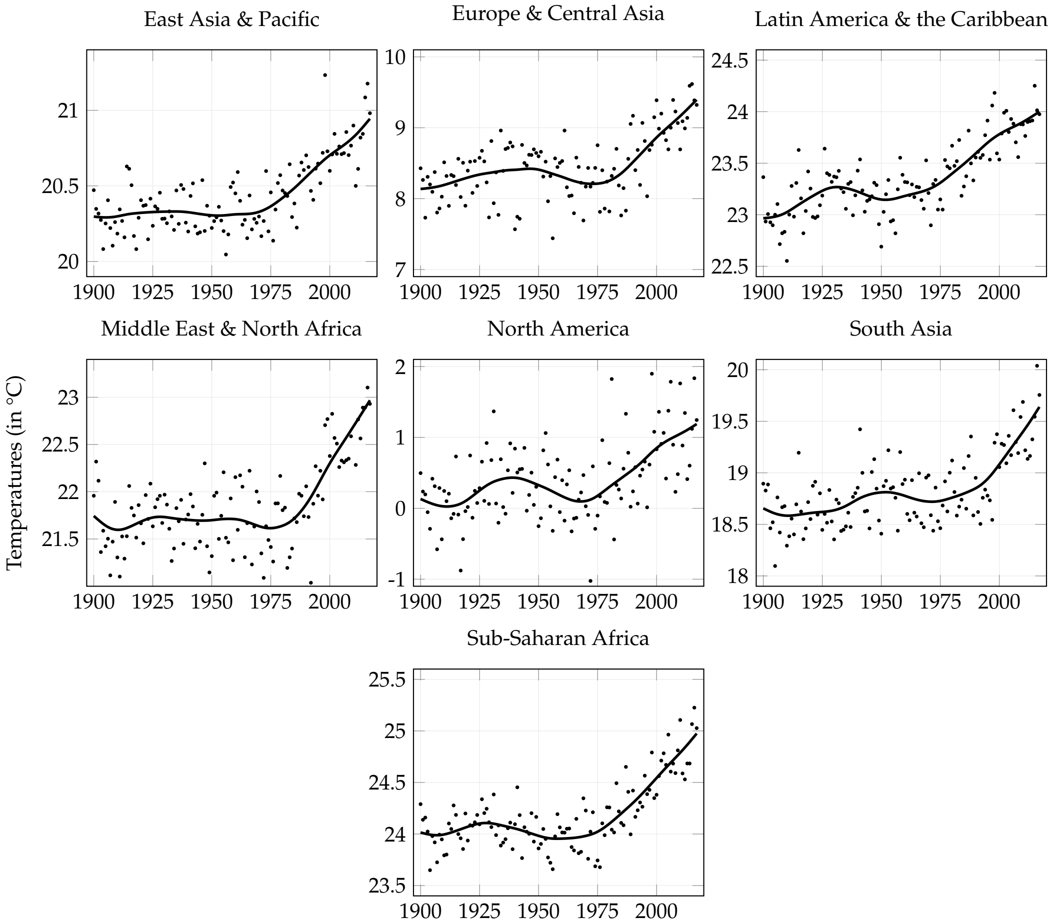
Source: Matsuura and Willmott (2019), calculation and elaboration by the authors.

There is a scientific consensus on the fact that the climate has changed since the pre-industrial period (1850–1900 according to the definition from the Intergovernmental Panel on Climate Change – IPCC). Because the data does not cover this period, we chose 1900–1950 as a reference for our sample.

Figure 1.1 shows the average mean temperature deviation between the early 21st and 20th centuries, *i.e.* between 2001–2017 and 1900–1950. Except for 6 small countries and administrative regions (with declines ranging from -0.1 to -0.22°C), all countries mean temperature have increased over time.[4] The mean temperature deviation is higher than 1°C (*i.e.* 1.8°F) in 42 countries and higher than 1.2°C (*i.e.* 2.2°F) in 24 countries, mainly from Sub-Saharan Africa, the Middle East and Central Asia, and Eastern Europe and Russia. On average, country mean temperatures are 0.75°C (1.35°F) higher in 2001–2017 than in 1900–1950.

[4]Mean temperatures have lightly declined only in Singapore (-0.22°C), Macao, Hong Kong, Comoros, Samoa and Malta

Figure 1.2 – Temperature Dynamics (1900 - 2017), by Region

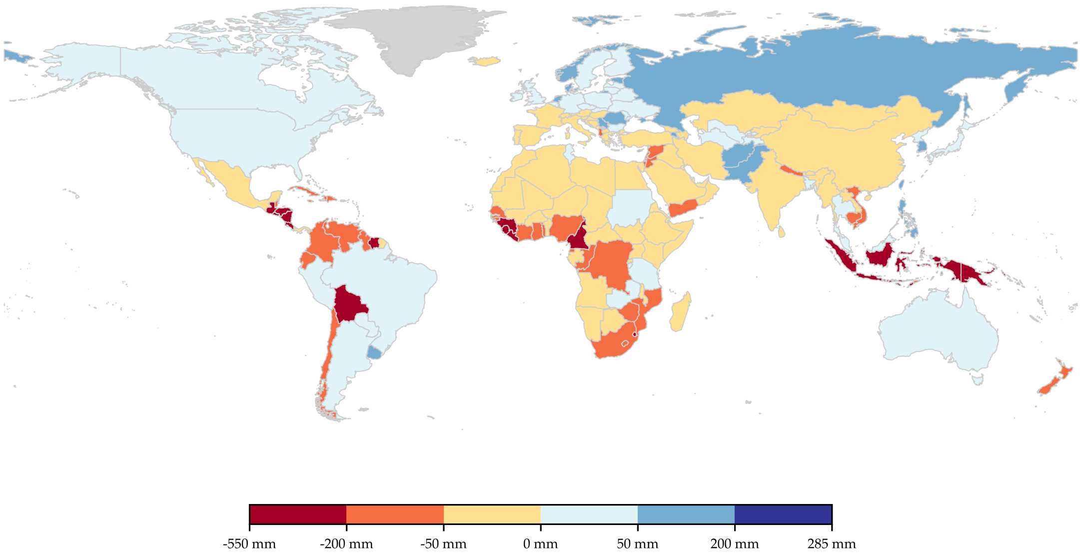


Source: Matsuura and Willmott (2019), calculations of regional temperatures by the authors using the unweighted average of country yearly mean temperatures and smoothing by the Hodrick–Prescott filter ($\lambda = 1600$).

This global increase is associated with substantial country variations, including between neighbouring countries: Mexico and Guatemala (temperature increase 1.8 times higher in Guatemala), Cuba and Haiti (6.7 times higher in Haiti), Jordan and Iraq (1.6 times higher in Iraq), the Central African Republic and Chad, Sudan and South Sudan (4.1 to 4.5 times higher).

Figure 1.2 shows the dynamic evolution of temperatures across economic regions (World Bank classification) between 1900 and 2017. Although temperature levels differ substantially between regions (and between countries within regions), a structural break can be observed in all regions between 1970 and 1980 (earlier in Latin America and the Caribbean): broadly constant until then, temperatures exhibit a positive trend until today, while the volatility of yearly mean temperature seems to decline over time (to be confirmed by further analysis).

Figure 1.3 – Yearly Precipitations difference: 2001-2017 Vs. 1900-1950



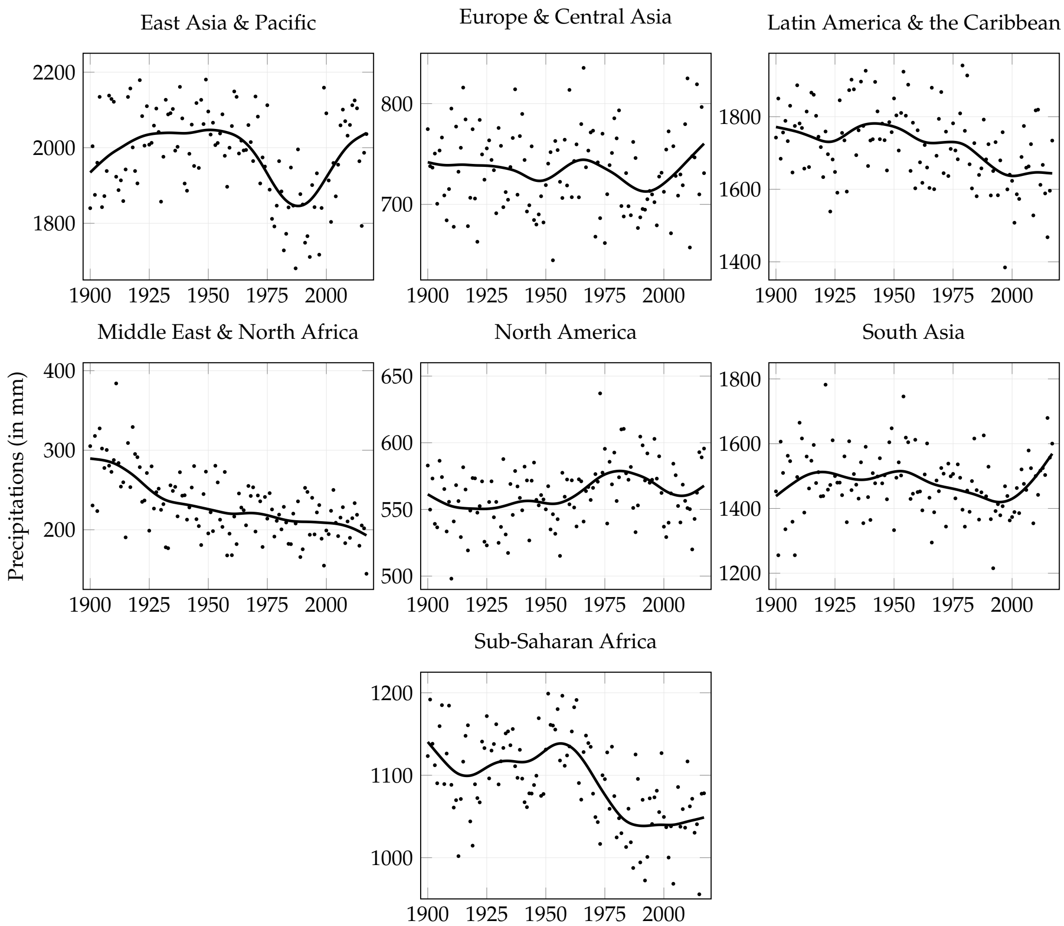
Source: Matsuura and Willmott (2019), elaborated by the authors. Units are in Millimeters.

As shown in Figure 1.3, yearly total precipitations deviation between 2001–2017 and 1900–1950 are more scattered. While precipitations have increased in 57 countries (45 mm on average), they are below historical levels in 128 countries (-83 mm on average). Country yearly precipitations have declined in 44 mm on average between the beginning of the 21st and the 20th centuries. In 14 countries, mainly located in Central America, Western Africa and Southeast Asia, this decline in absolute terms has been more dramatic and greater than 200 mm.

As evidenced in Figure 1.3 and Figure 1.4, the heterogeneity of precipitations patterns between countries and regions is greater than in the case of temperatures, and no global pattern can be detected by visual inspection. While global and country-level temperature dynamics is unequivocal, yearly and country-level precipitations observations might not be the optimal scale to detect macroeconomic effects, due to the importance of the locality and temporality of rainfalls, in line with the literature on the macroeconomic impact of climate change.

Finally, CO_2 data shows a strong divide between developing and developed countries, with strong implications for the econometric assessment of the impact of climate change on economic activity. First, there is little doubt that climate change can be attributed to human activity, and more specifically to greenhouse gas (GHG) emissions (see Bindoff et al., 2013; Cook et al., 2016; Hsiang and Kopp, 2018, among others). Figure 1.5 panel a shows that the global level of carbon dioxide (CO_2) emissions each year is at a historical peak, while Figure 1.5 panel b shows that the growth rate of global CO_2 emissions does not slow down. These patterns are problematic, notably because

Figure 1.4 – Precipitations Dynamics (1900 - 2017), by Region



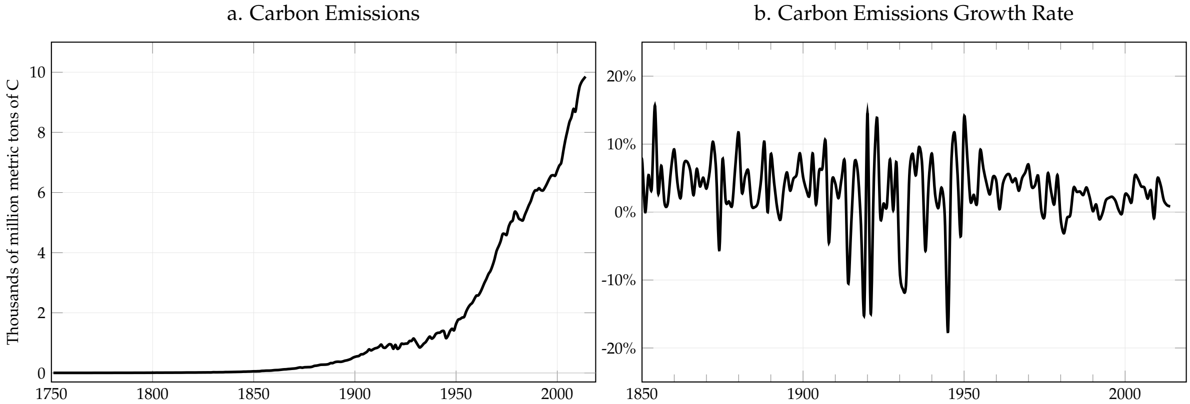
Source: Matsuura and Willmott (2019), calculations of regional precipitations by the authors using the unweighted average of country yearly total precipitations and smoothing by the Hodrick–Prescott filter ($\lambda = 1600$).

emissions at year t have an impact that will materialize for a long period (see Hsiang and Kopp, 2018, for a detailed description of the physics involved).

Second, as shown in Figure 1.6, while temperature increases and precipitation declines have generally affected middle- and low-income countries to a greater extent than high-income countries, the latter have been the primary contributor to global CO_2 emissions. The vast majority of low- and middle-income countries have only had a marginal contribution, below 1% or even 0.5% of historical global CO_2 emissions.

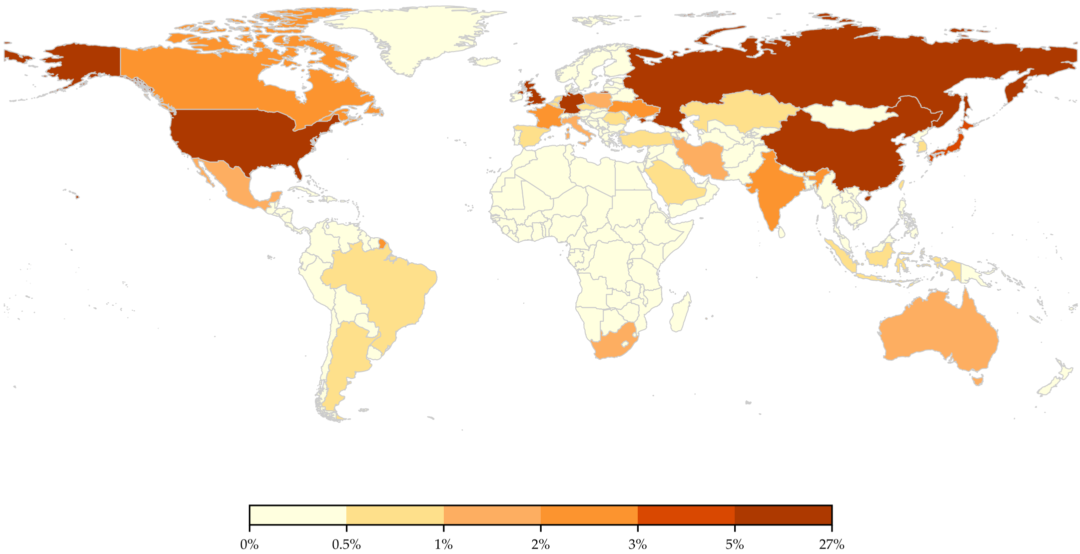
Third, while weather shocks seem to be relatively exogenous, econometric assessments of the effects of sustained climate deviations from historical norms may be biased due to reverse causality issues: economic growth, which lead to CO_2 emissions, does positively affect temperatures.

Figure 1.5 – Global Carbon Dioxide Emissions, 1751 - 2014



Sources: Boden et al. (2017), elaboration by the authors. Emissions correspond to total carbon dioxide emissions from fossil fuel consumption and cement production.

Figure 1.6 – Share of Total Historical Carbon Dioxide Emissions, in 2014



Source: Boden et al. (2017), elaborated by the authors. Emissions correspond to total carbon dioxide emissions from fossil fuel consumption and cement production.

For these reasons, assessing the effects of climate change on economic activity in low- and middle-income countries based on coefficients estimated on a global sample that includes high-income countries may lead to an underestimation of the effects of climate change. Because low- and middle-income countries have not had yet a significant impact on CO_2 emissions and therefore climate change, restricting the sample to these countries ensures the exogeneity of the dependent variables. Because three middle-income countries, China, India and Russia, have had a significant contribution to historical CO_2 emissions, these countries will be excluded from the sample in a robustness check.

4 Empirical Framework

We adapt the local projections method introduced in Jordà (2005) to assess the cumulative response of output to cumulative temperature deviations from their historical norms and separately estimate equation (1.1) for horizons $h = 0, 1, ..., 5$:

$$y_{i,t+h} - y_{i,t-1} = \theta_h \sum_{p=t}^{t+h} \widetilde{T_{i,p}} + \phi_h \sum_{p=t}^{t+h} \widetilde{P_{i,p}} + \vartheta_h \sum_{p=t}^{t+h} \widetilde{T_{i,p}}^2 + \varphi_h \sum_{p=t}^{t+h} \widetilde{P_{i,p}}^2 + \lambda \mathbf{X}'_{i,t} + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h \tag{1.1}$$

where i denotes the country and t the year. y_t denotes the log of real GDP per capita, and therefore the dependent variable $y_{i,t+h} - y_{i,t-1}$ captures the total growth of real GDP per capita in years t to $t + h$. $\widetilde{T_{i,t}}$ denotes the deviation in mean temperature of country i in year t from its historical values and $\widetilde{P_{i,t}}$ the deviation in total precipitations in year t from its historical values. In the benchmark specification, $\mathbf{X}'_{i,t}$ is a vector of control variables that include two lags of the dependent variables, $\Delta y_{t-1} = y_{t-1} - y_{t-2}$ and Δy_{t-2}, as well as two lags of the main independent variables, $\widetilde{T_{i,t-1}}$, $\widetilde{T_{i,t-2}}$, $\widetilde{P_{i,t-1}}$, $\widetilde{P_{i,t-2}}$, $\widetilde{T_{i,t-1}}^2$, $\widetilde{T_{i,t-2}}^2$, $\widetilde{P_{i,t-1}}^2$, $\widetilde{P_{i,t-2}}^2$.

This set of control variables remains parsimonious on purpose so that the estimates are not affected by the issue of over-controlling, as discussed in Dell et al. (2014). In robustness checks and alternative regressions, additional control variables are included to the vector $\mathbf{X}'_{i,t}$. α_i^h denotes country fixed effects and captures country-specific time-invariant factors, such as geography and history, that may affect real per capita GDP growth, and γ_t^h denotes time fixed effects that capture common shocks, such as the international business cycle.

Contrary to a large strand of the literature that assess the effect of temperature level on economic growth (Acevedo et al., 2020, 2019; Dell et al., 2012; Burke et al., 2015c, among others), we follow Kahn et al. (2021) and assess the effect of temperature deviations from their historical norms. This variable allows to suppress the cross-country differences in temperature levels and follows more closely the concept of climate change, while country fixed effects capture the average temperature level of each country over the period. We construct the temperature deviations from their historical norms, $\widetilde{T_{i,t}} = T_{i,t} - \overline{T_{i,1900-1950}}$, as the deviation in mean temperature of country i in year t ($T_{i,t}$) with respect to the average yearly mean temperature of country i over the period 1900–1950, in Celsius degrees (°C), and the precipitations deviation from their historical norms, $\widetilde{P_{i,t}}$, as the deviation in total precipitations in year t with respect to the average yearly total precipitations of country i over the period 1900–1950, in millimeters (mm). Because pre-industrial temperatures and precipitations are not available in the dataset we use, we consider the period 1900–1950 as the historical norm.

We define the effect of temperature deviations from their historical norms on output as the *cumulative* real GDP per capita variation in response to the *cumulative* temperature deviations from their historical norms during a given period. This empirical strategy allows us to obtain cumulative impulse - cumulative response functions and yields insight on the impact of climate change, *i.e.* sustained deviations of temperatures from historical averages, beyond short-run effects, while keeping the advantages of using random climate shocks in terms of identification (Tol, 2018). Our empirical strategy represents one step further towards estimating the macroeconomic effects of climate change in developing countries.

This strategy differs from the traditional local projections method which produces impulse response functions, *i.e.* yearly estimates of the effects of a single-period shock, or cumulative response functions, *i.e.* estimates of the cumulative effects of a single-period shock for different horizons. To make our results comparable across horizons, we annualize them in Appendix 1.B.

Most papers assessing the macroeconomic effects of climate change have used large panel data sets comprising as many countries as allowed by data availability, including when assessing the macroeconomic effects of climate change in developing countries. However, as discussed in Kahn et al. (2021), reverse causality issues are likely to arise: if climatic conditions might affect GDP, the scientific consensus argues that the reverse is true, as large quantities of CO_2 and other greenhouse gases are emitted by economic activity. As the global climate depends on recent and historical greenhouse gases emissions (Hsiang and Kopp, 2018), and because a high share of historical CO_2 emissions has been produced by high income countries (figure 1.6), our identification strategy deals with the reverse causality issue by including only low- and middle-income countries in our sample, *i.e.* those which have historically made a marginal contribution to global greenhouse gases emissions. We address potential concerns about China, Russia and India, all responsible for a significant share of historical CO_2 emissions, by excluding them from the sample as robustness checks.

5 Macroeconomic Effects of Global Warming

5.1 Main Results

Table 1.1 – Macroeconomic Effects of Temperature Deviations from their Historical Norms in Low- and Middle-Income Countries

	$h=0$	$h=1$	$h=2$	$h=3$	$h=4$	$h=5$
Panel A: Dependent variable is Real GDP per capita growth						
$\widetilde{T}$	-0.002	0.005	0.008***	0.010***	0.010***	0.011***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$\widetilde{T}^2$	-0.002	-0.005***	-0.008***	-0.009***	-0.009***	-0.010***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$\widetilde{P}$	-0.000	-0.000	-0.000*	-0.000**	-0.000**	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\widetilde{P}^2$	-0.000	-0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Obs.	5814	5684	5554	5424	5294	5164
R^2	0.08	0.12	0.15	0.15	0.15	0.16
Panel B: Dependent variable is Real GDP growth						
$\widetilde{T}$	-0.003	0.003	0.007**	0.008***	0.009***	0.010***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$\widetilde{T}^2$	-0.002	-0.005***	-0.007***	-0.008***	-0.008***	-0.008***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$\widetilde{P}$	-0.000	-0.000	-0.000*	-0.000**	-0.000**	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\widetilde{P}^2$	-0.000	-0.000	0.000	0.000	0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Obs.	5820	5690	5560	5430	5300	5170
R^2	0.08	0.11	0.13	0.14	0.14	0.14

Note: Control variables, year and country fixed effects are included in the regressions but not reported. Standard errors are in parentheses. * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

Table 1.1 presents the main estimates from equation (1.1) for each horizon, using real GDP per capita growth (Panel A) and real GDP growth (Panel B) as dependent variables. The results show a non-linear relation between temperature deviations from their historical norms and real GDP per capita and real GDP growth since the estimate for the linear term is positive and statistically significant from horizon $h = 2$ and the quadratic term is negative and statistically significant from horizon $h = 1$. As is usually found in the empirical literature that assesses the macroeconomic effects of weather shocks and climate change, the estimates for precipitations deviations from their historical norms are not statistically significant. They become statistically significant from horizon $h = 3$, but remain economically not significant.

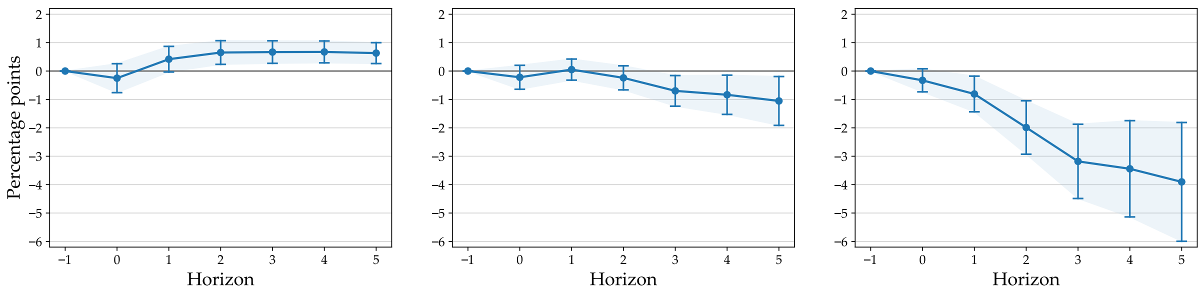
Equation (1.2) indicates the total, non-linear effect of temperatures deviations from their historical norms on real GDP per capita growth for a given year t and horizon $h \in [0, 5]$:

$$\frac{\partial \left(y_{i,t+h} - y_{i,t-1} \right)}{\partial \widetilde{T_{i,t,h}}} = \theta_h + 2\vartheta_h \widetilde{T_{i,t,h}} \tag{1.2}$$

Equation (1.2) is obtained by partially differentiating equation (1.1) with respect to temperatures deviation from their historical norms and allows to compute the cumulative impulse - cumulative response function of real GDP per capita to temperature deviations. In order to be representative of both the time and the country dimensions of the sample, the presentation of the results takes into consideration two different measures of temperature deviations from their historical norms.

Figure 1.7 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, Using Temperatures of the Full Sample

(a) 25^{th} percentile: +0.00°C at $h = 0$
(b) 50^{th} percentile: +0.34°C at $h = 0$
(c) 75^{th} percentile: +0.73°C at $h = 0$



Note: The three panels show the cumulative response of per capita real GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations is computed over the entire sample, since year 1960, and the values are as follows: +0.004°C, +0.34°C and +0.73°C for the 25^{th}, 50^{th} and 75^{th} percentiles, respectively, at $h = 0$, and +0.27°C, +1.83°C and +3.93°C °C for the 25^{th}, 50^{th} and 75^{th} percentiles, respectively, at $h = 5$. See Table 1.2 panel A for complete details on the values at each horizon.

Figure 1.7 reports the cumulative impulse - cumulative response of real GDP per capita growth to temperature deviations from their historical norms using, for each horizon, the 25^{th} percentile, the median and the 75^{th} percentile of the distribution of these temperatures deviations for the entire sample, *i.e.* since year 1960. Table 1.2 panel A reports, for each horizon, the distribution of these temperature deviations for the full sample.

Temperature deviations from their historical norms for the 25^{th} percentile have been modest over the period, amounting to 0.004°C for horizon $h = 0$ and 0.3°C for horizon $h = 5$. Figure 1.7 panel A provides evidence that such small deviations did not negatively affect real GDP per capita, and even had a slightly positive effect of 0.63 percentage points of real GDP per capita total growth over a 6 year horizon ($h = 5$), or equivalently of 0.10 percentage points of annual growth rate. At the median and the 75^{th} percentile of the distribution, temperature deviations are significantly higher and reach, respectively, +0.34°C and + 0.73°C at horizon $h = 0$, and +1.83°C and +3.93°C at horizon $h = 5$.

Table 1.2 – Distribution of Temperatures Deviations from Their Historical Norms

Panel:	*A. Full Sample of Estimations*			*B. Early 21st Century*		
Percentile:	25^{th}	50^{th}	75^{th}	25^{th}	50^{th}	75^{th}
$\widetilde{T_{h=0}}$	+0.004	+0.335	+0.729	+0.491	+0.737	+1.061
$\widetilde{T_{h=1}}$	+0.044	+0.658	+1.409	+0.981	+1.474	+2.123
$\widetilde{T_{h=2}}$	+0.100	+0.967	+2.046	+1.472	+2.211	+3.184
$\widetilde{T_{h=3}}$	+0.166	+1.248	+2.671	+1.963	+2.948	+4.245
$\widetilde{T_{h=4}}$	+0.204	+1.540	+3.309	+2.453	+3.685	+5.306
$\widetilde{T_{h=5}}$	+0.272	+1.830	+3.931	+2.944	+4.422	+6.368

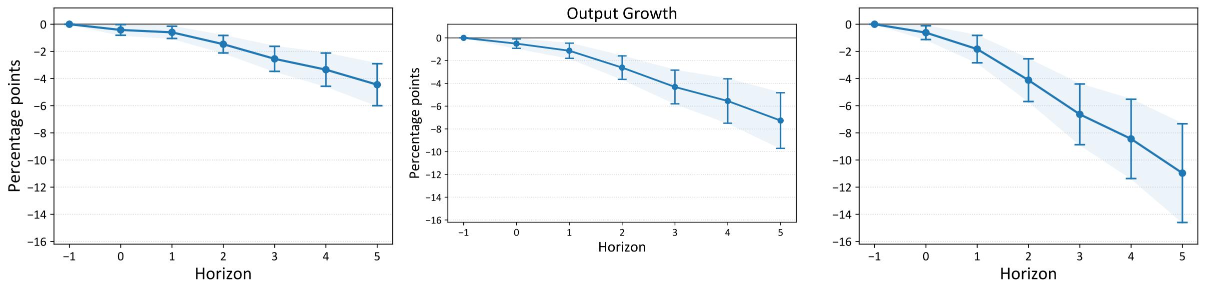
Note: All temperature changes are in °C. To convert into °F, multiply by nine-fifth. $\widetilde{T_h}$ denotes the deviation in mean temperature from its historical values during horizon h. Panel A indicates for horizons $h = 0, ..., 5$ the 25^{th}, 50^{th} and 75^{th} percentiles of the distribution of yearly mean temperature deviations from the average of yearly mean temperatures during period 1900 - 1950 in the full sample, used to obtain the results presented in Figure 1.7. Panel B indicates for horizons $h = 0, ..., 5$ the 25^{th}, 50^{th} and 75^{th} percentiles of the difference between the averages of yearly mean temperatures of the periods 2001–2017 and 1900–1950.

The results presented in Figure 1.7 panels B and C show that these positive temperature deviations have a negative effect on real GDP per capita growth. At the median (Figure 1.7 panel B), temperature hikes lead to a 1.05 percentage points decline in real GDP per capita total growth over a 6 year horizon (or a 0.16 percentage points decline in real GDP per capita annual growth rate), and to a 3.9 percentage points decline in total growth over a 6 year horizon (or a 0.60 percentage points decline in annual growth rate) at the 75^{th} percentile.

While this presentation of the results allow to understand the macroeconomic effect of global warming in developing countries during the period 1960–2017, it is not fully representative of each country's individual experience, since a country is not necessar-

Figure 1.8 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, Using Temperatures of the Full Sample Period

(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



Note: The three panels show the cumulative response of per capita real GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. The values are as follows: +0.49°C, +0.74°C and +1.06°C for the 25^{th}, the 50^{th} and the 75^{th} percentiles, respectively, at $h = 0$, and are multiplied by $h + 1$ for each horizon $h > 0$. See Table 1.2 panel B for complete details on the values at each horizon.

ily in the same category of the distribution each year and at each horizon.[5] Furthermore, the materialization of climate change we are interested in, global warming, was not perceived yet at the beginning of the period.

Figure 1.8 also reports the cumulative impulse - cumulative response of per capita output to temperature deviations from their historical norms and the coefficients θ_h and ϑ_h are still estimated by equation (1.1) using the full sample, but the temperature deviations from their historical values correspond to the 25^{th} percentile, the median and the 75^{th} percentile of the country average mean temperature deviations between the periods 2001–2017 and 1900–1950 presented in Figure 1.1. Since these temperature deviations are an annual average over a 20-years period, the mean temperature deviation is multiplied by $h + 1$ for horizons $h > 0$ (*i.e.* the number of years of each horizon), implicitly assuming that yearly temperature deviations are constant over the horizon.[6] The distribution of this variable is reported in Table 1.2 Panel B. For simplicity, and because it is more reperesentative of each country's recent and ongoing exeprience, the remainder of the paper uses this distribution of temperature deviations.

The results presented in Figure 1.8 show the recent macroeconomic effects of global warming in developing countries and evidence that these negative effects are large and have increased in the most recent period. Temperatures increases for the period

[5]For example, in a given year t, country i can be below the 25^{th} percentile for $h = 0$ if year t is relatively cold, and above the 50^{th} percentile for $h = 1$ if year $t + 1$ is relatively warm.

[6]Taking a 20 year average also allow to rank a country in a fixed place of the distribution for all years and all horizons.

2001–2017 are so high that countries at the 25^{th} percentile, the median and the 75^{th} percentile of the distribution of temperatures hikes have all experienced significant GDP per capita loss, implying that recent temperatures hikes are already well beyond the tipping point of the inverted U-shape relation between real GDP per capita growth and temperature deviations from their historical norms.

The results are statistically significant from horizon $h = 0$ for the country at the 25^{th} percentile, the median and the 75^{th} percentile of the distribution. The country at the 25^{th} percentile of the distribution, which has experienced an average temperature deviation of 0.49°C in 2001–2017 from its historical norms, loses on average 4.45 percentage points of real GDP per capita total growth over a 6 year horizon ($h = 5$), which corresponds to a 0.76 percentage points decline in real GDP per capita annual growth rate. These loss of real GDP per capita total growth amount to 7.26 percentage points for the median country over a 6 year horizon (*i.e.* a 1.25 percentage points loss in annual growth rate) and 10.97 percentage points for the country at the 75^{th} percentile of the distribution (*i.e.* a 1.92 percentage points loss in annual growth rate). The annualized results are reported in appendix Figure 1.B.1 for each horizon of the 25^{th} percentile, the median and the 75^{th} percentile of the distribution and show that the effect of temperature deviations on output growth increases in larger horizons. This indicates that the effect of sustained temperature deviations over a horizon is greater than the sum of the effects of each annual shock over that horizon.

Table 1.3 column (1) reports the estimated coefficients used in Figure 1.7 and Figure 1.8. At horizon $h = 5$, the effect of temperature deviations from their historical norms on real GDP per capita is non-linear: positive for small temperature deviations but negative for cumulative deviations greater than a total of 0.55°C over six years.

Contrary to much of the related literature, precipitations deviations from their historical norms appear to also have a statistically significant non-linear effect, since the coefficients of both the linear and quadratic terms are negative and significant. However, the results indicate that these deviations do not have economically significant effects: a one-litre cumulative deviation in annual precipitations over the six years horizon leads only to a 0.0012 percentage point decline in real GDP per capita total growth. This absence of macroeconomic effect of precipitations is a common result in the empirical literature and might be due to aggregation issues at the country level (Damania et al., 2020).

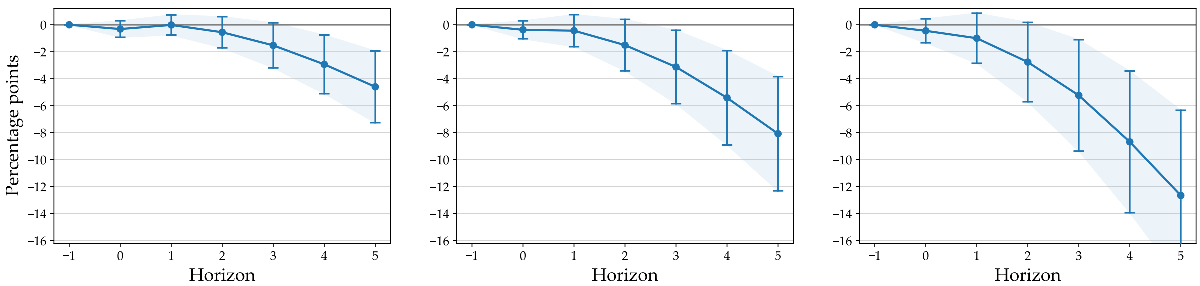
The fact that none of the coefficients are statistically significant at horizon $h = 0$ while all are at horizon $h = 5$ evidences that sustained changes in weather conditions, *i.e.* a variable that captures more closely the materialization of climate change, impact economic output beyond the short-term effects of weather shocks.

To assess whether temperature deviations from their historical norms have differentiated effects in countries with the lowest level of income per capita, we add interaction terms to equation (1.1) where the indicator function $\mathbb{1}_{(\text{low inc.})}$ takes the value of 1 if country i at year t has an income level below the 33rd percentile of the sample for that year. This definition is broadly consistent with the low-income category of the World Bank and this approach is more flexible than using World Bank or IMF lists of countries. After this modification, equation (1.1) is transformed as indicated in equation (1.3):

$$
\begin{aligned}
y_{i,t+h} - y_{i,t-1} = {} & \theta_h \sum_{p=t}^{t+h} \widetilde{T_{i,p}} + \vartheta_h \sum_{p=t}^{t+h} \widetilde{T_{i,p}}^2 + \zeta_h \sum_{p=t}^{t+h} \widetilde{T_{i,p}} \times \mathbb{1}_{\textit{(low inc.)}} + \kappa_h \sum_{p=t}^{t+h} \widetilde{T_{i,p}}^2 \times \mathbb{1}_{\textit{(low inc.)}} \\
& + \phi_h \sum_{p=t}^{t+h} \widetilde{P_{i,p}} + \varphi_h \sum_{p=t}^{t+h} \widetilde{P_{i,p}}^2 + \iota_h \sum_{p=t}^{t+h} \widetilde{P_{i,p}} \times \mathbb{1}_{\textit{(low inc.)}} + \eta_h \sum_{p=t}^{t+h} \widetilde{P_{i,p}}^2 \times \mathbb{1}_{\textit{(low inc.)}} \\
& + \lambda \mathbf{X'}_{i,t} + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h
\end{aligned}
\tag{1.3}
$$

Figure 1.9 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP in Lowest Income Countries, Using Recent Temperatures

(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



Note: The three panels show the cumulative response of per capita real GDP to a 1 °C increase in temperatures deviation from their historical norms in countries with an income per capita level below the 33th percentile of the sample. The distribution of the temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. The values are as follows: +0.49°C, +0.74°C and +1.06°C for the 25^{th}, the 50^{th} and the 75^{th} percentiles, respectively, at $h = 0$, and are multiplied by $h + 1$ for each horizon $h > 0$. See Table 1.2 panel B for complete details on the values at each horizon.

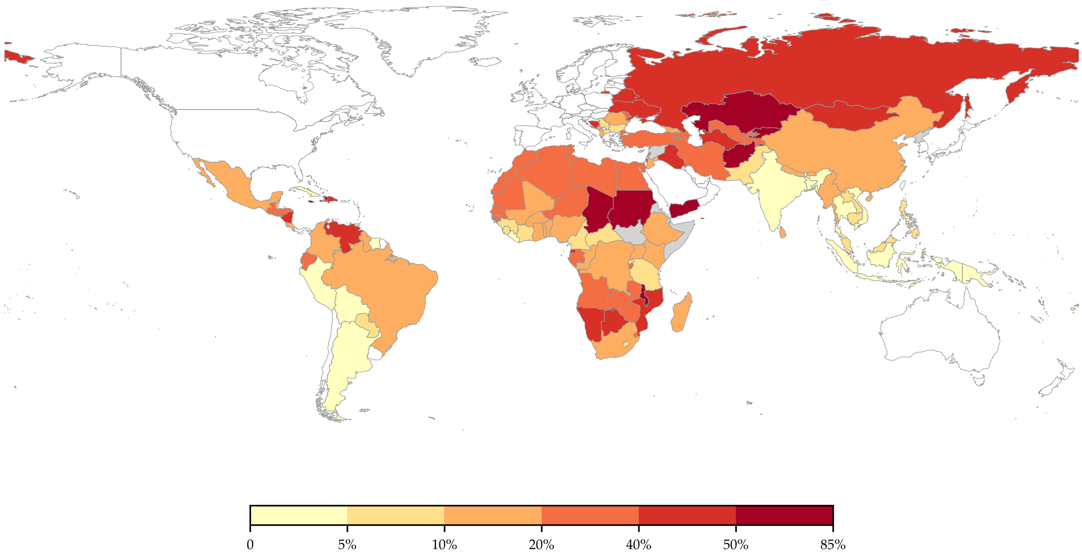
Equation (1.4) indicates the total, non-linear effect of temperatures deviations from their historical norms on real GDP per capita growth in countries with the lowest level of income per capita for a given year t and horizon $h \in [0, 5]$:

$$\frac{\partial\left(y_{i,t+h}-y_{i,t-1}\right)}{\partial\widetilde{T_{i,t,h}}}=\left(\theta_h+\zeta_h\right)+2\left(\vartheta_h+\kappa_h\right)\widetilde{T_{i,t,h}} \tag{1.4}$$

Figure 1.9 reports the effects of recent global warming in countries with the lowest level of income per capita and appendix Table 1.B.1 reports the estimates. Uncertainty increases slightly around the estimates, but these remain statistically significant for horizons $h = 3, 4$ and 5 and close to the estimate of the full sample, indicating that effects in countries with the lowest income do not differ from the effects in middle-income countries.

5.2 Cumulative Effects of Past Climate Change on Actual Income per Capita

Figure 1.10 – Cumulative Real GDP per Capita Loss due to Global Warming (1960–2017)



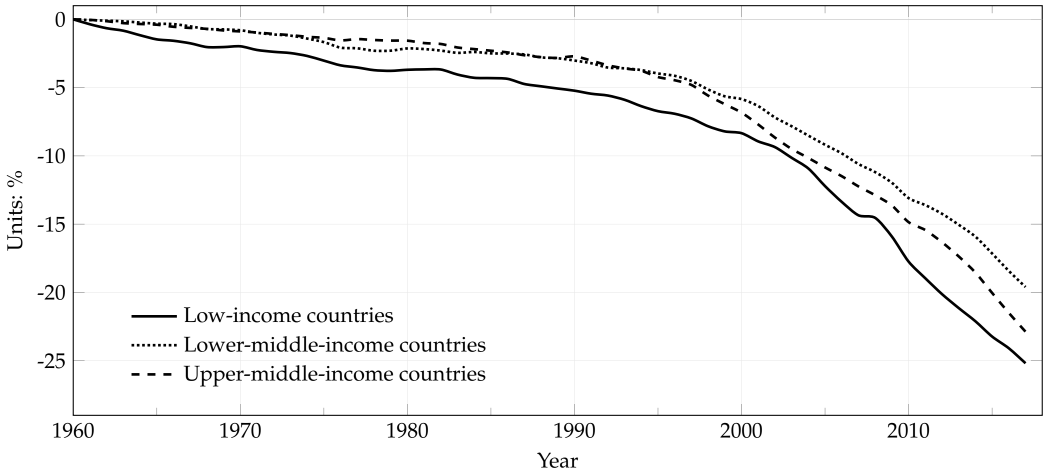
Source: elaborated by the authors. Countries in gray have missing data, countries in white are not included in the sample. The Figure indicates the cumulative loss in real GDP per capita in 2017 with respect to a counterfactual scenario characterized by mean annual temperatures equal to the historical norm (1900–1950) in each year throughout the period (1960–2017).

Estimates reported in Table 1.1 allow to compute for each country and each year the loss in real GDP per capita growth due to temperature deviations from their historical norms and build a counterfactual growth rate corresponding to a scenario in which temperature levels equal to historical norms. We use the estimates for horizon $h = 5$ and then annualize the losses. The counterfactual growth rates can then be compounded to build a counterfactual scenario for the level of real GDP per capita of each country.

Figure 1.10 reports the difference, expressed in percent, between the counterfactual level of real GDP per capita, absent of global warming, and the observed level.

Real GDP per capita losses with respect to the counterfactual scenario amount to 22% on average, but these losses are unevenly distributied, reflecting differences in temperature hikes across countries. The mose affected regions appear to be Central Asia, Austral, Saharan and Sahelian Africa as well as the Caribbean. Ten countries (dark red in Figure 1.10) have experienced losses amounting to 50% or more of the real GDP per capita of the counterfactual scenario. The magnitude of these macroeconomic effects are comparable to the findings in Ortiz-Bobea et al. (2021) for the agricultural sector and in Diffenbaugh and Burke (2019), which finds a median loss exceeding 25% for the 1961—2010 period.

Figure 1.11 – Real GDP per Capita Loss due to Global Warming, by Income Category



Source: elaboration by the authors. The figure indicates for each income category the unweighted average of countries' cumulative loss in real GDP per capita with respect to a counterfactual scenario characterized by mean annual temperatures equal to the historical norm (1900–1950). Income categories correspond to the 2019 World Bank classification.

Figure 1.11 shows the dynamics of real GDP per capita losses since 1960 in developing countries, according to their relative income levels.

In all income groups, real GDP per capita losses have accelerated around year 2000 and amounted to 20 to 25% of their levels in the counterfactual scenario, *i.e.* absent of climate change. The economic impacts of global warming are however slightly higher in low-income countries, reflecting higher temperature rises on average. This suggests additional challenges for this group of countries given their lower resilience and higher socioeconomic vulnerability: a given macroeconomic impact has larger consequences on their ability to ensure sustainable development (see the policy Section 7).

5.3 Robustness

Table 1.3 column (1) recalls the baseline estimates and columns (2) to (8) summarize a series of robustness checks for horizons $h = 0$ and $h = 5$. The dependent variables are multiplied by 100 so that the estimates can be interpreted as percentage points. The upper parts of Panel A and Panel B indicate the estimates using equation (1.1) and the bottom part of each panel indicates the effects at the 25^{th}, the 50^{th} and the 75^{th} percentiles of the distribution of country average mean temperature deviations between the periods 2001–2017 and 1900–1950, using equation (1.2). The respective cumulative impulse - cumulative response functions that detail the results for all horizons and use the same distribution for temperature deviations are presented in Appendix Figure 1.B.2 and Figure 1.B.3.

Table 1.3 column (2) reports the results excluding China, India and Russia from the sample and shows that, despite their relatively high contribution to historical global carbon emissions, including these countries to the sample does not lead to biased results since the estimates are close to the baseline estimates, reported in column (1). Column (3) reports the estimates with Driscoll and Kraay standard errors, that are robust to cross-sectional dependence and autocorrelation, additionally to heteroskedasticity (Driscoll and Kraay, 1998). Statistical significance decreases but remains from horizon $h = 2$ at the 25^{th} percentile and from horizon $h = 1$ at the median and the 75^{th} percentile, as shown in appendix Figure 1.B.2 panel B.

Céspedes and Velasco (2014) and Fernández et al. (2018) argue that commodity export value have large effects on developing countries' business cycle. Because this variable may be affected by weather shocks, especially when the country is pricemaker in global markets, it may confound the effects of weather shocks on economic output. Table 1.3 column (4) reports the estimates controlling for commodity export value contemporary growth rate and its two lags. The results, also reported in appendix Figure 1.B.2 panel C, show that the effect of temperature deviations from their historical norms on real GDP per capita increases while the standard errors shrink, reinforcing therefore the baseline results.

Since the effect of climate variables deviations from their historical norms on economic output might depend on their level, Table 1.3 column (5) reports the estimates controlling for temperature and precipitations levels.[7] Both the estimates and standard

[7] Including the quadratic terms for temperature and precipitations levels leads to similar results, available from the authors upon request.

Table 1.3 – Macroeconomic Effects of Temperature Deviations from their Historical Norms in Low- and Middle-Income Countries: Main Results and Robustness Checks

Figure:	Fig. 1.8 (1)	Fig. 1.B.2 (2)	Fig. 1.B.2 (3)	Fig. 1.B.2 (4)	Fig. 1.B.2 (5)	Fig. 1.B.2 (6)	Fig. 1.B.3 (7)	Fig. 1.B.3 (8)
Panel A: Contemporary effects ($h = 0$)								
$\widetilde{T}$	-0.250	-0.267	-0.250	-0.697**	-0.250	-0.061	-0.312	0.141
	(0.311)	(0.315)	(0.320)	(0.326)	(0.311)	(0.181)	(0.312)	(0.296)
$\widetilde{T}^2$	-0.174	-0.193	-0.174	0.003	-0.174	-0.096	-0.169	-0.371*
	(0.187)	(0.191)	(0.237)	(0.193)	(0.187)	(0.118)	(0.187)	(0.190)
$\widetilde{P}$	-0.000	-0.000	-0.000	0.000	-0.000	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\widetilde{P}^2$	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Obs.	5814	5681	5814	5381	5814	8298	5820	5814
R^2	0.08	0.08	-	0.07	0.08	0.09	0.08	0.13
At 25^{th}	-0.421*	-0.456*	-0.421**	-0.694***	-0.421*	-0.155	-0.479**	-0.223
percentile	(0.238)	(0.243)	(0.202)	(0.244)	(0.238)	(0.158)	(0.239)	(0.228)
At 50^{th}	-0.506**	-0.551**	-0.506**	-0.692***	-0.506**	-0.203	-0.562**	-0.405*
percentile	(0.250)	(0.256)	(0.224)	(0.252)	(0.250)	(0.176)	(0.250)	(0.245)
At 75^{th}	-0.619**	-0.676**	-0.619*	-0.690**	-0.619**	-0.266	-0.672**	-0.646**
percentile	(0.309)	(0.317)	(0.323)	(0.309)	(0.309)	(0.222)	(0.310)	(0.313)
Panel B: Cumulative effects ($h = 5$)								
$\widetilde{T}$	1.148***	1.165***	1.148**	0.759***	1.345***	0.254	0.975***	3.120***
	(0.279)	(0.282)	(0.525)	(0.277)	(0.303)	(0.164)	(0.281)	(0.310)
$\widetilde{T}^2$	-0.951***	-0.937***	-0.951**	-0.990***	-0.959***	-0.264**	-0.845***	-2.057***
	(0.188)	(0.190)	(0.371)	(0.182)	(0.187)	(0.111)	(0.189)	(0.238)
$\widetilde{P}$	-0.001**	-0.001**	-0.001	-0.001	-0.001**	-0.001**	-0.001*	-0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\widetilde{P}^2$	0.000	0.000	0.000	0.000**	0.000	0.000	0.000**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Obs.	5164	5046	5164	4756	5164	7376	5170	5164
R^2	0.16	0.16	-	0.15	0.16	0.11	0.14	0.40
At 25^{th}	-4.453***	-4.352***	-4.453**	-5.071***	-4.300***	-1.300**	-4.002***	-8.992***
percentile	(0.939)	(0.956)	(2.019)	(0.909)	(0.944)	(0.603)	(0.946)	(1.244)
At 50^{th}	-7.265***	-7.122***	-7.265**	-7.998***	-7.134***	-2.081**	-6.501***	-15.074***
percentile	(1.485)	(1.510)	(3.095)	(1.439)	(1.487)	(0.926)	(1.496)	(1.939)
At 75^{th}	-10.967***	-10.768***	-10.967**	-11.851***	-10.865***	-3.108**	-9.791***	-23.080***
percentile	(2.210)	(2.247)	(4.525)	(2.143)	(2.210)	(1.356)	(2.226)	(2.859)

Note. The table reports the baseline results (column 1) and several robustness checks: excluding China, India and Russia (2), Driscoll and Kraay (1998) standard errors (3), controlling for commodity export value (4) and temperatures and precipitations levels (5), including high-income countries (6), taking real GDP growth as a dependant variable (7) and including vountry-specific linear and quadratic time trends (8). Control variables, year and country fixed effects are included in the regressions but not reported. Standard errors are in parentheses. Dependent variables (first difference of the logarithm of real GDP - in column 7 - and real GDP per capita - in other columns) are multiplied by 100 so that estimated coefficients can be interpreted as percentage points. Effects at the 25^{th}, 50^{th} and 75^{th} percentiles are obtained as indicated in equation (1.2). * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

errors do not significantly differ from the baseline results, confirming that the macroeconomic effects of global warming are not entirely driven by climate variables levels but instead by their change over time.

As discussed in section 4, our identification strategy relies on the exclusion of high-income countries from the sample since these countries' economic activity has been responsible for a high share of historical CO_2 emissions. Table 1.3 column (6) reports the estimates when high-income countries are also included in the sample: the estimates remain negative and statistically significant, but become significantly lower in absolute value than those obtained when the sample is restricted to low- and middle-income countries, as shown in Figure 1.B.2 panel E. Therefore, empirically assessing the impact of global warming in low- and middle-income countries based on estimates obtained from samples that include high-income countries is likely to lead to an underestimation of the negative global macroeconomic effects of climate change.

Since real GDP per capita growth rate responds to both economic and populational dynamics and because strong evidence suggests that temperatures and weather shocks do affect population dynamics (Barreca et al., 2015; Barreca and Schaller, 2019; Burke et al., 2009; Ranson, 2014; Xu et al., 2020), Table 1.3 column (7) reports the estimated effects of temperature deviations from their historical norms on the real GDP growth rate instead of the real GDP per capita growth rate. The magnitude of the effects does not vary substantially and standard errors only slightly increase, suggesting that the macroeconomic effects of temperature deviations are robust to, and surpass, the populational effects during the time-period considered. As evidenced in appendix Figure 1.B.3 panel F, these effects are not limited to the economy and reduce the growth rate of the Human Development Index.

Finally, Table 1.3 column (8) reports the estimates when year fixed-effects in equation (1.1) are reimplaced with country-specific linear and quadratic time trends to capture within-country changes over the sample period, following the approach introduced in Burke et al. (2015c). Although these trends seem less justified when considering real GDP growth rates than levels, they can control for secular stagnation and convergence dynamics. Importantly, they also capture adaptation policies implemented by each country. The estimates for temperature deviations and temperature deviations squared are significant with the expected sign, and the macroeconomic effects remain statistically significant from horizon $h = 1$, as shown in Appendix Figure 1.B.3 panel E, despite the fact that a substantial part of the climate variation is captured by the time trends. Appendix Figures 1.B.3 panel B and 1.B.3 panel C reimplace year fixed effects with a common linear and a common linear and quadratic time-trends, respectively, while appendix Figure 1.B.3 panel D includes a country-specific linear time-trend. The results from these four alternative specifications indicate that despite capturing a significant share of climate variations, linear and quadratic time trends do not fully account for the cumulative macroeconomic effects of persistent climate deviations from its historical norms.

Climate change materializes in global warming, *i.e.* sustained temperatures hikes, but also in changes in temperature variability. To capture this penomenon, we included the cumulative deviations in within-year monthly temperature standard-deviation with respect to the historical norm. The coefficients are not statistically significant and the estimates of temperature deviations from their historical norms are not altered.[8]

Cumulative temperatures and precipitations deviations from their historical norms enter regression (1.1) separately but might have joint macroeconomic effects when they combine into a dryer climate (as argued in Lemaire, 2022, for several countries in the Middle East and North Africa). We use the 6-month Standardized Precipitation-Evapotranspiration Index (SPEI) elaborated by Vicente-Serrano et al. (2010) to capture sustained droughts deviations from their historical norms and estimate equation (1.1) adding this variable as a control as well as its two lags. Our results indicate that a dryer climate negatively affects real GDP per capita growth, but the effect of sustained temperatures deviations remains unaltered.[9]

6 Transmission Channels

This section analyses the macroeconomic channels through which temperature deviations from their historical norms affect real per capita GDP growth. Each regression estimates equation (1.1) by using a different dependent variable, while keeping two lag values of real per capita GDP growth rate in the vector of control variables $\mathbf{X}'_{i,t}$. For each dependent variable y, the cumulative response functions are obtained from equation (1.2).

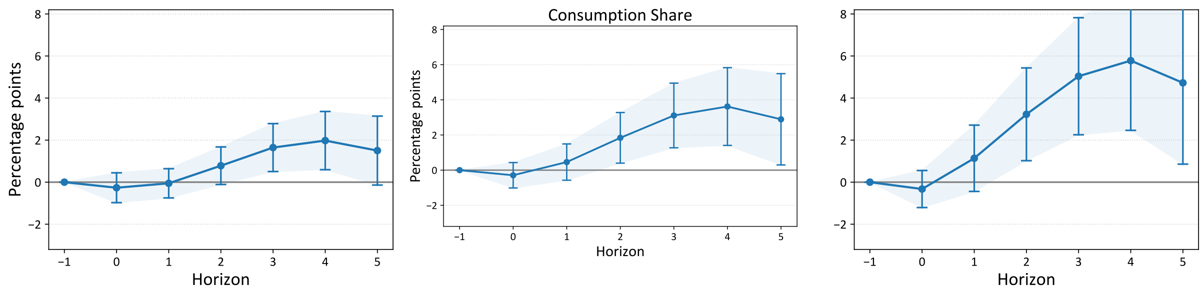
6.1 A Shift in the Composition of Demand

The results presented in Figure 1.12 show that the share of private consumption in GDP tends to increase when temperatures rise with respect to their historical norms. Furthermore, appendix Figure 1.C.1 panel A shows also a slightly positive effect of temperature hikes on the public consumption share in GDP, resulting in a higher total consumption share in GDP (Appendix Figure 1.C.1 panel B). These results suggest

[8] Results available from the authors upon request.
[9] Results available from the authors upon request.

Figure 1.12 – Cumulative Effect of Temperatures Deviations from their Historical Norms on the Share of Private Consumption in GDP

(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$

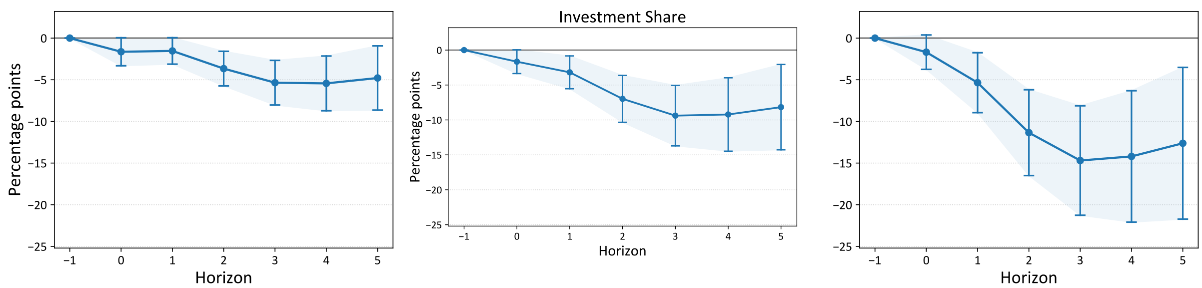


Note: The three panels show the cumulative response of the ratio of Private Consumption over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

that government might have attempted to implement adaptive and transition policies through higher public spending, but these policies have not been able to compensate for the negative impact of higher temperatures on output.

Figure 1.13 – Cumulative Effect of Temperatures Deviations from their Historical Norms on the Share of Investment in GDP

(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



Note: The three panels show the cumulative response of the ratio of Investment over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

Conversely, Figure 1.13 shows that the share of investment in GDP declines as temperatures rise. Appendix Figure 1.C.1 panel C confirms the negative impact on investment since the share of fixed investments also respond negatively to positive temperature deviations from their historical norms.

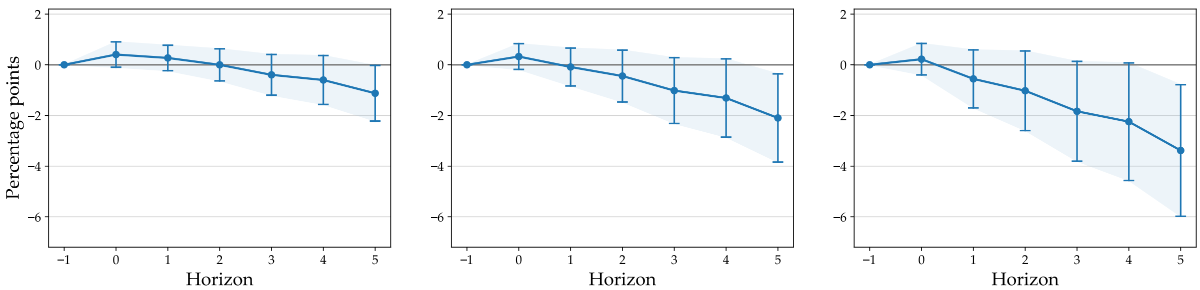
Together, these mechanisms raise concerns about long-term economic prospects by suggesting that a sustained increase in temperatures affects the outcome of the intertemporal trade-off between present and future consumption. While no evidence indicates the households' discounting factor might be affected, the results in Figure 1.8 show that with a declining output, and therefore lower income, the budget constraint also becomes more binding: households in developing countries satisfy their present subsistence requirements, and potentially try to implement individual adaptation (or maladaptation) strategies to a changing climate through higher consumption, at the cost of future prosperity and development. This mechanism suggests that sustained temperatures hikes will likely lead to a reversal of poverty and standard of livings gains from recent years and increases the probability of countries falling into development traps.

Figure 1.14 – Cumulative Effect of Temperatures Deviations from their Historical Norms on Trade Balance

(a) 25^{th} percentile: +0.49°C at $h = 0$

(b) 50^{th} percentile: +0.74°C at $h = 0$

(c) 75^{th} percentile: +1.06°C at $h = 0$



Note: The three panels show the cumulative response of the ratio of Trade Balance over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

The effects of temperature deviations from their historical norms on the trade balance, shown in Figure 1.14, are more ambiguous and only significant for horizon $h = 5$. For this variable only, which can take a negative value, the dependent variable in equation (1.1) is modified and corresponds to the total change in the trade balance ratio, expressed in percent of GDP. The overall weakly significant negative response of the trade balance ratio is due to an increased share of imports (Appendix Figure 1.C.1 panel D) over long horizons while the effect on exports growth is not statistically significant (Appendix Figure 1.C.1 panel E).

As indicated by equation (1.1), the previous results are obtained from independent estimations. However, the response of the share of demand components to climate change are not independent. We therefore adopt a three-stage least squares simultaneous equations approach for each horizon $h = 0, ..., 5$ as a robustness check. Appendix Figure 1.C.3 reports the results for the shares of private consumption (panel A), investment (panel B), public consumption (panel C) and the trade balance (panel D) and confirm the results obtained from independent estimations of equation (1.1).

6.2 Distinct Sectoral Effects

We also test sectoral effects to shed light on possible transmission mechanisms of positive temperature deviations from their historical norms. Figure 1.15 shows that the growth rate of the share of non-manufacturing industry in GDP significantly declines when temperatures deviations are positive. More specifically, following the World Bank's definition, the mining, construction, electricity, water, and gas sector are concerned, consistently with the negative response of investment and declining demand for commodity exports. Only the share of manufacture in GDP responds positively (Appendix Figure 1.C.3 panel B), possibly reflecting increased outsourcing from industrial to developing countries. This would stem from increasingly stringent environmental and climate-related regulations, in line with the pollution haven hypothesis (see Copeland and Taylor, 1994, for example). The opposite effects on the manufacturing sector on the one hand, and the rest of the industry as well as agriculture on the other hand, can explain the absence of statistically significant effects on export growth: the positive effect of higher manufacturing export on the trade balance appears to be offset by a decline in commodity and cash crops exports.

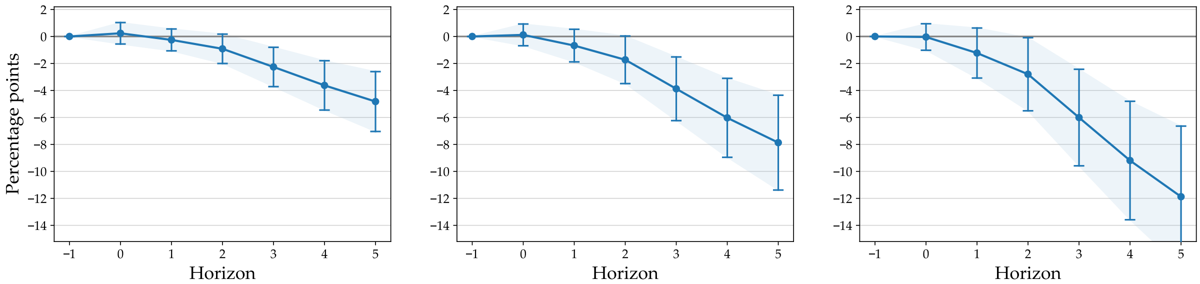
While the potential increase in FDI inflows is also expected to positively affect economic outcomes through spillovers on subcontractors in the manufacturing sector and higher demand for high-quality services, Appendix Figure 1.C.3 panel C shows that the service sector does not respond positively and remains unaffected by a sustained increase in temperatures.[10]

Sustained temperature hikes have a positive effect on the relative share of the agricultural sector in GDP (Figure 1.16), i.e. the decline of agricultural output observed in Figure 1.17 is less pronounced than that of the industrial sector. This is coherent with the previous results on private consumption due to a tighter budget constraint and the salience of subsistence requirements. This growing importance of the agricultural sector as temperature rises suggests a reinforcement of the "food problem": because of subsistence requirements, developing countries tend to devote a higher share of their

[10]Results presented in Appendix Figure 1.C.3 panel A show no relation between temperatures deviations from their historical norms and TFP growth.

Figure 1.15 – Cumulative Effect of Temperatures Deviations from their Historical Norms on the Share of Industrial Value Added in GDP

(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



Note: The three panels show the cumulative response of the ratio of Industrial Value Added over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

resources to food production and consumption (see Gollin et al., 2007; Schultz, 1953).

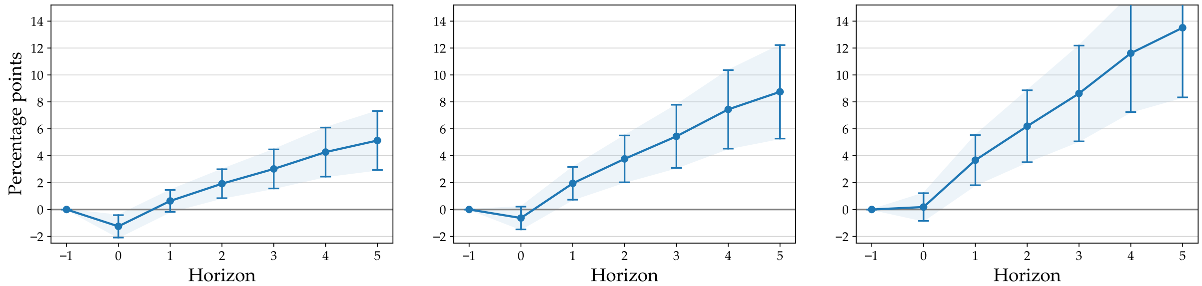
This challenges the common view that agriculture is that most affected sector by temperature hikes: in spite of large effects of temperature hikes and weather shocks on the agricultural sector shocks (see Ortiz-Bobea et al., 2021, for a recent example), the decline of the agricultural sector is outpaced by that of the secondary sector. This result is in line with the critiques of Integrated Assessment Models expressed in Keen (2020).

Using the International Agricultural Productivity dataset (USDA - ERS, 2019), we assess the effects of temperature deviations from their historical norms on the agricultural sector in more details. Results presented in Appendix 1.C show that temperature hikes translates into a lower use of machinery (Appendix Figure 1.C.4 panel B) and a decline of agriculture total factor productivity growth (Appendix Figure 1.C.4 panel A). Sustained temperature hikes also leads to enhanced use of inputs (Appendix Figure 1.C.4 panel C), fertilizers (Appendix Figure 1.C.4 panel D) and livestock growth (Appendix Figure 1.C.4 panel F), a liquid asset often seen as a form of self-insurance. Together, these results suggest a reallocation of available resources in favor of short-term subsistence output at the cost of future productivity. This is coherent with the previously described decline in investment and long-term development prospects.

All in all, global warming threatens recent gains in the fight against poverty and represent a major challenge for the development of low- and middle-income countries. Aggregate demand shifts from investment to consumption, increased outsourc-

Figure 1.16 – Cumulative Effect of Temperatures Deviations from their Historical Norms on the Share of Agricultural Value Added in GDP

(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



Note: The three panels show the cumulative response of the ratio of Agricultural Value Added over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

ing does not appear to be sufficient to maintain the trade balance, the share of industrial output declines while the economy becomes more dependent on agriculture, and agricultural inputs, fertilizers and livestock substitute for investments. While the literature has shown that economic development might be one of the best strategy for developing countries to be able to cope with the economic effects of climate change (Acevedo et al., 2019; Tol, 2018, 2020), our results suggest that it will become increasingly difficult as global temperatures rise.

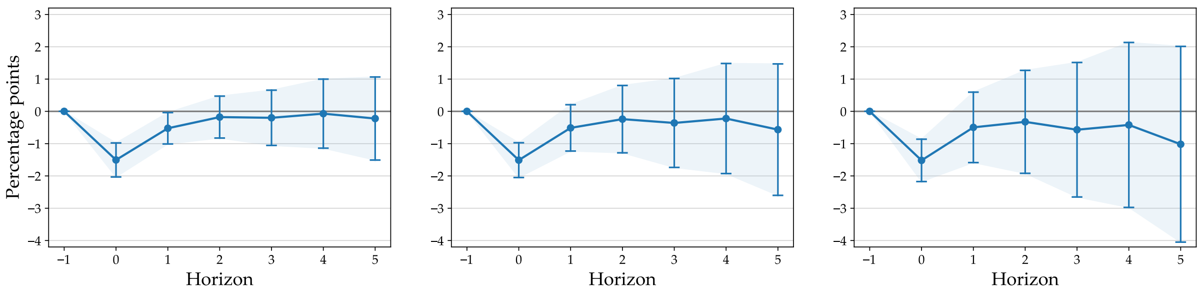
7 The Role of Structural Policies

This section focuses on the relation between temperature rises and real GDP per capita growth, and how structural policy variables may affect such outcomes. Because of possible reverse causality and correlations with other country characteristics, causal inference is difficult to draw from each individual result presented in this section, but the empirical evidence shown here may provide useful correlations and pointers for possible policy action. For each specific policy variable, we estimate equation (1.1) distinguishing two subsamples of observations depending on whether the policy variable or institutional quality index is below or above the full sample median for each year. Then, as in the previous sections, we obtain the cumulative impulse – cumulative response from equation (1.2) and present them for each subsample.

Figure 1.18 panel A show the effect of global warming on real GDP per capita

Figure 1.17 – Cumulative Effect of Temperatures Deviations from their Historical Norms on Agricultural Output

(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



Note: The three panels show the cumulative response of the ratio of Agricultural Output to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

growth when institutional quality is high (above the median, in dark blue) and low (below the median, in light orange). The results indicate that a higher institutional quality is associated with a reduced negative impact of temperature hikes on per capita output growth, suggesting that improving institutional quality, in particular in branches of government most affected by climate change, may be instrumental in adapting to and attenuating climate change (Hunjra et al., 2020).

Similarly, Figure 1.18 panel B shows that the effects of temperature hikes on per capita output growth is all the lower as cell phone subscriptions increase. This may reflect how TICs may contribute to increase economic growth and resilience to changing patterns of climate shocks through better access to information (Janvry et al., 2016; Ceballos et al., 2019) . These technologies may also increase economic resilience with strong leapfrogging effects through increases in firm productivity (Chauvet and Jacolin, 2017) or financial inclusion (Jacolin et al., 2021).

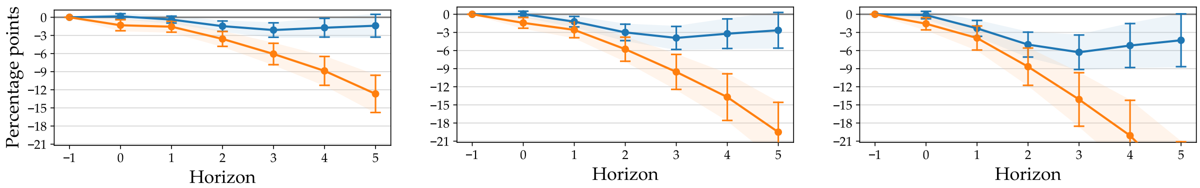
Access to electricity is also associated with a reduced impact, but the evidence is less robust since this effect appears when comparing the country-year observations above the 75^{th} percentile to those below the 25^{th} (Appendix Figure 1.D.1 panel C) but disappears when the threshold is set at the median (Figure 1.18 panel C).

The impact of deforestation is at first glance ambiguous. Deforestation may be seen as a pro-growth policy since alternative land use (urbanization, agriculture) might often appear to be highly profitable in the short run. However, in addition to their economic value, forests might themselves foster growth in neighbouring regions because of their effectiveness in preventing soil erosion, in protecting agricultural output in the

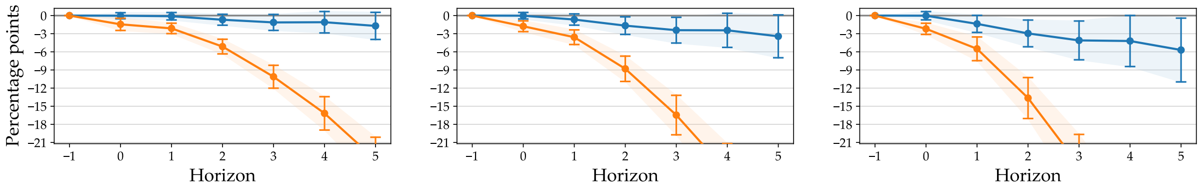
Figure 1.18 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, According to Policy Levels

Panel A. Institutional Quality

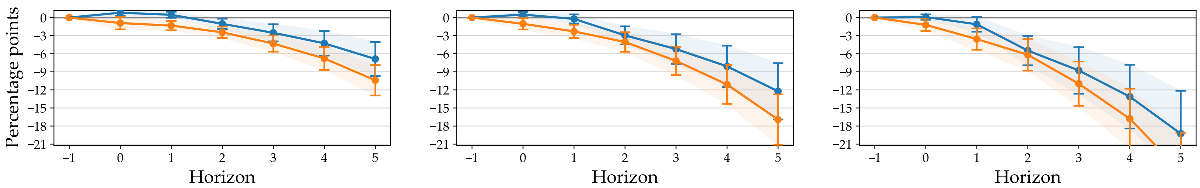
(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



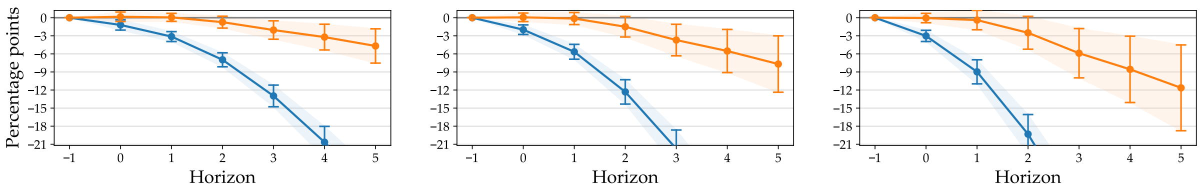
Panel B. Mobile Cellular Subscriptions



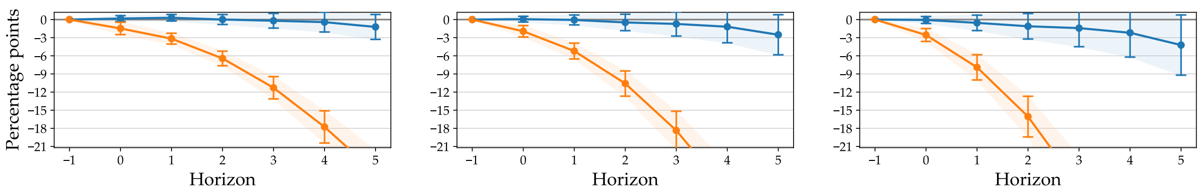
Panel C. Access to Electricity



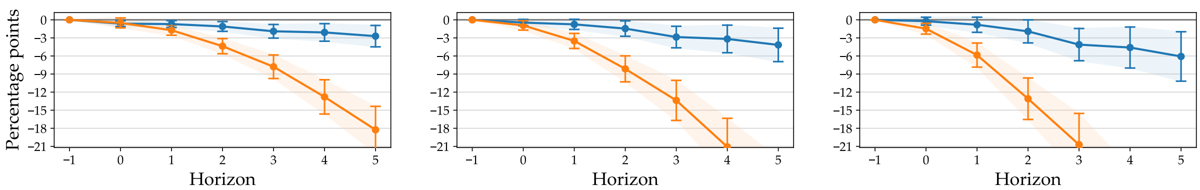
Panel D. Deforestation



Panel E. Coal Consumption



Panel F. De Facto Exchange Rate Regime



Note: Each panel shows the cumulative response of per capita real GDP to a 1 °C increase in temperatures deviation from their historical norms. The dark blue colour includes observations above the respective policy median value, while the light orange colour includes observations below the median.

long run, and their major role in the local (and global) climate (Heal, 2020). The results presented in Figure 1.18 panel D suggest that the latter effect might dominate the former, since a higher rate of deforestation is associated with a more negative effect of temperature deviations on per capita output growth.

Figure 1.18 panel E shows that a higher level of coal consumption per inhabitant is associated with a reduced effect of temperature hikes on per capita output growth. Coal consumption is positively associated with the size of the manufacturing sector, which favours economic growth in both the short- and the long-run but also contributes to climate change. This suggests that following a free-rider policy might be paying off: developing the manufacturing sector helps reduce the negative economic effects of global warming since this sector appears to be more resistant than others (Appendix Figure 1.C.3 panel B) and is growth-enhancing (Rodrik, 2016). However, because they are highly energy-intensive, industrialization policies might also exacerbate climate change, unless investments in energy production favour alternative renewable sources of energy. This externality emerging from industrialization policies underline the necessity for international cooperation to tackle effectively climate change.

The *de facto* exchange rate regime might also matter: the results presented in Figure 1.18 panel F show that a more flexible exchange rate regime is associated with a reduced effect of temperature hikes on per capita output growth. This result suggests that exchange rates may be a policy option to adapt to global warming (see also Arcand et al., 2008). This constitutes an interesting topic for further research.

In line with the literature, our results indicate that a wide array of structural policies might serve as adaptation policies and help face the macroeconomic effects of global warming. However, such adaptation policies also become more difficult to implement when temperatures rise as shown in section 7. In our view, these results bring to light a more general pattern: a higher level of development is associated with a lower effect of global warming on per capita output growth and a higher capacity to face the consequences of global warming, while the ability of least developed countries to implement adaptation policies is eroded by temperature rises. For the least developed countries, a horse race has already started between development policies and climate change. Domestic policies should aim at developing the country and building resilience to climate change, but our results suggest that these efforts might not be enough: external financing for climate change adaptation should be substantial and least developed countries should have the priority.

8 Conclusion

This article adds to the recent empirical literature on the macroeconomic effects of climate change by focusing on developing countries and by departing from the hypothesis that labour productivity is the main transmission channel. Instead, our empirical strategy allows to capture the effects through land productivity. The empirical literature has also focused on the effect of weather variables levels or first difference (*i.e.* weather shocks instead of climate change) on per capita output and output growth. By using the local projections method to capture the effects of sustained temperature and precipitations deviations from their historical norms on per capita output growth over different horizons, this study makes one step further to close the gap between weather shocks and climate change, and assesses the macroeconomic effects of global warming. This article also adds to the existing literature by inspecting the underlying transmission mechanisms, both on the demand and the supply sides, and discussing the role of policy variables.

We show that in developing countries, sustained temperature deviations from their historical norms, *i.e.* global warming, negatively affects the growth rate of per capita real GDP. Our central estimate indicates that in the median country, a sustained 1°C increase in temperature deviations from their historical norms reduces the real GDP per capita annual growth rate in 1.25 percentage points (0.82–1.69 p.p., 90% confidence interval). Our results are robust to excluding large carbon-emitting developing countries (China, India and Russia), controlling for commodity terms of trade, temperature and precipitation levels, and the occurrence of climate-related natural disasters, to including country-specific and common time trends, and to using real GDP growth as an alternative dependent variable.

Turning to the transmission mechanisms, we show that global warming shifts a share of aggregate demand from investment to consumption, possibly reflecting the salience of subsistence requirements in developing countries. Focusing on aggregate supply, we find that the relative importance of the industrial sector declines as the importance of agriculture grows, reinforcing the "food problem" in presence of subsistence requirements. Within the agricultural sector, while output growth declines, we also find evidence of a reallocation of resources towards short-term subsistence at the cost of future prosperity.

Finally, we provide evidence of correlations between structural policy variables and the effect of global warming on per capita real GDP growth: higher levels of development appear to be related to lower macroeconomic damages from global warming. While this suggests that development policies might help foster resilience to climate change, least developed countries will suffer the most since climate change has already made the implementation of such policies more challenging.

Overall, our results suggest that global warming threatens recent gains in the fight against poverty by making subsistence requirements more binding and will reinforce development traps, hindering further adaptation to climate change in developing countries.

Our empirical estimates of the economic effects of global warming in developing countries call for a closer scrutiny of the calibration of developing countries' damage functions in general equilibrium models. Future empirical research could use microeconomic data to provide evidences on the effectiveness of structural policies and allow for a causal interpretation of the relations between specific policies and the economic effects of global warming: a deeper and more precise understanding of these relations would help limit the increasing climate burden faced by countries the least equipped to face it.

Appendix

1.A Country List, Classification and Data Sources

Table 1.A.1 – List of Countries Included in the Main Regression Analysis

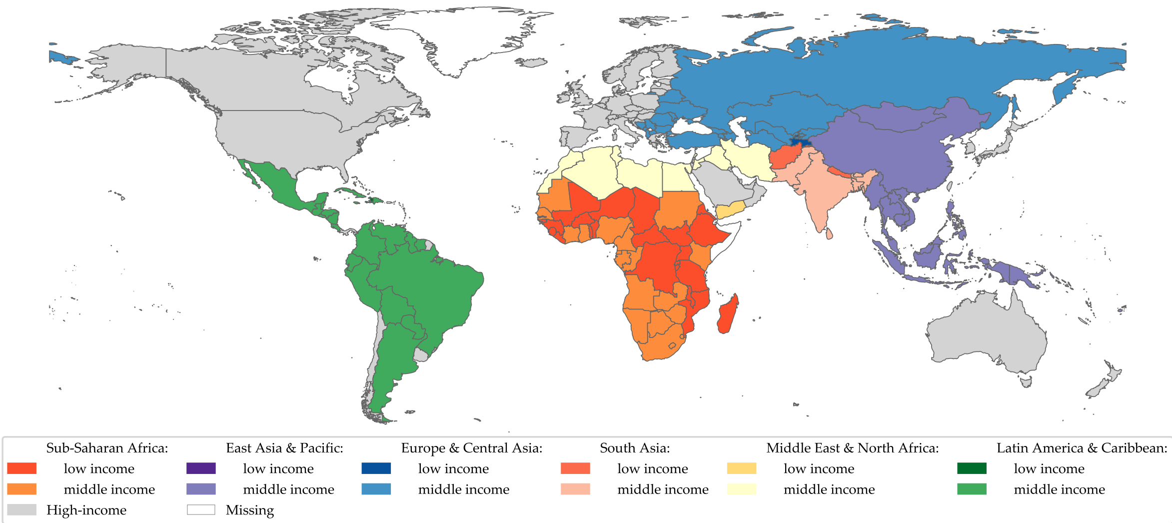
Low-Income Countries	Afghanistan, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Democratic Republic of the Congo, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Liberia, Madagascar, Malawi, Mali, Mozambique, Nepal, Niger, Rwanda, Sierra Leone, South Sudan, Tajikistan, Tanzania, Togo, Uganda, Yemen
Lower-Middle Income Countries	Angola, Bangladesh, Bhutan, Bolivia, Cambodia, Cameroon, Cape Verde, Comoros, Congo, Côte d'Ivoire, Egypt, El Salvador, Eswatini, Ghana, Honduras, India, Indonesia, Kenya, Kosovo, Kyrgyzstan, Lao, Lesotho, Mauritania, Moldova, Mongolia, Morocco, Myanmar, Nicaragua, Nigeria, Pakistan, Palestine (West Bank and Gaza), Papua New Guinea, Philippines, Sao Tome and Principe, Senegal, Solomon Islands, Sudan, Timor-Leste, Tunisia, Ukraine, Uzbekistan, Vanuatu, Viet Nam, Zambia, Zimbabwe
Upper-Middle Income Countries	Albania, Algeria, Argentina, Armenia, Azerbaijan, Belarus, Belize, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, China, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, Equatorial Guinea, Fiji, Gabon, Georgia, Grenada, Guatemala, Guyana, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Lebanon, Libya, North Macedonia, Malaysia, Mauritius, Mexico, Montenegro, Namibia, Paraguay, Peru, Romania, Russia, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Serbia, South Africa, Sri Lanka, Suriname, Thailand, Turkey, Turkmenistan, Venezuela

Note: the sample selection of middle- and low-income countries is exclusively based on data availability. Countries can be excluded either because no data for the GDP per capita are available in the WDI dataset, or because no climate data can be obtained from Matsuura and Willmott (2019).

Table 1.A.2 – Data Sources

Variable:	Source:
Socio-Economic Variables:	
Real GDP per capita	World Bank - WDI (2019), and IMF–IFS
Sectoral Value Added (Services, Manufacturing, Industry)	World Bank - WDI (2019)
Agricultural data	USDA - ERS (2019)
Commodity Export Value	Gruss and Kebhaj (2019)
Human Development Index	UNDP - HDI (2019)
Climate Variables:	
Terrestrial Temperature and Precipitation	University of Delaware: Matsuura and Willmott (2019)
Natural Disasters	CRED - EM-DAT (2019)
CO_2 Emissions	Boden et al. (2017); Friedlingstein et al. (2019)

Figure 1.A.1 – Country Classification



Source: The World Bank, elaborated by the authors. The classification corresponds to Fiscal Year 2020.

1.B Additional Results and Robustness Checks

Table 1.B.1 – Macroeconomic Effects of Temperature Deviations from their Historical Norms in Low-Income Countries

	Dependent variable is Real GDP per capita growth					
	$h=0$	$h=1$	$h=2$	$h=3$	$h=4$	$h=5$
$\widetilde{T}$	-0.002	0.004	0.007**	0.008***	0.008***	0.009***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$\widetilde{T} \times \mathbb{1}_{(low\ inc.)}$	0.000	0.005	0.007	0.009*	0.012***	0.015***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
$\widetilde{T}^2$	-0.002	-0.006***	-0.008***	-0.009***	-0.008***	-0.009***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$\widetilde{T}^2 \times \mathbb{1}_{(low\ inc.)}$	0.001	0.001	0.001	0.001	-0.002	-0.003
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
$\widetilde{P}$	-0.000	-0.000	-0.000*	-0.000**	-0.000**	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\widetilde{P} \times \mathbb{1}_{(low\ inc.)}$	0.000	0.000	-0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\widetilde{P}^2$	-0.000	-0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\widetilde{P}^2 \times \mathbb{1}_{(low\ inc.)}$	0.000	-0.000	-0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Obs.	5814	5684	5554	5424	5294	5164
R^2	0.08	0.12	0.15	0.16	0.16	0.17

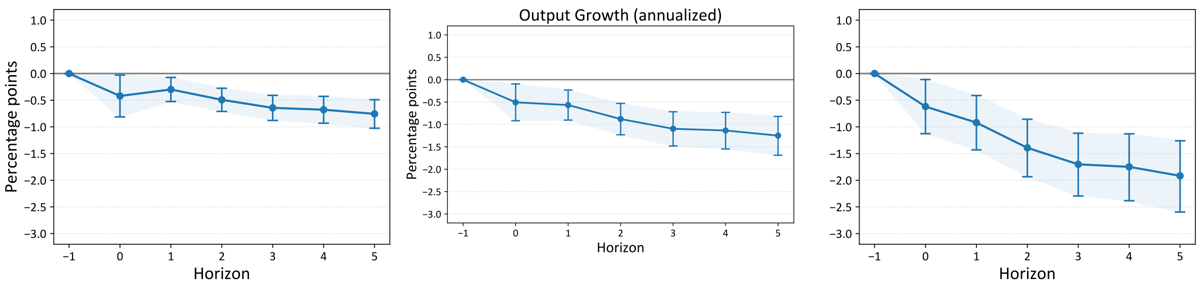
Note: $\mathbb{1}_{(\text{low inc.})}$ is an indicator function that takes the value of 1 if country *i* at year *t* has an income level below the 33rd percentile of the sample for that year. Control variables, year and country fixed effects are included in the regressions but not reported. Standard errors are in parentheses. * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

Figure 1.B.1 – Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP Annual Growth Rate, Using Temperatures of the Full Sample

(a) 25^{th} percentile: +0.49°C at $h = 0$

(b) 50^{th} percentile: +0.74°C at $h = 0$

(c) 75^{th} percentile: +1.06°C at $h = 0$

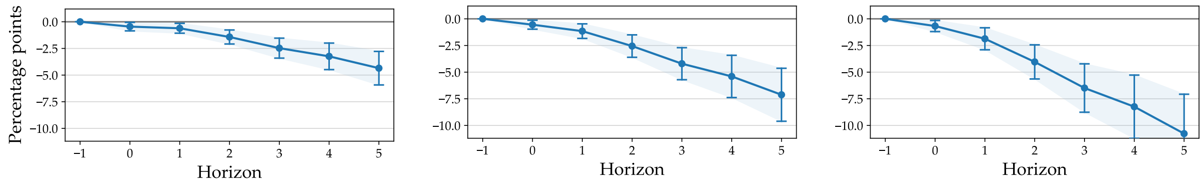


Note: The three panels show the annualized response of per capita real GDP growth rate to a 1 °C increase in temperatures deviation from their historical norms. Annualized growth rates are computed from the results reported in Figure 1.8. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. The values are as follows: +0.49°C, +0.74°C and +1.06°C for the 25^{th}, the 50^{th} and the 75^{th} percentiles, respectively, at $h = 0$, and are multiplied by $h + 1$ for each horizon $h > 0$. See Table 1.2 panel B for complete details on the values at each horizon.

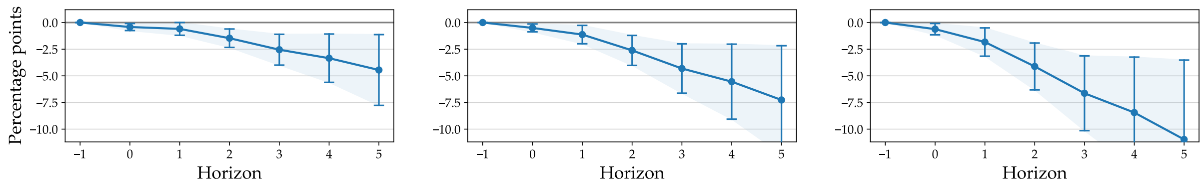
Figure 1.B.2 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP

Panel A. Excluding China, India and Russia

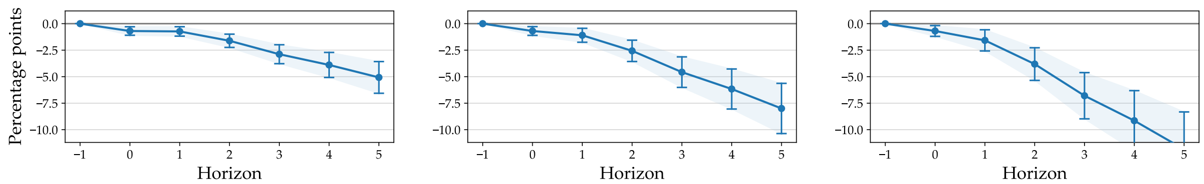
(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



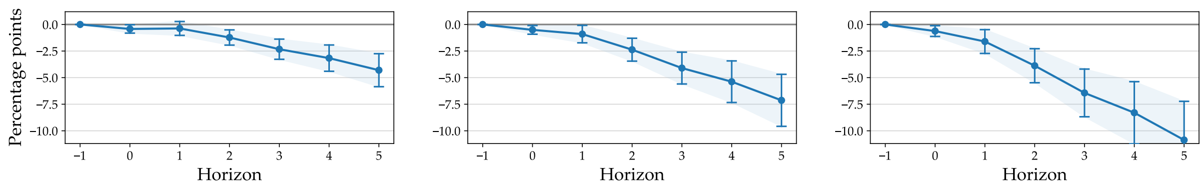
Panel B. Driscoll-Kraay Standard Errors



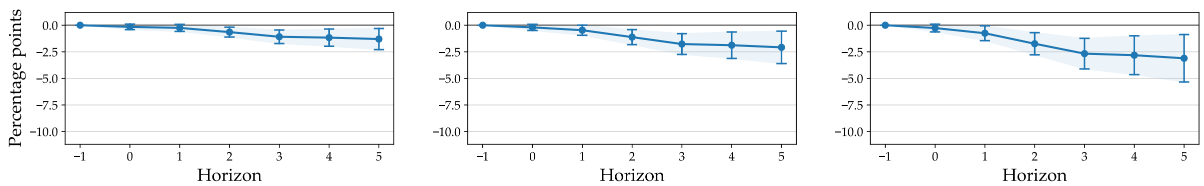
Panel C. Controlling for Commodity Exports Value



Panel D. Controlling for Temperatures and Precipitations Levels



Panel E. Sample includes High Income Countries

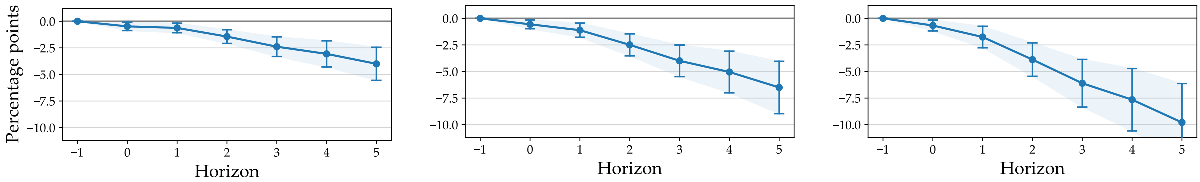


Note: Each panel shows the cumulative response of per capita real GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

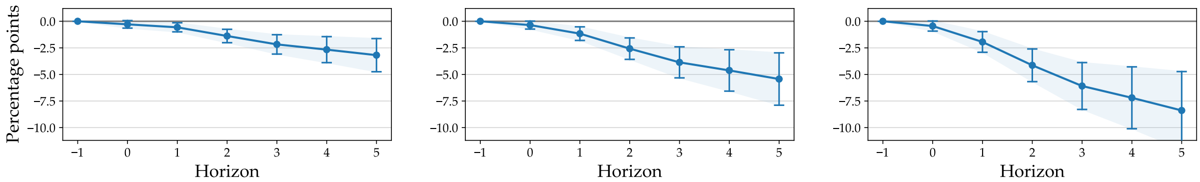
Figure 1.B.3 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP

Panel A. Real GDP as dependent variable

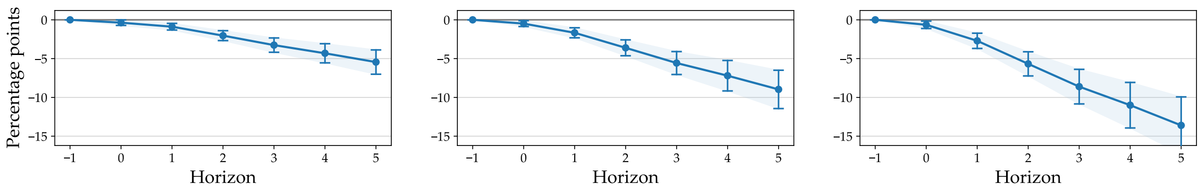
(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



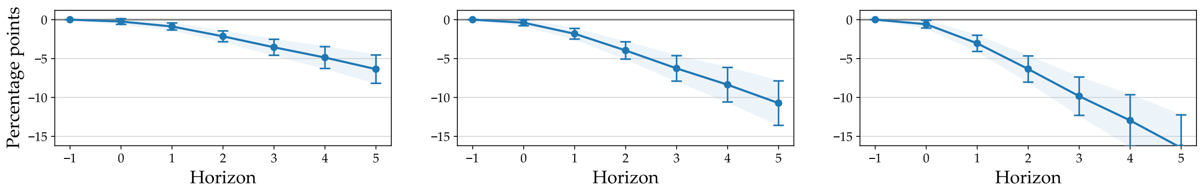
Panel B. Including a Linear Time Trend



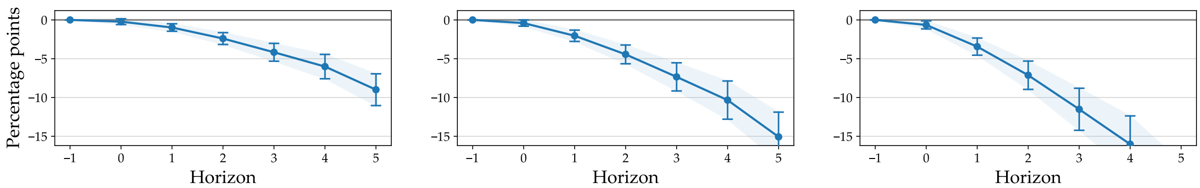
Panel C. Including a Linear and Quadratic Time Trends



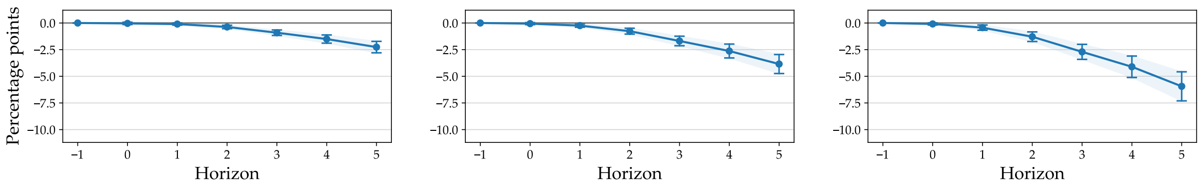
Panel D. Including a Country-Specific Linear Time Trend



Panel E. Including a Country-Specific Linear and Quadratic Time Trends



Panel F. Human Development Index as dependent variable



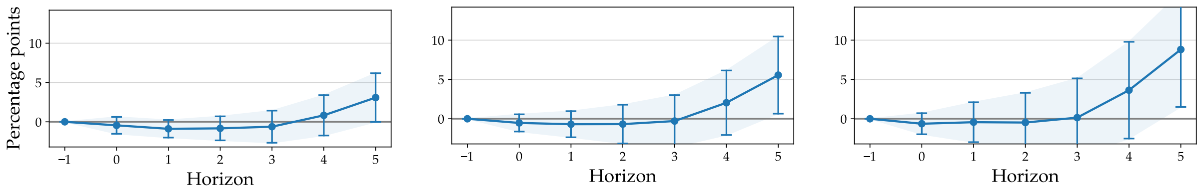
Note: Each panel shows the cumulative response of per capita real GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

1.C Additional Transmission Channels

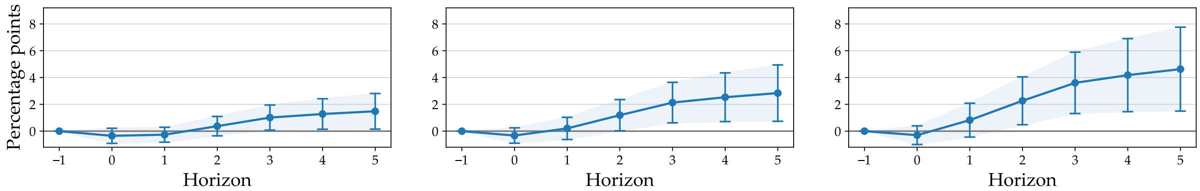
Figure 1.C.1 – Cumulative Effect of Temperatures Deviations from their Historical Norms on Demand Components of GDP

Panel A. Public Consumption

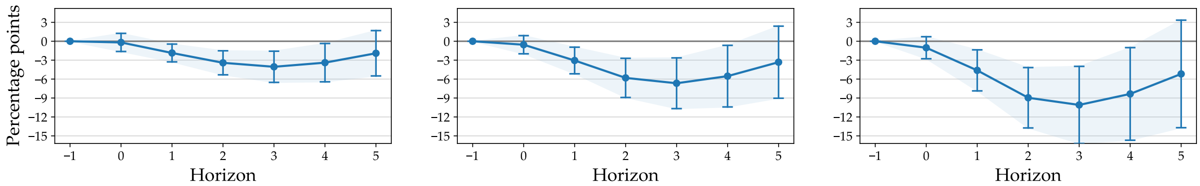
(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



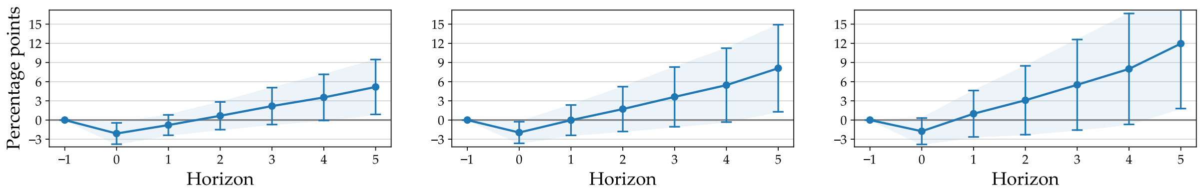
Panel B. Total Consumption



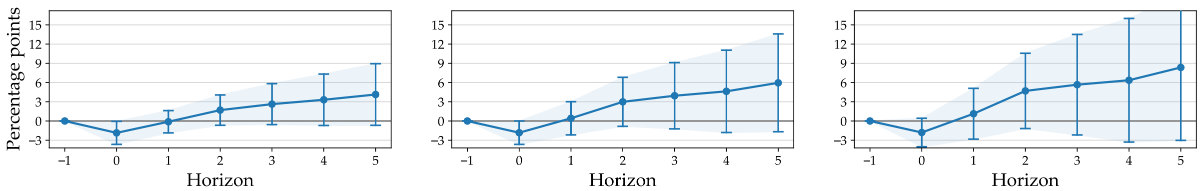
Panel C. Fixed Investment



Panel D. Imports



Panel E. Exports

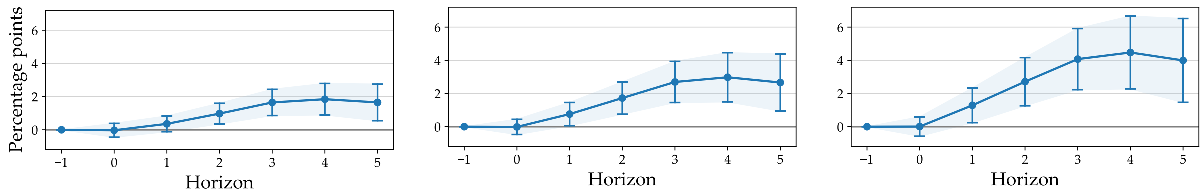


Note: Each panel shows the cumulative response of the ratio of the respective demand component over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

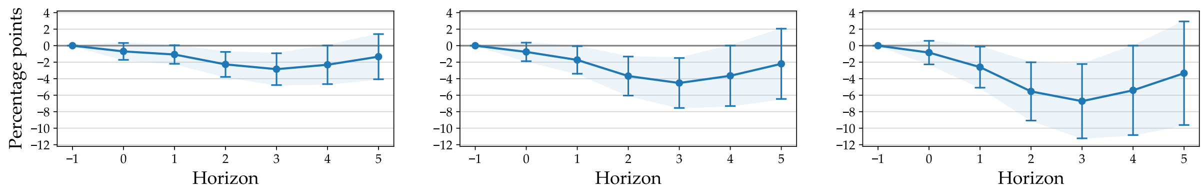
Figure 1.C.2 – Cumulative Effect of Temperatures Deviations from their Historical Norms on Sectoral Components of GDP

Panel A. Private Consumption

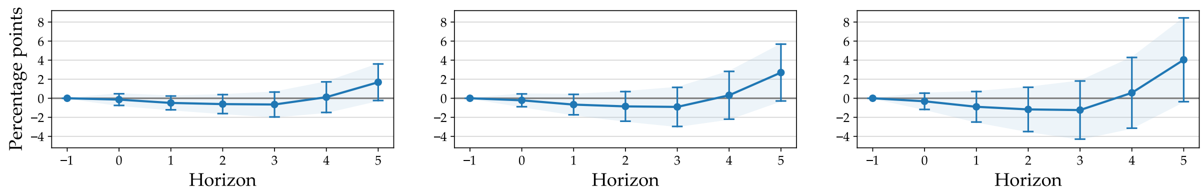
(a) 25th percentile: +0.49°C at $h = 0$ (b) 50th percentile: +0.74°C at $h = 0$ (c) 75th percentile: +1.06°C at $h = 0$



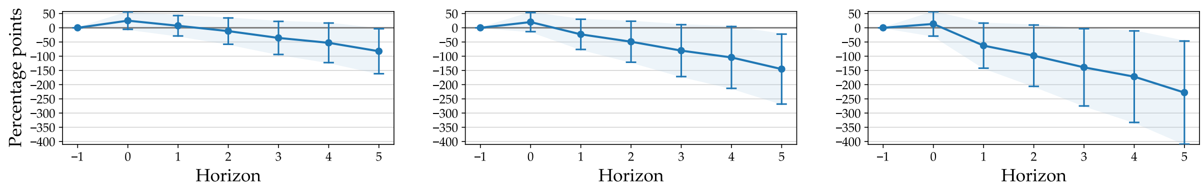
Panel B. Investment



Panel C. Public Consumption



Panel D. Trade Balance

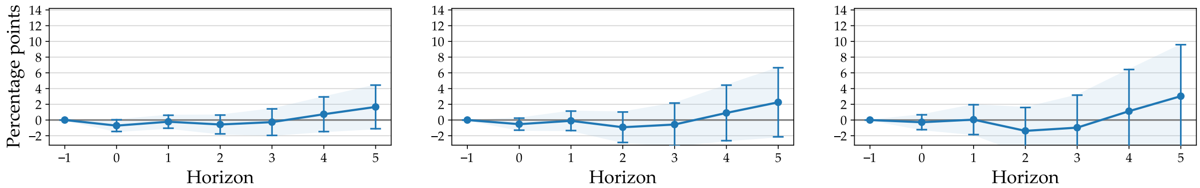


Note: Each panel shows the cumulative response of the ratio of the respective sectoral component over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

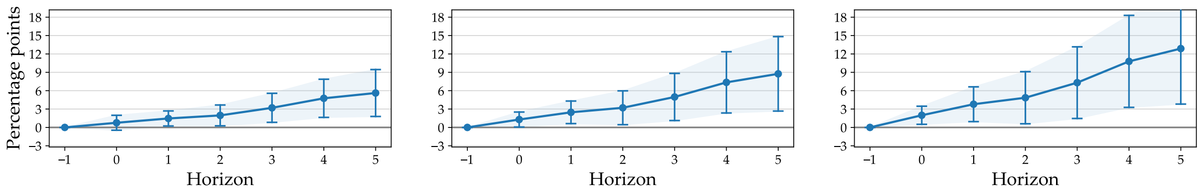
Figure 1.C.3 – Cumulative Effect of Temperatures Deviations from their Historical Norms on Sectoral Components of GDP

Panel A. Total Factor Productivity

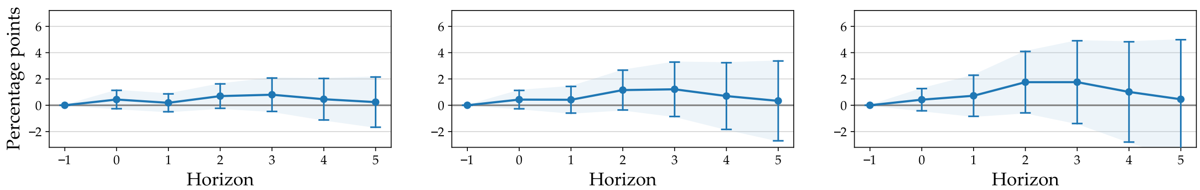
(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



Panel B. Manufacturing Value Added



Panel C. Services Value Added

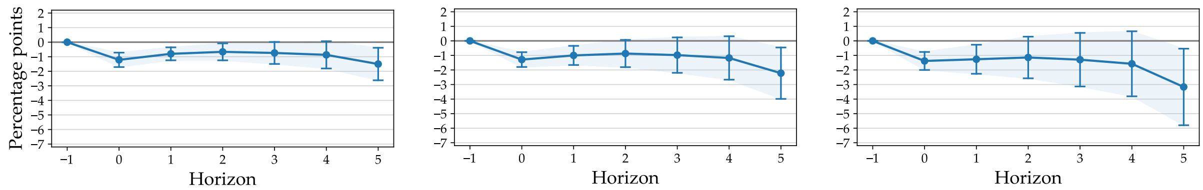


Note: Each panel shows the cumulative response of the ratio of the respective sectoral component over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

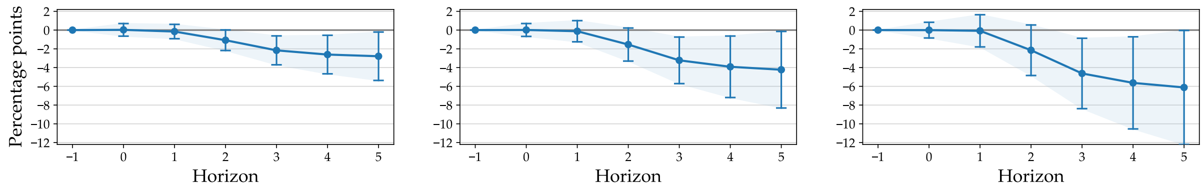
Figure 1.C.4 – Cumulative Effect of Temperatures Deviations from their Historical Norms on Agriculture

Panel A. Agriculture Total Factor Productivity

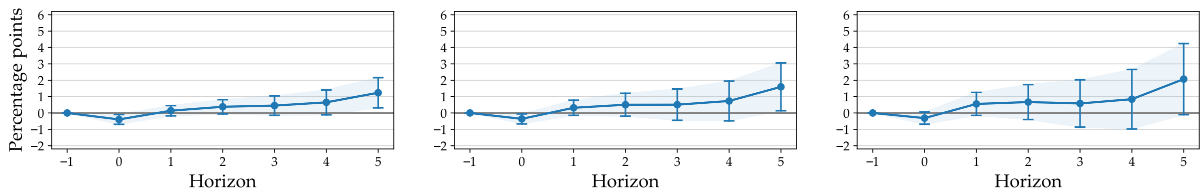
(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



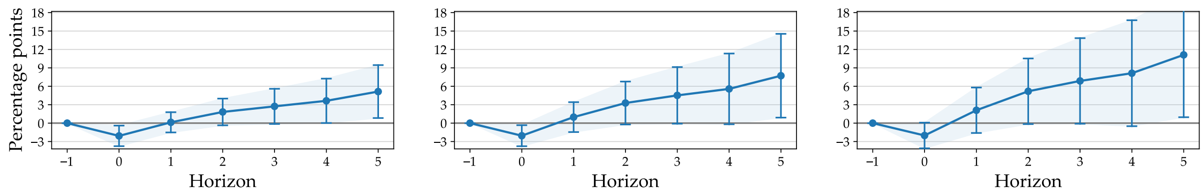
Panel B. Agricultural Machinery



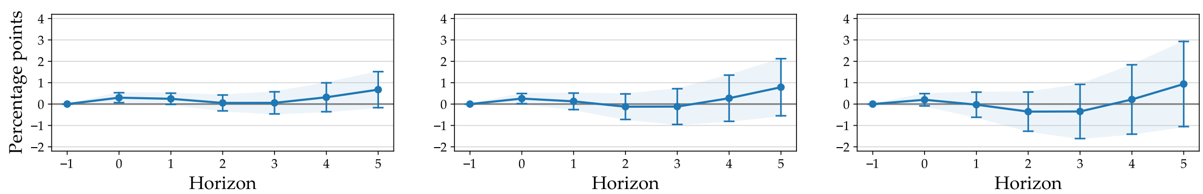
Panel C. Agricultural Inputs



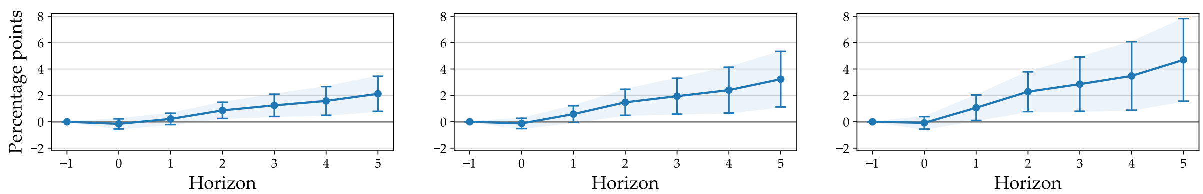
Panel D. Fertilizers Use



Panel E. Agricultural Labour



Panel F. Livestock



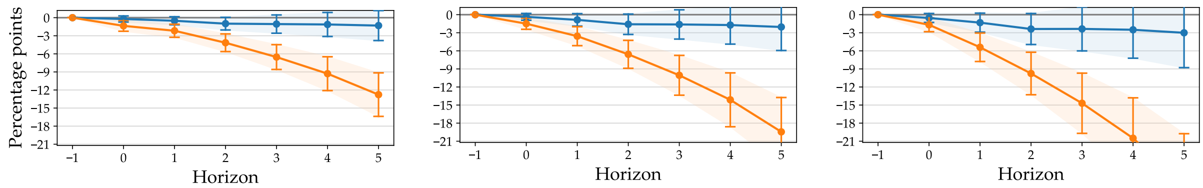
Note: Each panel shows the cumulative response of the respective variable to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in Figure 1.1. See Table 1.2 panel B for complete details on the values at each horizon.

1.D Additional Policy Results

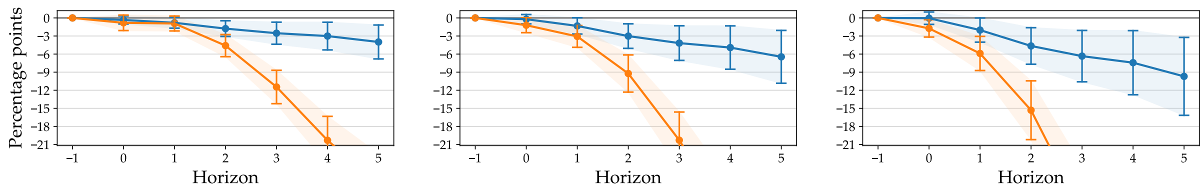
Figure 1.D.1 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, According to Policy Levels

Panel A. Institutional Quality

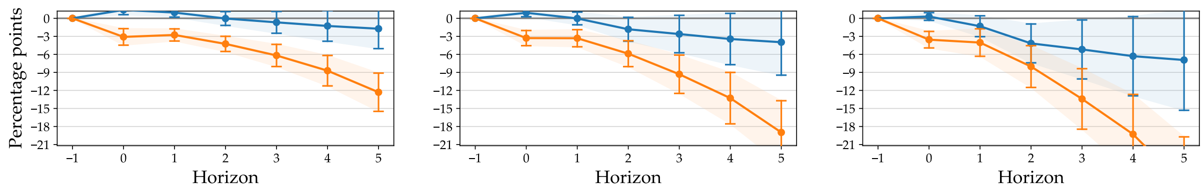
(a) 25^{th} percentile: +0.49°C at $h = 0$ (b) 50^{th} percentile: +0.74°C at $h = 0$ (c) 75^{th} percentile: +1.06°C at $h = 0$



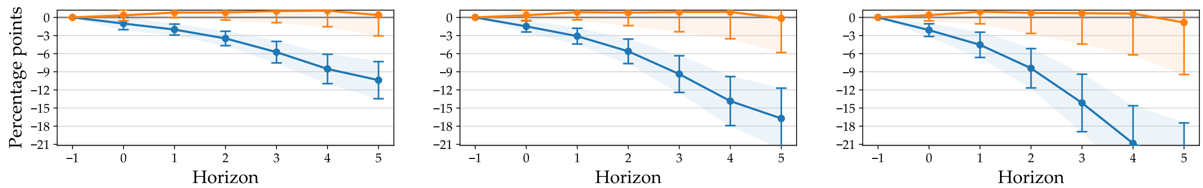
Panel B. Mobile Cellular Subscriptions



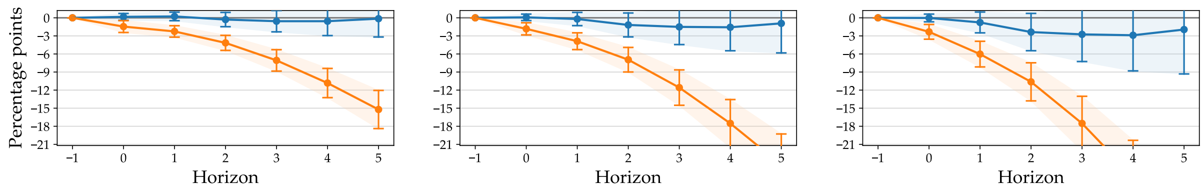
Panel C. Access to Electricity



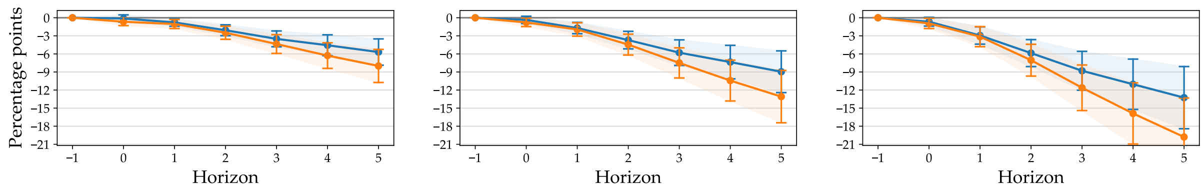
Panel D. Deforestation



Panel E. Coal Consumption



Panel F. De Facto Exchange Rate Regime



Note: Each panel shows the cumulative response of per capita real GDP to a 1 °C increase in temperatures deviation from their historical norms. Dark blue colour includes observations above the respective policy 75^{th} percentile, while light orange colour includes observations below the 25^{th} percentile.

Chapter 2

Drought and Growth in the Middle East and North Africa

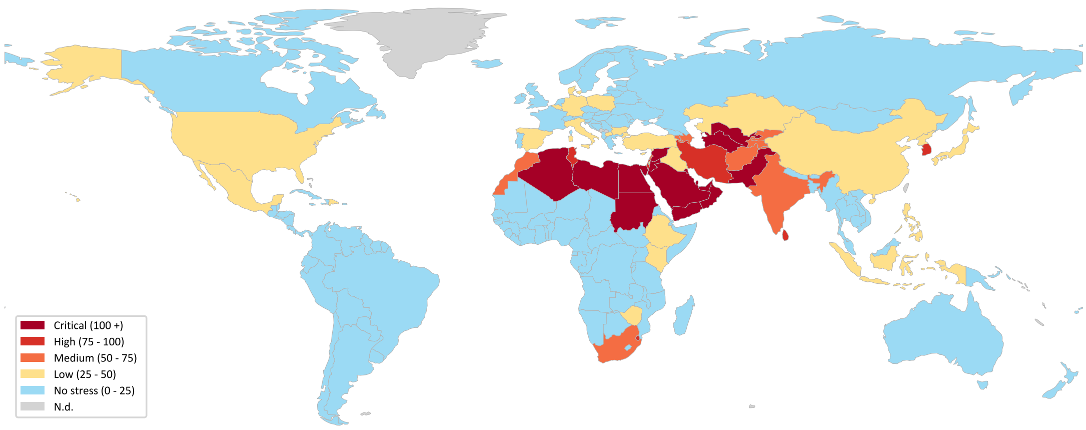
Abstract

Water scarcity and droughts have long characterized the Middle East and North Africa, and climate change represents an additional challenge to this region's development prospects. Using macroeconomic and climate panel data for Arab League members, Iran and Turkey during the period 1960-–2018, this paper assesses the effects of sustained drought deviations from their historical norms on output growth in the region and shows that droughts decrease output growth in oil importing countries, with no or statistically weakly significant positive effects in oil exporting countries. These effects do not strengthen as the horizon increases and vanish after one year but do not revert in subsequent periods, leading to lasting losses in output level in oil importing countries. The agricultural sector and civil violence appear to be two of the transmission channels. The results advocate for carefully planned economic diversification in the region and shed light to associated risks.

1 Introduction

Water scarcity has always been a defining element of Arab League members, Iran and Turkey's economic development. Figure 2.1 shows that the region experiences the most accute levels of water stress in the world, and that water stress reaches critical levels in a majority of its countries. Changing droughts patterns result from changing patterns in the combination of temperatures and precipitations and will continue evolving as the global climate changes. The region's challenging environment makes it particularly vulnerable to climate change, and adaptation efforts and policies are an absolute necessity to foster resilient economies and reinforce the foundations for inclusive growth and sustainable development. This is reflected in the fact that Egypt hosts COP27 in 2022 and the United Arab Emirates COP28 in 2023. A deeper understanding of the effects of droughts on the economy would allow to better elaborate and calibrate adaptation policies in the region.

Figure 2.1 – Water stress index (2018)



Note: The data are from FAO's AQUASTAT Database. The water stress index indicates freshwater withdrawal as a proportion of available freshwater resources (in %). The data are available at https://www.fao.org/aquastat/statistics/query/index.html.

This paper combines macroeconomic and climate data to empirically assess the effects of sustained droughts deviations from their historical norms on real GDP growth in Arab League member countries, Iran and Turkey. Dry climate conditions affect agricultural production, cattle mortality and infrastructure construction and maintainance costs, in addition to wide range of other impacts. This paper tests whether the assumption that droughts negatively affect GDP growth is confirmed by the data in the region. This paper also tests the assumption that oil-exporting countries' GDP growth is less affected by droughts. Several contries of the region rely particularly heavily on the oil sector and on oil exports. Since the supply is largely independent from climate conditions in the producing countries and the demand is exogenous, a higher dependence on this sector could be associated with a lower effect of droughts on macroeconomic fluctuations.

A recent and growing empirical literature has sought to shed light on the macroeconomic effects of climate change using panel data. These studies have mainly focused on the relation between temperatures and output (Dell et al., 2012; Burke et al., 2015c; Acevedo et al., 2020) and found a negative relation between these two variables. Kotz et al. (2021) studies this relation using data on daily temperatures and Colacito et al. (2019) shows that in the U.S., temperatures affect aggregate outuput through a wide range of sectors. Kahn et al. (2021) depart from using mean annual temperatures and consider instead temperatures deviation from their historical norms in order to focus on temperature *changes* instead of temperature *levels*. de Bandt et al. (2021) follow this approach and adopt an empirical strategy that allows to assess the effects of sustained temperature deviations from their historical norms on output growth. These papers usually control for precipitations, but results from this literature mainly indicate an absence of relation with output level or output growth. This can be explained by several issues arising when aggregating precipitation data at the country level (Damania et al., 2020). Little attention has been paid to the macroeconomic effects of changes in the combination of temperatures and precipitations.

This paper contributes to the literature in several ways. First, it assesses the macroeconomic effects of sustained changing patterns of drought conditions, a consequence of climate change that has been relatively neglected by macroeconomists. Second, it focuses on a region that will be greatly impacted by climate change despite having contributed little to historical CO_2 emissions (4.4 % of global historical CO_2 emissions according to data from Boden et al., 2017), preventing therefore reverse causality concerns in the empirical strategy. Third, it sheds light on potential transmission mechanisms and heterogenous effects by taking into account the diversity across countries in the region.

To assess the relation between sustained drought deviations from their historical norms and output growth, this paper uses macroeconomic data from the World Bank - WDI (2020) and IMF - IFS (2020) datasets and the **spei!** (**spei!**) from Vicente-Serrano et al. (2010) which measures droughts. The drought index is obtained as the opposite of the **spei!** so that an increase in the index corresponds to drier climate conditions. Additional control variables are obtained from several other sources. The panel dataset has a yearly frequency, covers the period 1960–2018 and includes 21 Arab League member countries, Iran and Turkey. Bahrain is excluded from the sample due to missing climate variables. The empirical strategy uses the local projections method introduced in Jordà (2005) and builds upon de Bandt et al. (2021) to assess the effects of sustained drought index deviations from its historical norms on real GDP growth in the region. This strategy allows to make a step forward in assessing the effects of climate change instead of weather shocks.

The results show that droughts lead to a decline in the contemporaneous output growth rate in oil-importing countries and have no statistically significant effect on output growth rate in oil-exporting countries, since the results for this group are only weakly significant in the main specification and do not resist several robustness checks. The results also show that the effects do not strengthen as the horizon increases and vanish after one year. Since these effects do not revert afterwards, droughts do not have permanent effects on output growth, but lead to lasting losses in output level in oil-importing countries. Civil violence appears to be one of the transmission channels of the effects of droughts on growth. The agricultural sector is another channel through which droughts decrease real GDP growth, and irrigation has not proved to be an effective adaptation strategy at the macroeconomic level. These results shed light on the importance of economic diversification, and the risks associated.

The remainder of the article is organized as follows. Section 2 reviews the literature and Section 3 describes the data and introduces some stylized facts on droughts in the region. Section 4 details the empirical strategy, Section 5 presents the results of drought effects on output growth and Section 6 discusses robustness checks. Section 7 analyses transmission channels and Section 8 concludes.

2 Review of the Literature

The relation between the climate and the economy has long been studied. In the past millenia, Ibn Khaldun (1377) discussed how temperature deviations from a certain average, corrected by air humidity in the case of Hadhramaut and part of the Arabian Peninsula, affect human characteristics and production, while Montesquieu (1748) argued that high temperatures substantially diminish labour productivity.

Recently, a growing body of the literature has sought to shed light on the macroeconomic effects of climate change using panel data. These studies have mainly focused on the relation between temperatures and output (Dell et al., 2012; Burke et al., 2015c; Acevedo et al., 2020) and usually found a negative relation. Kahn et al. (2021) consider instead temperatures deviation from their historical norms in order to focus on temperature *changes* instead of temperature *levels*. de Bandt et al. (2021) adopt this approach within an empirical strategy derived from the local projections method (Jordà, 2005) that allows to assess the effects of sustained temperature deviations from their historical norms on output growth in developing countries. These sustained temperature deviations from their historical norms correspond more closely to the notion of climate change than earlier studies in this strand of the literature, and this paper builds upon the empirical strategy introduced in de Bandt et al. (2021).

The previous papers usually control for precipitations, but their results mainly indicate an absence of relation with output level or output growth. While controling for the effects of precipitations is essential to assess the relation between temperatures and the macroeconomy, including these two variables separately does not allow to assess the combined effects of joint changes in these climate variables.

This joint effect of temperatures and precipitations has received little attention from macroeconomists, and this paper tries to fill this gap in the literature. Generoso et al. (2020) is an exeption: the authors assess the relation between the global climate cycle, and more specifically El Niño Southern Oscillation events, and economic growth. They take into account local weather conditions using the **spei!**. This paper uses the opposite of this index (so that a positive value corresponds to a drought) to assess the macroeconomic effects of sustained drought deviations from their historical norms in Arab League members, Iran and Turkey.

The relation between the climate and the economy has recently received renewed attention in the **mena!** (**mena!**) region. Cross-country analyses, such as Abou-Ali et al. (2021); Abdelfattah et al. (2021) and Abdel-Latif et al. (2021) have focused on the effects of temperature hikes while controling for precipitations, and the same is true for single-country studies (Karahasan and Pinar, 2021; Yüksel et al., 2021). Giovanis and Ozdamar (2021) is a notable exception as the authors assess the effects of self-declared droughts using microeconomic data from household surveys. This paper contributes to this literature by assessing the macroeconomic effects of droughts, measured by climate data, in one of the regions most affected by, and most vulnerable to, climate change.

3 Data and Stylized Facts

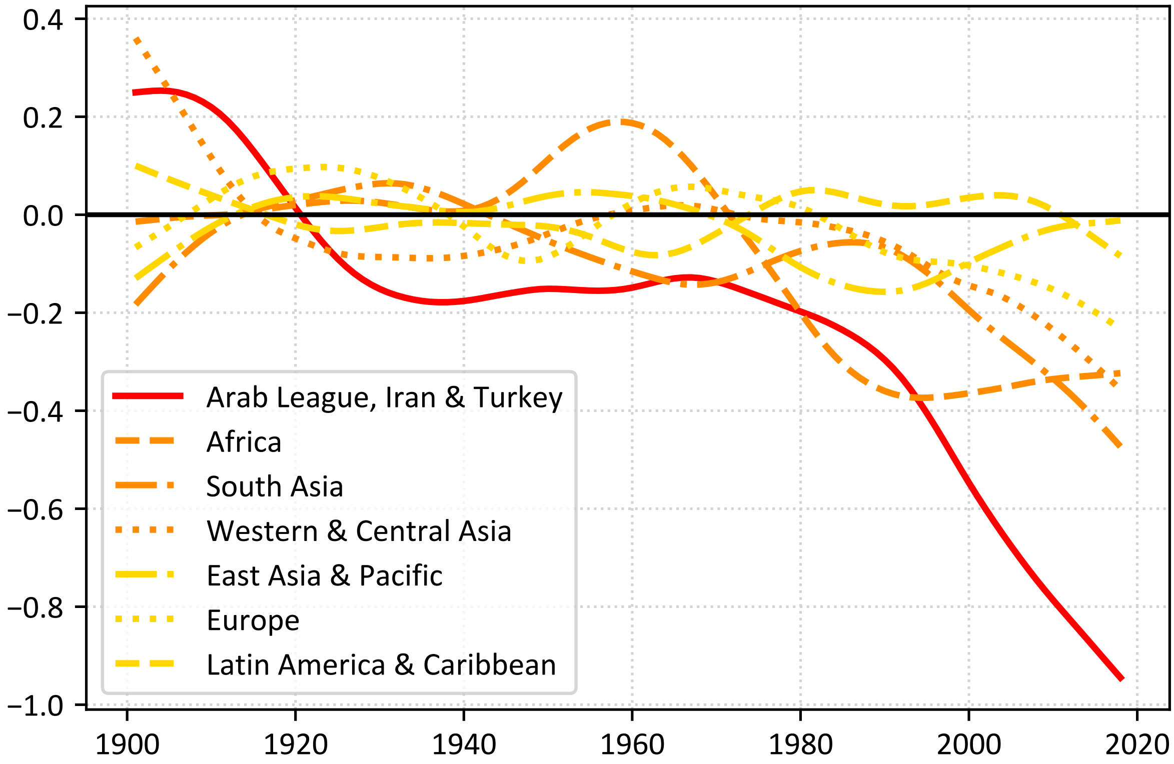
This paper uses country-level annual data in order to assess the effects of droughts on real GDP growth. The data cover a total of 23 countries, corresponding to 21 Arab League members as well as Iran and Turkey, between 1960 and 2018. Bahrain is not included in the sample due to missing climate data. Appendix Table 2.A.1 contains the list of the countries included in the sample, and Appendix Table 2.A.2 lists all the data sources used in this paper.

The main variable of interest is constructed using the Standardized Precipitation-Evapotranspiration Index (**spei!**) elaborated by Vicente-Serrano et al. (2010) and corresponds to the **spei!** deviation from its historical norm, define as its average during the period 1901–1950. The global dataset is gridded with a 0.5° latitude × 0.5° longitude resolution (approximately 55km near the equator) and covers the period 1901–2018 at a monthly frequency. It is standardized at the grid level and it denotes the difference between precipitations and evapotranspiration for a specific duration: For each grid cell, a positive value indicates therefore wetter climate conditions than its own average, and a negative value indicates dryer climate conditions than the average. The main specifications of this paper use the 6-month **spei!**. Country-level data are obtained by computing the unweighted average of all the observations within the land boundaries of each country.

The **spi!** (**spi!**), developped in McKee et al. (1993), is an alternative to the **spei!** and has been used to assess the economic effects of droughts (for example in Dallmann and Millock, 2017). The **spei!** includes information on evapotranspiration, in addition to precipitations, making this indicator more suitable to identify droughts in the context of global warming. The **pdsi!** (**pdsi!**), developped in Palmer (1965), is another alternative but has a relatively weaker comparability across regions than the **spi!** and the **spei!**.

Following de Bandt et al. (2021), and contrary to the methodology used mostly for developed countries (Dell et al., 2012; Burke et al., 2015c; Acevedo et al., 2020; Kahn et al., 2021, among others), climate observations are not weighted by local population density. Droughts can affect the economy by decreasing labour productivity. In many developing countries, the lack of access to drinkable water generates economic losses due to time, efforts and extra spending mobilized to obtain this critical resource. This happens both in large cities' informal neighbourhoods and in the countryside, where population density is much lower. Weighting the climate variable by population density would impede to capture properly the economic losses from declining labour productivity in the countryside. In addition, drought can also have macroeconomic effects through other channels, such as land productivity or crop yield. Since this channel occurs where population is relatively scarce, weighting by population density would once again impede to capture this mechanism through which drought affect economic activity. For these reasons, this paper uses an agnostic approach by taking the unweighted aggregation of climate data at the country level.

Figure 2.1 – Standardized Precipitation-Evapotranspiration Index Deviation from Historical Norm



Note: The SPEI data are from Vicente-Serrano et al. (2010), country and regional level aggregation and elaboration are from the author. SPEI data correspond to the 6-month SPEI. A decrease in the SPEI indicates a dryer climate. The historical norm corresponds to the period 1901–1950.

Figure 2.1 shows the evolution of the deviation of the 6-month **spei!** from its historical norm accross regions. Arab League members, Iran and Turkey correspond to the region where climate conditions dries out the most with respect to historical levels, and this phenomenon seems to have accelerated since the 1990s. This graph suggests that freshwater resources renewal is unlikely to increase and that water stress is therefore likely to remain a distinct feature of the region, unless freshwater withdrawals decrease significantly.

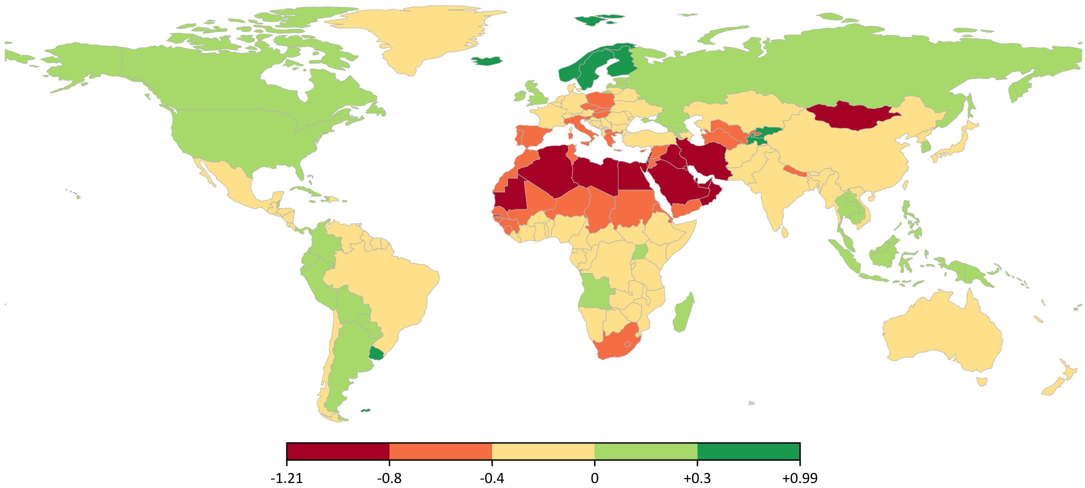
This paper uses the **spei!** deviation from its historical norm, to assess the effects of one dimension of climate change, namely changing drought patterns, instead of just drought episodes. The historical norm is defined as the period 1901–1950, *i.e.* after the pre-industrial period often considered by the **ipcc!** (**ipcc!**) due to data restrictions, but before climate change materialized in sustained increases in mean annual temperatures.[1] Since the **spei!** is normalized at the grid level, its average value is equal to 0

[1] This happened in all continents between the 1960s and the beginning of the 1980s. See de Bandt et al. (2021).

for all countries during 1901–2018, implying that this long-term average is the period of reference. The use of the period 1901–1950 as a period of reference is motivated by this paper's objective to assess the macroeconomic effects of one dimension of climate change.[2]

Figure 2.2 shows for each country the average **spei!** deviation from its historical norm over the period 2001–2018, where the historical norm corresponds to the period 1901–1950. The data presented in this figure confirm that the region is by far the one that has dried out the most during that period and that all its countries are affected to a high degree.

Figure 2.2 – Standardized Precipitation-Evapotranspiration Index Deviation from its Historical Norm



Note: The SPEI data are from Vicente-Serrano et al. (2010), country level aggregation and elaboration are from the author. A decrease in the SPEI indicates a dryer climate. The figure indicates the average SPEI deviation from the historical norm during the period 2001–2018. The historical norm corresponds to the period 1901–1950. This graph is better seen if printed in color.

Droughts correspond to negative values of the **spei!**. In order to ease the interpretation of the results, the remainder of this paper uses a yearly drought index, indicated in equation (2.1), that corresponds to the opposite value of the yearly **spei!** deviation from its historical norm, indicated in equation (2.2). As a consequence, an increase in the drought index corresponds to dryer climate conditions.Therefore:

$$\widetilde{Drought}_t = -\widetilde{SPEI}_t \tag{2.1}$$

[2]Robustness checks presented in section 6 ensure that the results are not driven by the indicator's construction.

with:

$$\widetilde{SPEI}_t = SPEI_t - \overline{SPEI_{1901-1950}} \tag{2.2}$$

Other climate and weather data are used as control variables. Terrestrial mean annual temperatures and total annual precipitations are obtained from Matsuura and Willmott (2019). The structure of this dataset is similar to the **spei!** dataset and the data are aggregated at the country level using the same methodology. Climate-related natural disasters occurrences are obtained from CRED (2020) and correspond to floods, extreme temperature events, landslides, storms and wildfires.

Economic variables come from several sources. The main dependent variable is the real GDP growth rate. It is built using annual GDP data in constant local currency from the World Bank - WDI (2020) and the IMF - IFS (2020) datasets. Agricultural sector data, including output and total factor productivity as well as livestock, are obtained from USDA - ERS (2019), and irrigation data from the FAOSTAT database. Commodity terms of trade are used as a control variable and are obtained from Gruss and Kebhaj (2019). Civil violence intensity data are from the Major Episodes of Political Violence dataset from the Center for Systemic Peace. This variable is coded on a 0 to 10 scale, where 0 denotes the absence of conflict, and scores from 1 to 10 denote increasing intensity of conflicts, from "Sporadic or Expressive Political Violence" to "Extermination and Annihilation". This variable excludes civil wars from episodes of civil violence to focus on events which involve a lower degree of organization. Labour productivity data come from the ILOSTAT database and oil and **ngl!** (**ngl!**) production from the IEA Oil Information Statistics through OECD's statistics portal.

Table 2.1 reports the summary statistics for each variable used in this paper and for the entire sample. Appendix Table 2.A.3 reports the summary statistics for oil exporters and Appendix Table 2.A.4 does the same for oil importers.

4 Empirical Framework

Following de Bandt et al. (2021), this paper uses a variant of the local projections method (Jordà, 2005) introduced in Ramey and Zubairy (2018) to capture the effects of a cumulative drought index deviation from its historical norm on cumulative output growth over different horizons. Equation (2.3) is therefore separately estimated for horizons $h = 0, 1, ..., 5$:

$$y_{i,t:t+h} = \theta^h \sum_{p=t}^{t+h} \widetilde{Drought}_{i,p} + \mathbf{\Theta}^h \widetilde{\mathbf{X}}'_{i,t} + \delta_i^h + \gamma_t^h + \varepsilon_{i,t}^h \tag{2.3}$$

Table 2.1 – Summary Statistics

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
GDP growth rate	1039	4.58	9.63	-64.05	123.14
Drought index deviation[a]	1334	0.40	0.71	-2.21	2.33
Temperatures deviation[a]	1368	0.38	0.67	-1.62	2.95
Precipitations deviation[a]	1368	-32.66	88.05	-920.03	553.77
Temperatures	1368	22.72	4.54	9.34	29.03
Precipitations	1368	314.54	480.56	8.78	2946.00
Floods occurrence (EMDAT)	1392	0.29	0.72	0.00	6.00
Extreme temperatures occurrence (EMDAT)	1392	0.02	0.13	0.00	2.00
Landslide occurrence (EMDAT)	1392	0.02	0.14	0.00	2.00
Storm occurrence (EMDAT)	1392	0.07	0.29	0.00	3.00
Wildfire occurrence (EMDAT)	1392	0.01	0.10	0.00	2.00
Commodity terms of trade	1221	88.03	20.17	39.07	125.78
Civil violence	1112	0.06	0.28	0.00	3.00
Agricultural output growth	1287	0.04	0.13	-0.85	1.31
Agricultural TFP growth	1287	0.02	0.13	-0.78	1.21
Livestock growth	1287	0.02	0.08	-0.57	0.85
Share of irrigated land	1382	11.79	21.17	0.05	100.00
Labour productivity growth	384	0.00	0.11	-0.63	1.21
Oil and NGL output growth	773	0.05	0.46	-1.00	7.55

Note: [a] Deviation from the historical norm, which corresponds to the period 1901–1950.

where i denotes the country and t the year. $y_{i,t:t+h}$ denotes total real GDP growth during years t to $t+h$, $\widetilde{Drought}_{i,t}$ denotes the drought index deviation from its historical norm of country i in year t. $\widetilde{\mathbf{X}'}_{i,t}$ is a vector of control variables that includes two lags of the dependent variable (the real GDP growth rate in $t-1$ and $t-2$) and two lags of the drought index deviation from its historical norm in the main specification. δ_i denotes country fixed effects and captures country-specific time-invariant factors that may affect real GDP growth, such as geography and history, and γ_t denotes time fixed effects that capture common shocks, such as the international business cycle. Standard errors are clustered at the country level.

The specification of equation (2.3) remains parsimonious on purpose so that estimates are not affected by the issue of over-controlling, in line with the common practice when using the Local Projections Method and as discussed in Dell et al. (2014). Many of the traditional growth determinants are highly likely to response to weather shocks, including droughts, and adding them to the main specification would lead to bias in the estimates. Robustness checks include additional control variables in the vector $\widetilde{\mathbf{X}'}_{i,t}$.

Specification of equation (2.3) allows to assess whether the effects of lasting droughts strengthen over time. To test whether one-off droughts have immediate or lasting macroeconomic effects, this paper relies on the traditional local projections approach as specified in equation (2.4):

$$y_{i,t+h} = \theta^h \widetilde{Drought}_{i,t} + \mathbf{\Theta}^h \widetilde{\mathbf{X}}'_{i,t} + \delta_i^h + \gamma_t^h + \varepsilon_{i,t}^h \tag{2.4}$$

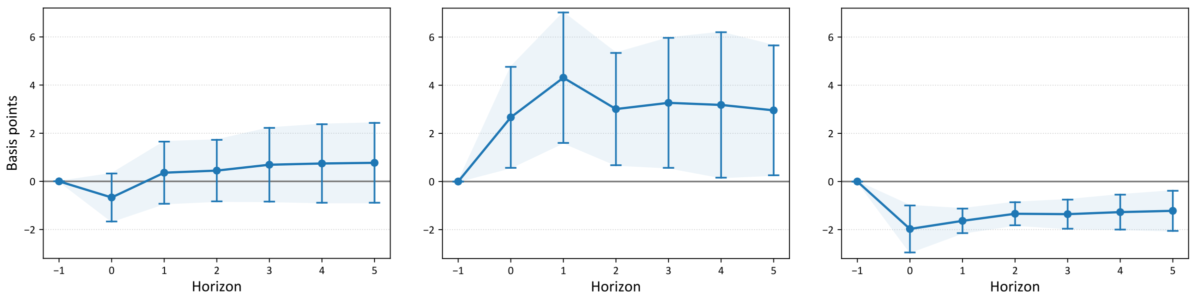
where $y_{i,t+h}$ is the real GDP growth rate at year $t+h$ and $\widetilde{Drought}_{i,t}$ is the drought index deviation from its historical norm at year t. All the remaining variables are as in equation (2.3). Equation (2.4) is also separately estimated for horizons $h = 0, 1, ..., 5$ and allows to build the impulse response function of the real GDP growth rate to a drought deviation from its historical norm.

5 Results

Table 2.1 presents the main estimates from equation (2.3) where each column corresponds to horizons $h = 0, 1, ..., 5$. panel A shows the results for the entire sample, panel B for oil exporters and Panel C for oil importers.[3] The results indicate that cumulative drought index deviations from its historical norm do not seem to affect output growth in the sample since estimates for all horizons are not significantly different from zero.

Figure 2.1 – Cumulative Response of GDP Growth to Cumulative Drought

(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of cumulative drought index deviations from its historical norm on total GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Taking into account heterogeneity within the MENA region by splitting the sample between oil exporters and importers leads to different results however. Estimates reported in panel B show that droughts seem to lead to higher growth in oil-exporting countries, but the estimates are only weakly significant, at the 10 % level. On the con-

[3]The division of the sample between oil exporters and oil importers follows that of the **imf!** (**imf!**) and is indicated in Appendix Table 2.A.1.

Table 2.1 – Cumulative Response of GDP Growth to Cumulative Drought

Dependent Variable:	Real GDP Growth					
	$h = 0$	$h = 1$	$h = 2$	$h = 3$	$h = 4$	$h = 5$
Panel A: Sample includes Arab League Members, Iran and Turkey						
$\widetilde{Drought}_h$	-0.007	0.004	0.004	0.007	0.007	0.008
	(0.006)	(0.008)	(0.008)	(0.009)	(0.010)	(0.010)
Observations	912	888	864	840	818	796
R^2	0.10	0.13	0.15	0.16	0.18	0.18
Panel B: Sample includes oil exporters						
$\widetilde{Drought}_h$	0.027*	0.043**	0.030*	0.033*	0.032	0.030
	(0.013)	(0.016)	(0.014)	(0.016)	(0.018)	(0.016)
Observations	383	373	363	353	343	333
R^2	0.22	0.27	0.29	0.31	0.34	0.34
Panel C: Sample includes oil importers						
$\widetilde{Drought}_h$	-0.020***	-0.016***	-0.013***	-0.014***	-0.013**	-0.012**
	(0.006)	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)
Observations	529	515	501	487	475	463
R^2	0.18	0.24	0.24	0.24	0.24	0.26

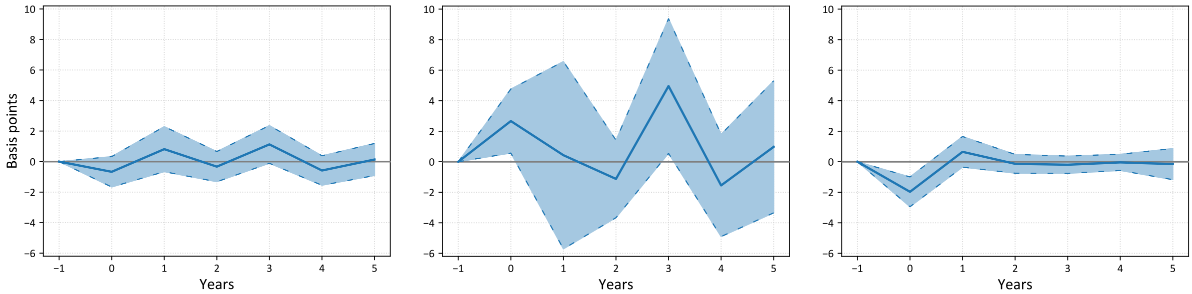
Note: The estimates are in percentage points. Standard errors in parentheses are clustered at the country level. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

trary, estimates in panel C show that droughts lead to lower GDP growth rates in oil-importing countries, and this effect is statistically significant at the 1 % or the 5 % levels for all horizons $0 \leq h \leq 5$. Figure 2.1 represents graphically these results and evidences the heterogeneity of output response to droughts within the region.

Droughts can lead to lower output growth in oil-importing countries of the MENA region through several channels. First, these events can increase the cost of access to drinkable water and decrease labour productivity. Second, droughts can damage physical capital and public infrastructure, and can lower the value of services provided by biodeversity, which are increasingly recognised by economists (Heal, 2020; Svartzman et al., 2021). Third, drought can decrease land productivity and crop yields, and increase cattle mortality. This channel is particularly important since food security relies to a large extent on water availability and several oil-importing countries of the region remain commodity exporters to a large extent, relying partially on fruits that require relatively high quantities of freshwater to grow. Finally, droughts can affect output growth through increased social unrest.

Figure 2.2 – Impulse Response of GDP Growth to Drought

(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

The increase in output growth in oil-exporting countries could result from endogenous policy response to counter the destabilizing effects of droughts on economic activity, although the effect appears to be only weakly significant. Increased social transfers made possible by the buildup of financial assets when oil prices are high might reduce social unrest after droughts and increase consumption in the short term.

The output growth response to droughts in both oil-exporting and oil-importing countries does not seem to build upon the immediate effect over time, although the effects remain sizable in the medium-term. These results contrast with the findings in de Bandt et al. (2021) for temperatures hikes in developing countries.

The local projection method allows to assess whether one-off droughts have lasting effects on output growth. The impulse response functions in Figure 2.2 report the estimates obtained from equation (2.4) and show that droughts affect GDP growth contemporaneously. This effect vanishes the following year however, although a weakly significant positive effect seem to remain after three years in oil-exporting countries. Table 2.2 reports the estimates from equation (2.4) for the entire sample (panel A), oil-exporting (panel B) and oil-importing countries (panel C). These results justify the horizon's upper limit, set to five years after the shock. This corresponds to a standard practice when using the Local Projections method, and extending it would make the estimates more noisy without adding information.

The results reported in Figure 2.2 and Table 2.2 confirm that droughts have an immediate but temporary effect on output growth which does not strengthen over time. However, the result also indicate that such episodes lead to permanent output losses in oil-importing countries, since output growth does not appear to compensate for the contemporary loss in subsequent years: while droughts do not appear to lead to permanent changes in output growth, they lead to lasting losses in the level of output in oil-importing countries from the region.

Table 2.2 – Impulse Response of GDP Growth to Drought

Dependent Variable:	Real GDP Growth					
Year	t	$t+1$	$t+2$	$t+3$	$t+4$	$t+5$
Panel A: Sample includes Arab League Members, Iran and Turkey						
$\widetilde{Drought}_t$	-0.007	0.008	-0.003	0.011	-0.006	0.001
	(0.006)	(0.009)	(0.006)	(0.008)	(0.006)	(0.006)
Observations	912	909	903	879	855	831
R^2	0.10	0.11	0.12	0.12	0.12	0.12
Panel B: Sample includes oil exporters						
$\widetilde{Drought}_t$	0.027*	0.004	-0.011	0.050*	-0.016	0.010
	(0.013)	(0.037)	(0.015)	(0.027)	(0.020)	(0.026)
Observations	383	382	378	368	358	348
R^2	0.22	0.19	0.20	0.20	0.18	0.18
Panel C: Sample includes oil importers						
$\widetilde{Drought}_t$	-0.020***	0.006	-0.001	-0.002	-0.000	-0.002
	(0.006)	(0.006)	(0.004)	(0.003)	(0.003)	(0.006)
Observations	529	527	525	511	497	483
R^2	0.18	0.18	0.21	0.21	0.22	0.22

Note: The estimates are in percentage points. Standard errors in parentheses are clustered at the country level. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

The sample division between oil importers and exporters might reflect a different division, between countries with relatively high and low incomes. If this is the case, the difference in output responses to droughts might be explained by other reasons related to differences in development levels, such as health infrastructures and sanitary conditions, policy making and implementation capacity, and financial constraints, among other reasons. The division between oil importers adn exporters does not correspond perfectly to the division across income levels, however: although several oil exporters have the status of high-income countries, some others such as Yemen have a much lower income level, and oil importers' income levels are also highly heterogenous.

Figure 2.3 Panel A reports the results for the full sample, divided between relatively high and low income countries, *i.e.* above or below the sample median income per capita based on the 2019 purchasing power parity GDP per capita. Output growth in countries with a higher level of income appears not to be affected by droughts, while output growth decreases significantly in countries with a lower income. However, decomposing the sample first according to the status of oil importer (Figure 2.3 Panel B) and oil exporter (Panel C), and then by the level of income shows that being an oil importer or exporter matters more than the relative level of income. Both relatively high and low income oil importers face a drop in output growth when the drought indicator increases (Panel B), while this drop in output growth is absent among oil exporters, both with relatively low and high income levels.

Figure 2.3 – Impulse Responses of GDP Growth to Drought, by Income Level

Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level. Each group of countries (oil exporters and oil importers) is divided into two subgroups of equal size according to the income per capita in 2019 expressed in purchasing power parity.

6 Robustness Tests

This section presents a series of tests to show that the main results resist several robustness checks.

The first series of tests corresponds to the choice of the variable that captures droughts. The main independent variable is the opposite of the 6-month **spei!**. This index is built taking into account a 6-month period over which water deficits and surpluses can accumulate. It is therefore able to capture seasonal trend in weather conditions (Generoso et al., 2020). The results do not depend on the choice of this specific indicator however. Appendix Figure 2.B.1 shows that the negative effect of droughts on oil-importing countries output growth and the positive but weakly significant effect of droughts on oil-exporting countries output growth are confirmed when using the opposite of the 3-month **spei!**, and Appendix Figure 2.B.2 shows that the same is true when using the 12-month **spei!**.

Appendix Figure 2.B.3 reports the results obtained when using the inverse of the **spei!**6 indicator (*i.e.* the variable $Drought_t$), instead of the inverse of the deviation of **spei!**6 to its historical norm ($\widetilde{Drought}_t$). The estimates are exactly identical as in the baseline regression, by construction, since the variables are perfectly correlated (and only differ in level).

Robustness tests for the results obtained from the impulse response functions are reported in Table 2.1 for horizon $h = 0$. The main results are also confirmed when using alternative drought indexes. Appendix Figure 2.B.4 shows the impulse response functions obtained when estimating equation (2.4) using the opposite of the 3-month **spei!**, and Appendix Figure 2.B.5 reports the same functions when using the 12-month **spei!**. Table 2.1 columns (1) and (2) report the estimate for $h = 0$. These robustness checks confirm that droughts negatively affect GDP growth contemporaneously and that this effect vanishes the following year in oil-importing countries. The positive but weakly significant effect on output growth in oil-exporting countries becomes statistically not significant when using the 3- and 12-month **spei!**, confirming the weakness of the relation between drought and growth in oil-exporting countries.

The second series of tests confirms that the main results of this paper are robust to alternative specifications. Appendix Figure 2.B.6 shows the impulse response functions when only one lag of both the GDP growth rate and the drought index are included in the set of control variables, as opposed to two lags in the baseline specification, and Table 2.1 column (3) resports the estimate for $h = 0$. Results for both oil-exporting and oil-importing countries remain unchanged. Excluding entirely the lags of the dependent and independent variables from the specification does not change the

Table 2.1 – Impulse Response of GDP Growth to Drought (Robustness Checks)

Dependent Variable:	Real GDP Growth Rate at year t									
Full IRF:	Fig. 2.B.4	Fig. 2.B.5	Fig. 2.B.6	Fig. 2.B.7	Fig. 2.B.8	Fig. 2.B.9	Fig. 2.B.10	Fig. 2.B.11	Fig. 2.B.12	Fig. 2.B.13
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Sample includes Arab League Members, Iran and Turkey										
$\widetilde{Drought}_t$	-0.002	-0.008	-0.004	-0.013*	-0.007	-0.004	-0.004	-0.007	-0.005	-0.008
	(0.008)	(0.006)	(0.006)	(0.007)	(0.005)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)
Observations	912	912	936	912	912	890	890	912	859	806
R^2	0.10	0.11	0.11	0.11	-	0.10	0.10	0.11	0.12	0.12
Panel B: Sample includes oil exporters										
$\widetilde{Drought}_t$	0.045*	0.013	0.027	-0.007	0.027	0.028	0.028	0.026*	0.026*	0.026
	(0.023)	(0.013)	(0.015)	(0.014)	(0.016)	(0.018)	(0.018)	(0.012)	(0.013)	(0.016)
Observations	383	383	393	383	383	373	373	383	383	359
R^2	0.23	0.22	0.24	0.10	-	0.23	0.23	0.22	0.22	0.21
Panel C: Sample includes oil importers										
$\widetilde{Drought}_t$	-0.020**	-0.016**	-0.018**	-0.017**	-0.020***	-0.016**	-0.016**	-0.020***	-0.019**	-0.020***
	(0.007)	(0.005)	(0.006)	(0.008)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Observations	529	529	543	529	529	517	517	529	476	447
R^2	0.17	0.18	0.18	0.15	-	0.19	0.19	0.19	0.23	0.21

Note: Each column presents the contemporary effect of droughts on GDP growth. The robustness check to which it corresponds is indicated in the main text and in Appendix 2.B, which contains the figures of the full impulse response functions for each test. The estimates are in percentage points. Standard errors in parentheses are clustered at the country level (except for column (5) which reports Driscoll and Kraay (1998) standard errors). * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

results either.[4]

Following Burke et al. (2015c), an alternative specification of equation (2.4) includes country-specific linear and quadratic time trends in order to capture within-country changes over the sample period, including convergence dynamics. The results shown in Table 2.1 column (4) and Appendix Figure 2.B.7 are again robust to this robustness check, despite the fact that time trends capture a share of the drought index variation.

Table 2.1 column (5) and Appendix Figure 2.B.8 report the estimated coefficients of the baseline specification with Driscoll and Kraay (1998) standard errors, which are robust to cross-sectional dependence in addition to autocorrelation and heteroskedasticity. The main results remain unchanged.

The third series of robustness checks tests whether the results resist to including additional control variables that might explain output growth in countries included in the sample. Table 2.1 column (6) and Appendix Figure 2.B.9 report the results when mean annual temperatures and total annual precipitations deviations from their historical norms are included as control variables. These results confirm the negative contemporary effect of droughts on output growth in oil-importing countries.Table 2.1 column (7) and Appendix Figure 2.B.10 show the results obtained when temperature and precipitations deviations from their historical norms are reimplaced by temperature and precipitations levels, in order to control for the separate effects of these variables. These results lead to the same conclusion.

Table 2.1 column (8) and Appendix Figure 2.B.11 report the results obtained when climate-related natural disasters occurrences are included as additional control variables and shows that the main results of this paper are robust to this alternative specification. Table 2.1 column (9) and Appendix Figure 2.B.12 report the results adding commodity terms of trade as a control variable. Commodity terms of trade are know to be a major determinant of the business cycle in developing countries, and including this control variable does not affect the results of this paper.

Civil conflicts have been highly prevalent in the region and have had strong macroeconomic effects in affected countries, both on the real and the monetary sectors (see Devadas et al., 2021; Lemaire, 2021, for examples in the MENA region). Furthermore, droughts usually represent a negative shock on food supply and can therefore lead to civil conflicts. Table 2.1 column (10) and Appendix Figure 2.B.13 report the results controlling for civil conflict intensity and shows that the main results of this paper are robust to this additional test.

The last robustness test assesses whether any single country affects the results decisively. Appendix Table 2.B.1 reports the baseline results when countries are excluded

[4]These results are not reported but are available from the author upon request.

from the sample one by one. In the case of oil importers, the negative effect of drought on growth remain significant at the 1% or the 5% level, and the estimates value remain close to the baseline level of -0.02. The estimate value decreases in absolute terms to -0.015 when Syria is removed from the sample, but it remains negative and statistically significant at the 1% level. In the case of oil exporters, the range of estimates value is greater and their statistical significance remains low, at the 10% level, or even disappears when some countries are separately removed from the sample. This indicates that the positive and weakly significant effect of drought on growth in oil-exporting countries is not robust.

To sum up, the series of robustness tests presented in this section confirm that droughts have a negative effect on output growth in oil-importing countries. They also confirm that the positive effect of droughts on growth in oil-exporting countries is only weakly significant and not robust, and must therefore be interpreted with caution.

7 Transmission Channels

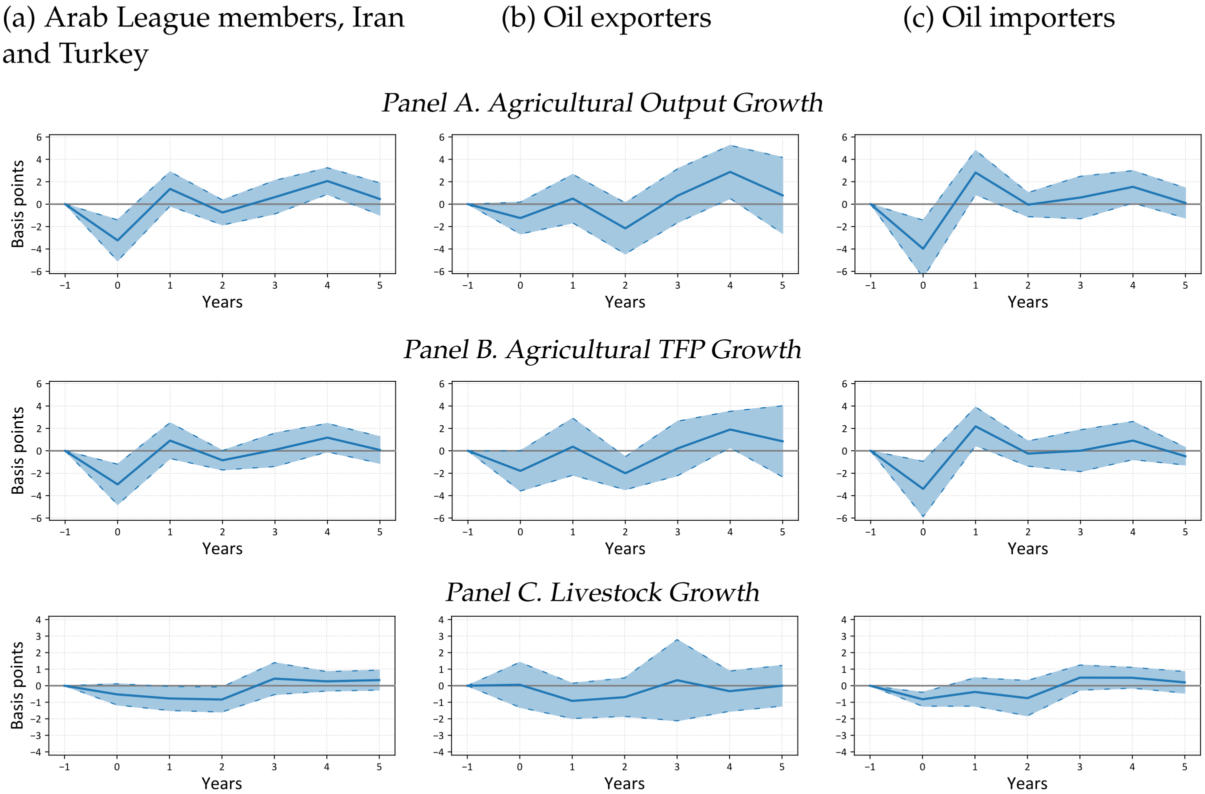
This section presents additional results showing that the agricultural sector and civil conflicts are two of the transmission mechanisms through which droughts lead to lower economic growth in oil-importing countries in the region.

The adverse effects of climate change and weather shocks on agricultural productivity have been documented by the literature and can be very large (see Ortiz-Bobea et al., 2021, for example). This is all the more important since countries in the sample are large virtual water net importers (Hoekstra and Hung, 2005) due to the low availability of domestic water resources and negative agricultural shocks can further increase food dependency in this context. The literature has also shown that conflicts, and particularly civil conflicts, respond to weather shocks and climate conditions (see Hsiang et al., 2011; Burke et al., 2015b; Damette and Goutte, 2022, among others).

Figure 2.1 shows the response of agricultural sector growth to droughts based on equation (2.4), where the dependent variable $y_{i,t+h}$ is reimplaced by agricultural output growth (Panel A), agricultural total factor productivity growth (Panel B), and livestock growth (Panel C). The vector of control variables $\widetilde{\mathbf{X}'}_{i,t}$ is modified accordingly to include two lags of the dependent variable.

The results for the agricultural sector show that agricultural output growth, agricultural total factor productivity growth and livestock growth all significantly decrease when droughts occur in oil-importing countries. Contrary to the aggregate results, the negative contemporary effect appears to be partially compensated the following year.

Figure 2.1 – Impulse Responses of Agricultural Sector Growth to Drought



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual agricultural sector growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

In the case of agricultural output growth, droughts lead to a 3.98 basis points decline in the contemporary growth rate, followed by a 2.82 basis points increase in the growth rate the year after, denoting a partial recovery. Results for oil exporters are not statistically different from zero, showing an absence of reaction of the agricultural sector to droughts in these countries, potentially explained by a more capital-intensive structure in the Gulf.

The decline in the agricultural sector output and total factor productivity growth as well as the decline in livestock growth can partially explain the observed decline in real GDP growth. Adaptation policies such as developing the irrigation system have long been considered and implemented to increase the region's resilience to droughts.

To test whether irrigation is an adaptation policy that is effective at eliminating the negative effects of droughts on agricultural sector growth in oil-importing countries of the region, equation (2.5) is separately estimated for horizons $h = 0, 1, ..., 5$:

$$\begin{aligned} y_{i,t+h} =& \theta^h Drought_{i,t} + \alpha^h Irrigation_{i,t} + \beta^h Drought_{i,t} \times Irrigation_{i,t} \\ &+ \mathbf{\Theta}^h \widetilde{\mathbf{X}'}_{i,t} + \delta_i^h + \gamma_t^h + \varepsilon_{i,t}^h \end{aligned} \tag{2.5}$$

where the variables are as in equation (2.4) and $Irrigation_{i,t}$ denotes the share of agricultural land area dedicated that is irrigated. This specification allows to recover the coefficient β^h which indicates whether irrigation affects the impact of droughts on output growth.

Table 2.1 presents the estimates from equation equation (2.5) for horizon $h = 0$. Droughts do affect agricultural sector growth, and irrigation alone does not. The interaction term between droughts and irrigation is small and not statistically different from zero. This result indicates that, at the macroeconomic level, irrigation does not fully protect oil-importing economies of the region from the effects of droughts on the agricultural sector.

Equation (2.4) allows to test alternative potential transmission channels by reimplacing the dependent variable $y_{i,t+h}$ by the prevalence of civil violence (Panel A), labour productivity growth (Panel B), and oil and NGL output growth (Panel C). The vector of control variables $\widetilde{\mathbf{X}'}_{i,t}$ is again modified to include two lags of the dependent variable. Figure 2.2 shows the impulse response function of these three variables to droughts.

The results presented in Figure 2.2 panel A show that droughts lead to an increase in civil violence in oil-importing countries in the region, while oil-exporting countries remain unaffected. Part of the decline in real GDP growth due to droughts in oil-importing countries might therefore be attributed to this increase in civil violence. Contrary to the aggregate results, which indicate in temporary decline in the real GDP growth rate, and the results for the agricultural sector, which indicate a partial recovery after an initial decline, the effect of droughts on civil violence appear to be persistent. The intrinsic dynamics of civil violence might explain this persistent effect: droughts can trigger civil violence, which will have a tendency to be self-sustaining afterwards.

Other potential transmission mecanisms include labour productivity growth, which might be affected differently in oil-importing and oil-exporting countries, as well as oil and NGL output growth. Oil-exporting countries could increase oil (and gas where available) production when droughts occur to prevent their income from falling and cover higher food imports needs.

Table 2.1 – Agricultural Sector Contemporary Response to Drought

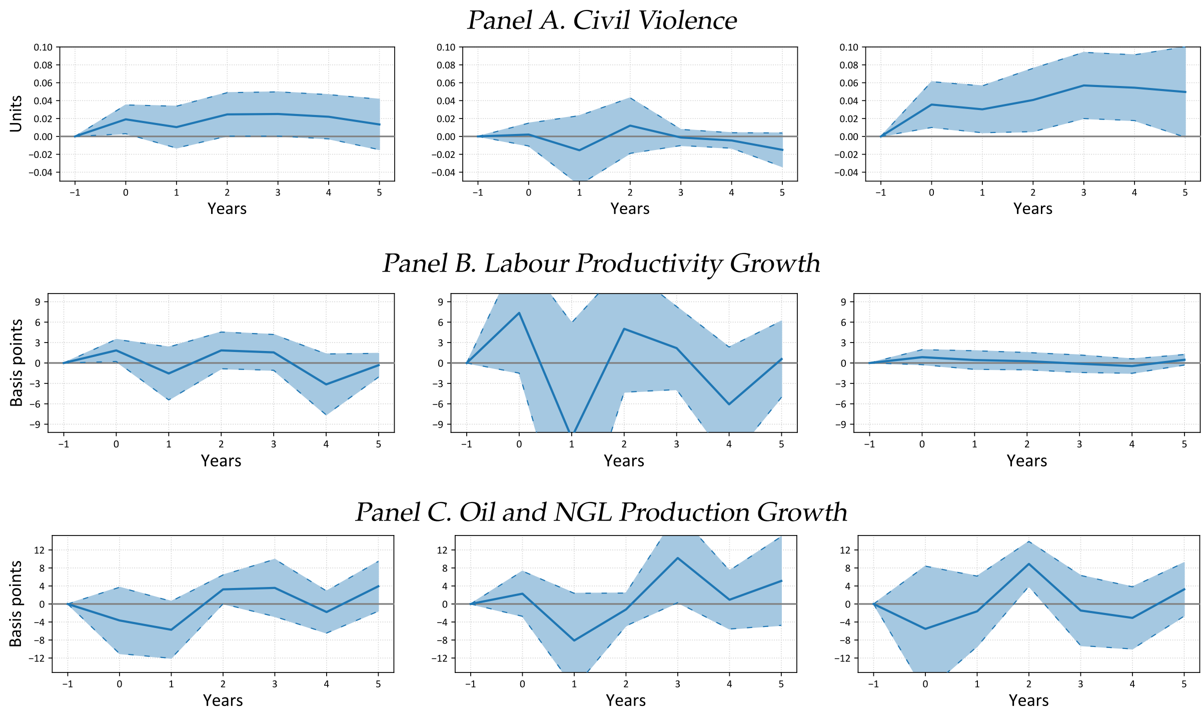
Dependent variable	*Agricultural Output Growth* (1)	*Agricultural TFP Growth* (2)	*Livestock Growth* (3)
$\widetilde{Drought}_t$	-0.045**	-0.038**	-0.008**
	(0.017)	(0.016)	(0.003)
$Irrigation_t$	-0.002	-0.002	0.000
	(0.001)	(0.001)	(0.001)
$\widetilde{Drought}_t \times Irrigation_t$	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)
$\widetilde{Drought}_{t-1}$	0.022**	0.015*	-0.001
	(0.010)	(0.007)	(0.006)
$\widetilde{Drought}_{t-2}$	0.009	0.005	-0.004
	(0.011)	(0.011)	(0.006)
$Agricultural\ Output\ Growth_{t-1}$	-0.402***	-	-
	(0.065)	-	-
$Agricultural\ Output\ Growth_{t-2}$	-0.071*	-	-
	(0.038)	-	-
$Agricultural\ TFP\ Growth_{t-1}$	-	-0.426***	-
	-	(0.071)	-
$Agricultural\ TFP\ Growth_{t-2}$		-0.079	-
	-	(0.048)	-
$Livestock\ Growth_{t-1}$	-	-	0.127
	-	-	(0.091)
$Livestock\ Growth_{t-2}$	-	-	-0.032
	-	-	(0.040)
Country Fixed Effects	Y	Y	Y
Year Fixed Effects	Y	Y	Y
Observations	633	633	633
R^2	0.33	0.32	0.11

Note: The estimates are in percentage points. Standard errors in parentheses are clustered at the country level. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

The results presented in Figure 2.2 panel B and panel C show that none of these potential transmission mecanisms are active in the region. Labour productivity growth does not respond to droughts, and oil output growth does not increase in oil-exporting countries in response such events.

Figure 2.2 – Impulse Responses of Civil Violence, Labour Productivity Growth and Oil/NGL Production Growth to Drought

(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on civil violence, labour productivity growth and oil and natural gas liquids production growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

8 Conclusion

This paper assesses the effects of droughts on real GDP growth in Arab League members, Iran and Turkey, the region where water stress is the most accute in the world. It adds to the empirical literature on the macroeconomic effects of climate change by focusing on changes in drought patterns with respect to their historical norms, which capture the joint effect of temperatures and precipitations, instead of changes in temperatures and precipitations taken separately. The empirical strategy relies on two specifications of the local projections method that allow to assess the effects of drought deviations and sustained drought deviations from their historical norms over several horizons.

This paper finds that droughts lead to a decline in the contemporaneous output growth rate in oil-importing countries. The evidence in oil-exporting countries is mixed due to weak statistical significance but suggests at most a mild positive contemporary effect. In both cases, the effect does not strengthen as the horizon increases and vanishes after one year. Since this effect does not revert afterwards, drought do not have a permanent effect on output growth, but lead to a lasting loss in output level in oil-importing countries. This result resists a series of robustness checks on the drought index construction, the empirical specification and additional control variables.

The analysis of the transmission mechanisms indicate that the observed temporary decline in real GDP growth in oil-importing countries of the region in response to an increase in the drought index can be partially explained by an temporary adverse effect on the agricultural sector growth and a more lasting increase in civil violence. Labour productivity growth and oil and natural gas liquids output growth, two alternative potential transmission channels, do not appear to respond to droughts in the region.

This paper's results strongly advocate for economic diversification in oil-importing countries of the region. Output growth still depends substantially on the climate-dependent agricultural sector in several of these countries. Further diversification of their productive sectors would increase their business cycles' resilience to weather shock and climate change. Such a development strategy should therefore be incorporated in their set of adaptation policies and efforts, and be considered as such since it would allow to better cope with the effects of climate change. This global challenge, attributed mainly to past and current carbon emissions in countries outside of the region, makes economic diversification an even more pressing condition to foster resilient economies and lay the foundations for inclusive growth and sustainable development.

Several oil-exporting countries of the region have attempted to difersify their economies away from oil production and reduce their dependence on this sector, with heterogenous but limited success so far. This is partly due to changing regulations and increasing mitigation efforts in the EU and the US, among other countries. These efforts are essential to ensure future economic growth and sustainable development in oil-exporting countries, but this paper's results illustrate the fact that currently, the oil sector largely insulates their business cycles from weather shocks. The tourism sector is an important component in many of the current diversification strategies, in part due to its capacity to attract foreign currencies, but Covid-19 has shown that it is even more dependent on the international business cycle than the oil sector, and its resilience to droughts and climate change is far from certain. Economic diversification in these countries must therefore be carefully planned and carried out in order not to increase further their business cycle's dependence to exogenous shocks.

Future empirical research could assess the macroeconomic effects of droughts using higher frequency data. A growing strand of the literature has shown that income distribution matters for the business cycle, and droughts does not affect all individuals and social groups equally. Assessing the effects of droughts on income and wealth inequality could also provide valuable insight for the conduct and elaboration of both stabilization and structural economic policy in the region.

Appendix

2.A Data, Sources and Descriptive Statistics

Table 2.A.1 – List of Countries Included in the Sample

Arab League members, Iran and Turkey	United Arab Emirates, Comoros, Djibouti, Algeria, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Libyan, Morocco, Mauritania, Oman, Palestine, Qatar, Saudi Arabia, Sudan, Somalia, Syrian, Tunisia, Turkey, Yemen
Oil exporters	United Arab Emirates, Algeria, Iran, Iraq, Kuwait, Libyan, Oman, Qatar, Saudi Arabia, Yemen
Oil importers	Comoros, Djibouti, Egypt, Jordan, Lebanon, Morocco, Mauritania, Palestine, Sudan, Somalia, Syrian, Tunisia, Turkey

Note: Bahrain is not included in the sample due to missing data for the Standardized Precipitations Evapotranspiration Index.

Table 2.A.2 – Data Sources

Variable:	Source:
Socio-Economic Variables:	
Real GDP growth rate	World Bank - WDI (2020); IMF - IFS (2020)
Commodity terms of trade	Gruss and Kebhaj (2019)
Agricultural sector	USDA - ERS (2019)
Irrigation	FAOSTAT
Civil violence	Major Episodes of Political Violence (Center for Systemic Peace)
Labour productivity growth	ILOSTAT
Oil and NGL output growth	IEA Oil Information Statistics
Climate Variables:	
Standardized Precipitations-Evapotranspiration Index	Vicente-Serrano et al. (2010)
Terrestrial temperature and precipitation	Matsuura and Willmott (2019)
Climate-related natural disasters	CRED (2020)

Table 2.A.3 – Summary Statistics (Oil Exporters)

Variable	Obs.	Mean	Std. Dev.	Min.	Max.
GDP growth rate	458	5.03	12.76	-64.05	123.14
Drought index deviation[a]	580	0.58	0.72	-2.21	2.33
Temperatures deviation[a]	627	0.45	0.66	-1.17	2.68
Precipitations deviation[a]	627	-20.80	44.73	-171.49	538.44
Temperatures	627	24.39	2.86	15.98	28.64
Precipitations	627	124.42	71.55	11.58	729.67
Floods occurrence (EMDAT)	638	0.30	0.79	0.00	6.00
Extreme temperatures occurrence (EMDAT)	638	0.00	0.06	0.00	1.00
Landslide occurrence (EMDAT)	638	0.01	0.11	0.00	1.00
Storm occurrence (EMDAT)	638	0.06	0.26	0.00	2.00
Wildfire occurrence (EMDAT)	638	0.00	0.07	0.00	1.00
Commodity terms of trade	594	73.01	17.92	39.07	104.73
Civil violence	536	0.03	0.17	0.00	1.00
Agricultural output growth	605	0.05	0.15	-0.85	1.31
Agricultural TFP growth	605	0.02	0.14	-0.78	1.21
Livestock growth	605	0.03	0.09	-0.57	0.85
Share of irrigated land	641	11.28	13.04	0.40	55.56
Labour productivity growth	176	-0.00	0.15	-0.63	1.21
Oil and NGL output growth	524	0.05	0.44	-0.83	7.55

Note: [a] Deviation from the historical norm, which corresponds to the period 1901–1950.

Table 2.A.4 – Summary Statistics (Oil Importers)

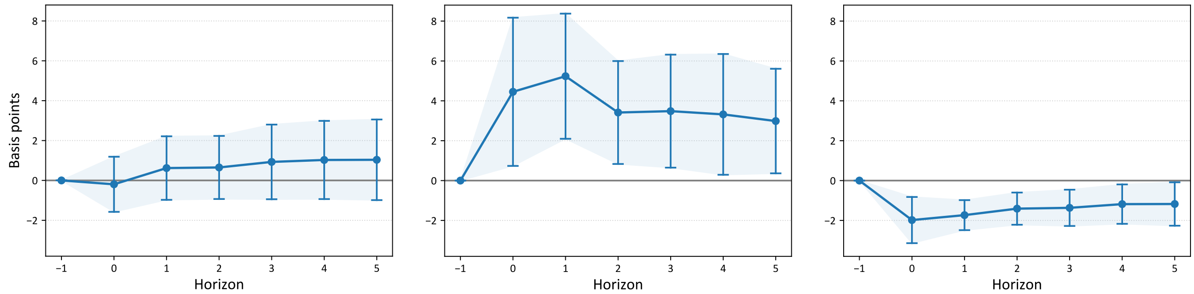
Variable	Obs.	Mean	Std. Dev.	Min.	Max.
GDP growth rate	581	4.23	6.10	-42.45	49.45
Drought index deviation[a]	754	0.26	0.67	-1.93	2.20
Temperatures deviation[a]	741	0.32	0.67	-1.62	2.95
Precipitations deviation[a]	741	-42.70	111.40	-920.03	553.77
Temperatures	741	21.31	5.18	9.34	29.03
Precipitations	741	475.42	604.76	8.78	2946.00
Floods occurrence (EMDAT)	754	0.29	0.65	0.00	5.00
Extreme temperatures occurrence (EMDAT)	754	0.03	0.17	0.00	2.00
Landslide occurrence (EMDAT)	754	0.02	0.16	0.00	2.00
Storm occurrence (EMDAT)	754	0.07	0.31	0.00	3.00
Wildfire occurrence (EMDAT)	754	0.01	0.11	0.00	2.00
Commodity terms of trade	627	102.26	8.47	81.10	125.78
Civil violence	576	0.08	0.36	0.00	3.00
Agricultural output growth	682	0.03	0.11	-0.47	0.73
Agricultural TFP growth	682	0.02	0.11	-0.48	0.66
Livestock growth	682	0.02	0.07	-0.39	0.64
Share of irrigated land	741	12.24	26.25	0.05	100.00
Labour productivity growth	208	0.01	0.05	-0.24	0.19
Oil and NGL output growth	249	0.05	0.49	-1.00	5.79

Note: [a] Deviation from the historical norm, which corresponds to the period 1901–1950.

2.B Additional Robustness Checks

Figure 2.B.1 – Cumulative Response of GDP Growth to Cumulative Drought (3-Month SPEI)

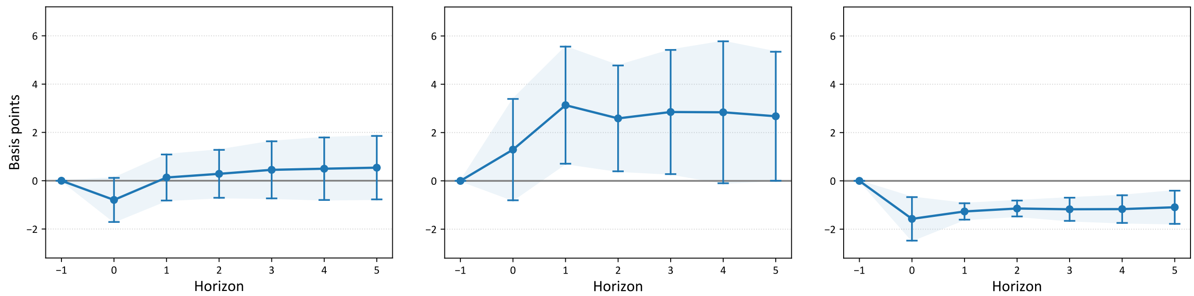
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in percentage points. Standard errors in parentheses are clustered at the country level. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

Figure 2.B.2 – Cumulative Response of GDP Growth to Cumulative Drought (12-Month SPEI)

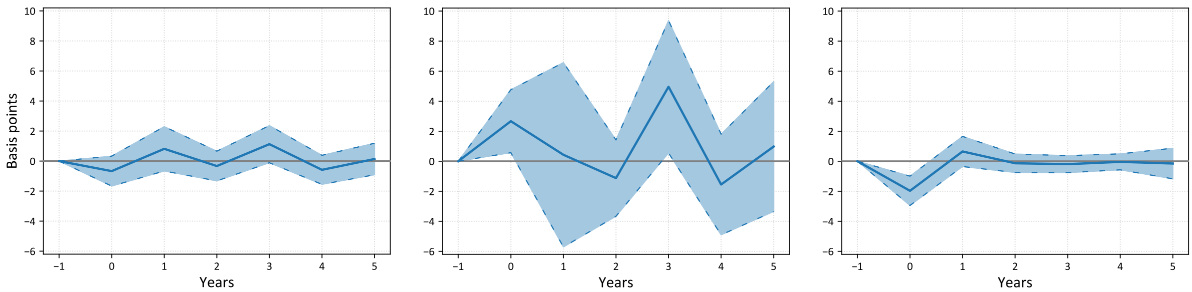
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in percentage points. Standard errors in parentheses are clustered at the country level. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

Figure 2.B.3 – Impulse Response of GDP Growth to Drought (inverse of the SPEI6 index)

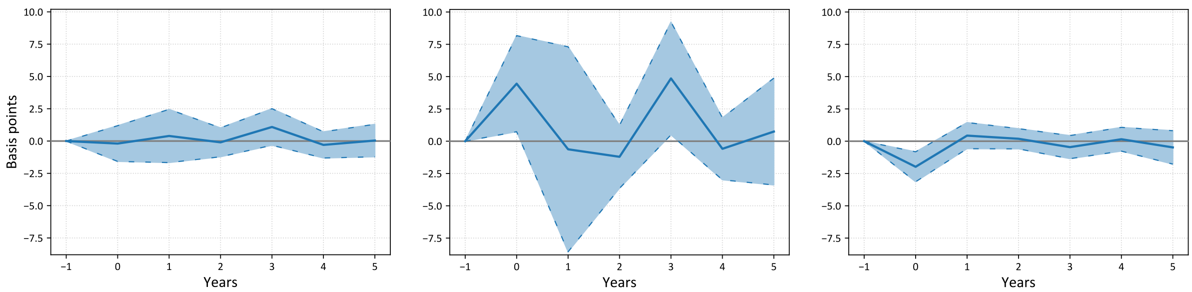
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of the drought index on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Figure 2.B.4 – Impulse Response of GDP Growth to Drought (3-Month SPEI)

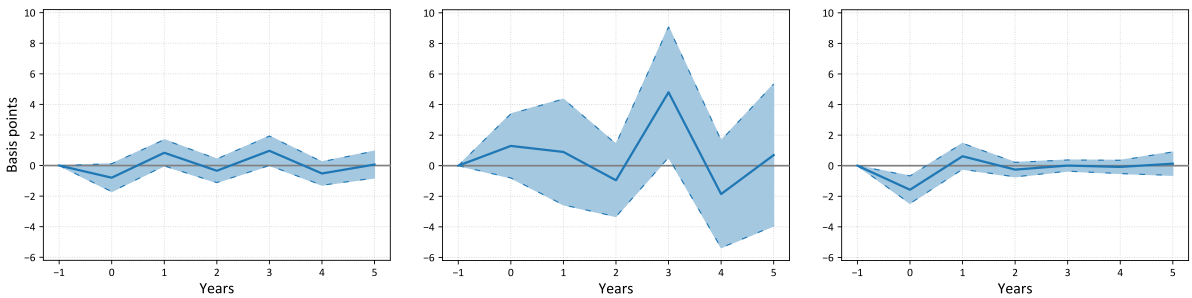
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Figure 2.B.5 – Impulse Response of GDP Growth to Drought (12-Month SPEI)

(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



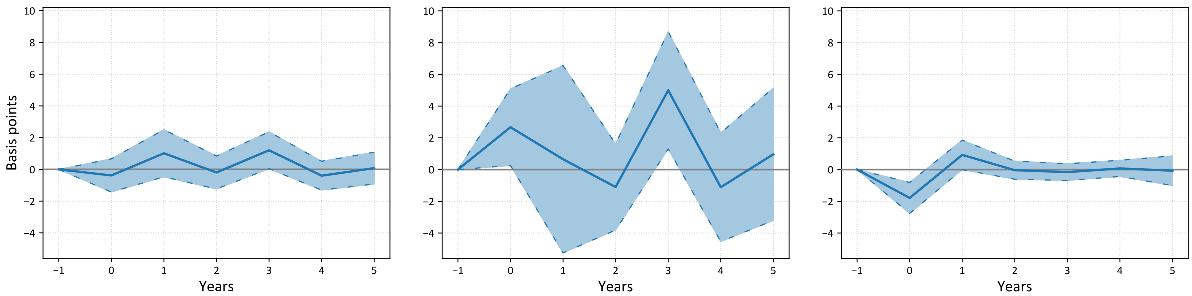
Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Figure 2.B.6 – Impulse Response of GDP Growth to Drought (Controls Include One Lag)

(a) Arab League members, Iran and Turkey

(b) Oil exporters

(c) Oil importers



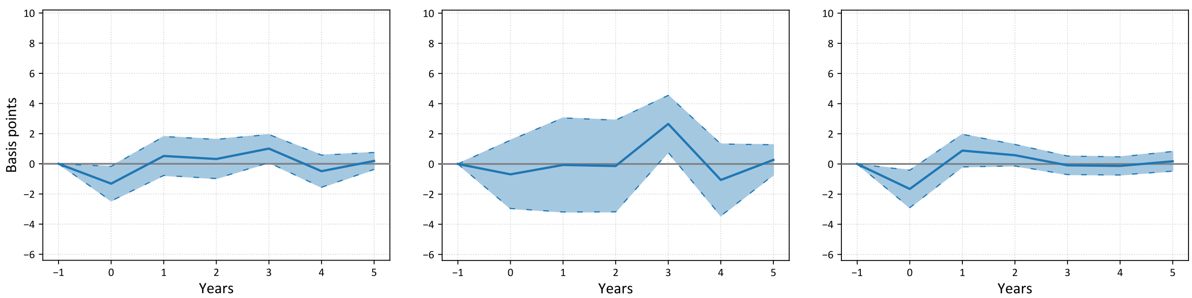
Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Figure 2.B.7 – Impulse Response of GDP Growth to Drought (Controls Include Country-Specific Linear and Quadratic Time Trend)

(a) Arab League members, Iran and Turkey

(b) Oil exporters

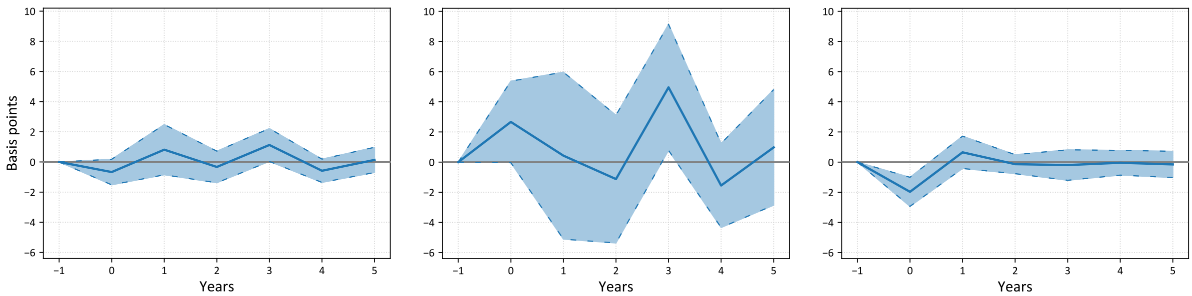
(c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Figure 2.B.8 – Impulse Response of GDP Growth to Drought (Driscoll and Kraay Standard Errors)

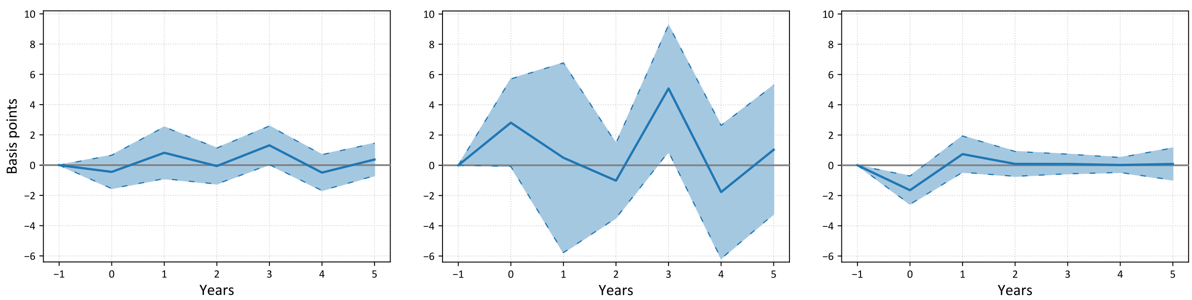
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level using Driscoll and Kraay standard errors (Driscoll and Kraay, 1998).

Figure 2.B.9 – Impulse Response of GDP Growth to Drought (Controls Include Temperature and Precipitations Deviations from their Historical Norms)

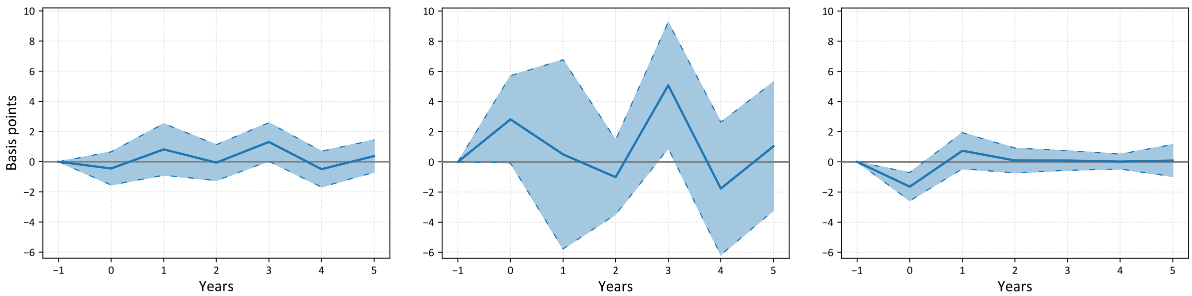
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Figure 2.B.10 – Impulse Response of GDP Growth to Drought (Controls Include Temperature and Precipitations Levels)

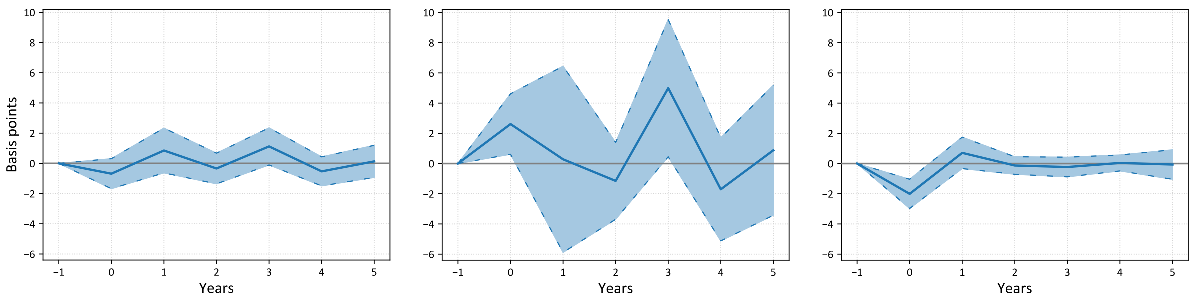
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Figure 2.B.11 – Impulse Response of GDP Growth to Drought (Controls Include Climate-Related Natural Disasters Occurrences)

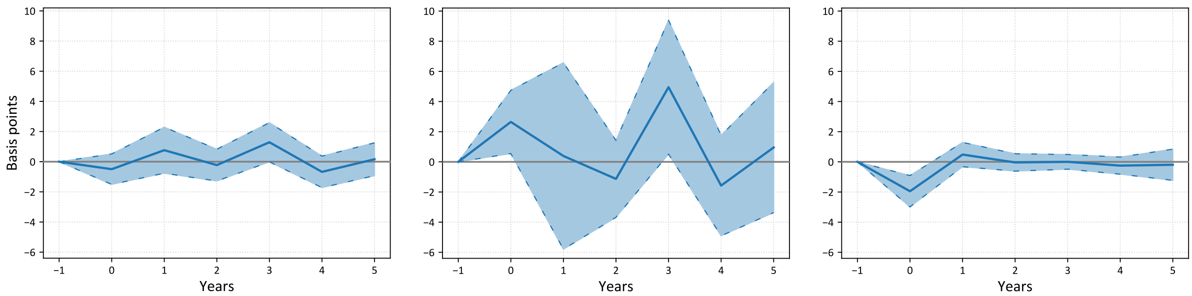
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Figure 2.B.12 – Impulse Response of GDP Growth to Drought (Controls Include Commodity Terms of Trade)

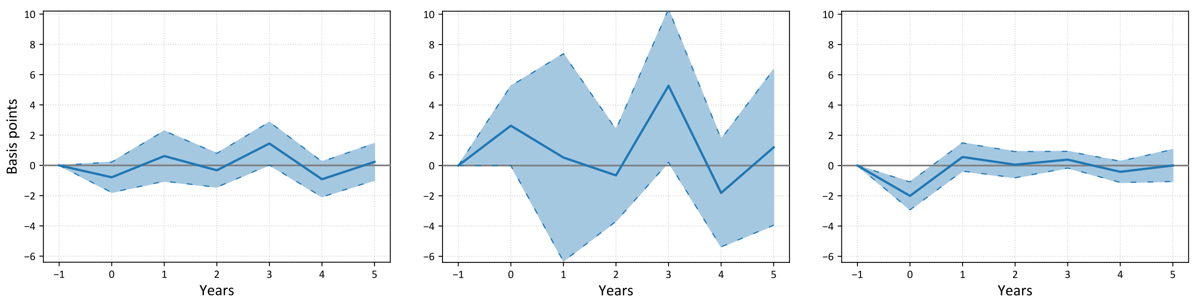
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Figure 2.B.13 – Impulse Response of GDP Growth to Drought (Controls Include Civil Conflict Intensity)

(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, ..., 5$. Confidence intervals correspond to the 10 % level.

Table 2.B.1 – Contemporary Response of GDP Growth to Drought, Excluding Countries One by One

Country Excluded	Coefficient	Standard Error	Observations	R^2
Panel A: Sample includes oil importers				
Baseline	*-0.020******	*(0.006)*	*529*	*0.18*
Comoros	-0.022***	(0.007)	493	0.20
Djibouti	-0.020***	(0.006)	526	0.18
Egypt	-0.022***	(0.006)	473	0.20
Jordan	-0.020**	(0.006)	489	0.18
Lebanon	-0.019***	(0.006)	501	0.19
Morocco	-0.018**	(0.007)	479	0.20
Mauritania	-0.019**	(0.006)	474	0.21
Palestine	-0.021***	(0.006)	507	0.19
Somalia	-0.019**	(0.006)	498	0.22
Sudan	-0.021**	(0.007)	473	0.19
Syria	-0.015***	(0.004)	484	0.17
Tunisia	-0.021***	(0.006)	478	0.19
Turkey	-0.020**	(0.007)	473	0.20
Panel B: Sample includes oil exporters				
Baseline	*0.027**	*(0.013)*	*383*	*0.22*
Algeria	0.037**	(0.013)	327	0.26
Iraq	0.035**	(0.012)	335	0.25
Iran	0.021	(0.013)	327	0.27
Kuwait	0.028*	(0.014)	359	0.23
Libya	0.023*	(0.012)	366	0.28
Oman	0.027	(0.016)	332	0.25
Qatar	0.027*	(0.014)	367	0.23
Saudi Arabia	0.020	(0.012)	335	0.25
United Arab Emirates	0.026*	(0.014)	342	0.23
Yemen	0.026	(0.015)	357	0.22

Note: The table reports the contemporary effect of droughts on output growth (*i.e.* for $h = 0$) when countries are excluded from their respective sample one by one. The estimates are in percentage points. Standard errors in parentheses are clustered at the country level. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

Bibliography

ABDEL-LATIF, H., H. ABOU-ALI, Y. ABDELFATAH, N. ROSTOM, A. ABDELFATAH, AND S. KAAWACH (2021): "Stolen Dreams or Collateral Damage: Climate and Economic Growth in Time of Covid-19," *ERF Working Paper No. 1523*.

ABDELFATTAH, Y., A. ABDELFATTAH, H. ABOU-ALI, AND H. ABDEL-LATIF (2021): "Long-Term Macroeconomic Effects of Climate Change: Evidence from the MENA Region," *ERF Conference Paper*.

ABOU-ALI, H., R. HAWASH, R. ALI, AND Y. ABDELFATTAH (2021): "Is it Getting Too Hot to Work in the MENA Region?" *ERF Working Paper No. 1515*.

ACEMOGLU, D., S. JOHNSON, AND J. A. ROBINSON (2002): "Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution," *The Quarterly Journal of Economics*, 117, 1231–1294.

ACEVEDO, S. (2014): "Debt, Growth and Natural Disasters: A Caribbean Trilogy," *IMF Working Paper 14/125*.

——— (2016): "Gone With the Wind: Estimating Hurricane and Climate Change Costs in the Caribbean," *IMF Working Paper 16/199*.

ACEVEDO, S., C. BACCIANTI, M. MRKAIC, N. NOVTA, E. PUGACHEVA, AND P. TOPALOVA (2019): "Weather Shocks and Output in Low-Income Countries: The Role of Policies and Adaptation," *IMF Working Paper 19/178*.

ACEVEDO, S., M. MRKAIC, N. NOVTA, M. POPLAWSKI-RIBEIRO, E. PUGACHEVA, AND P. TOPALOVA (2017): "The Effects of Weather Shocks on Economic Activity: How Can Low-Income Countries Cope?" *IMF World Economic Outlook, Chapter 3*.

ACEVEDO, S., M. MRKAIC, N. NOVTA, E. PUGACHEVA, AND P. TOPALOVA (2020): "The Effects of Weather Shocks on Economic Activity: What are the Channels of Impact?" *Journal of Macroeconomics*, 65, 103207.

ALBUQUERQUE, P. H. AND W. RAJHI (2019): "Banking Stability, Natural Disasters, and State Fragility: Panel VAR Evidence from Developing Countries," *Research in International Business and Finance*, 50.

ALESTRA, C., G. CETTE, V. CHOUARD, AND R. LECAT (2022): "Growth Impact of Climate Change and Response Policies: The Advanced Climate Change Long-Term (ACCL) Model," *Journal of Policy Modeling*, 44, 96–112.

ARAGÓN, F. M., F. OTEIZA, AND J. P. RUD (2021): "Climate Change and Agriculture: Subsistence Farmers' Response to Extreme Heat," *American Economic Journal: Economic Policy*, 13, 1–35.

ARCAND, J.-L., P. GUILLAUMONT, AND S. GUILLAUMONT JEANNENEY (2008): "Deforestation and the Real Exchange Rate," *Journal of Development Economics*, 86, 242–262.

AROURI, M., C. NGUYEN, AND A. BEN YOUSSEF (2015): "Natural Disasters, Household Welfare, and Resilience: Evidence from Rural Vietnam," *World Development*, 70, 59–77.

AUFFHAMMER, M. (2018): "Quantifying Economic Damages from Climate Change," *Journal of Economic Perspectives*, 32, 33–52.

AUFFHAMMER, M. AND M. E. KAHN (2018): "Chapter 5 - The Farmer's Climate Change Adaptation Challenge in Least Developed Countries," in *Handbook of Environmental Economics*, ed. by P. Dasgupta, S. K. Pattanayak, and V. K. Smith, Elsevier, vol. 4, 193–229.

BARNETT, M., W. A. BROCK, AND L. P. HANSEN (2020): "Pricing Uncertainty Induced by Climate Change," *The Review of Financial Studies*, 33, 1024–1066.

BARRECA, A., O. DESCHENES, AND M. GULDI (2015): "Maybe Next Month? Temperature Shocks, Climate Change, and Dynamic Adjustments in Birth Rates," *NBER Working Paper 21681*.

BARRECA, A. AND J. SCHALLER (2019): "The Impact of High Ambient Temperatures on Delivery Timing and Gestational Lengths," *Nature Climate Change*.

BENTO, A., N. S. MILLER, M. MOOKERJEE, AND E. R. SEVERNINI (2020): "A Unifying Approach to Measuring Climate Change Impacts and Adaptation," *NBER Working Paper 27247*.

BINDOFF, N. L., P. A. STOTT, K. M. ACHUTARAO, M. R. ALLEN, N. GILLETT, D. GUTZLER, K. HANSINGO, G. HEGERL, Y. HU, S. JAIN, I. I. MOKHOV, J. OVERLAND, J. PERLWITZ, R. SEBBARI, AND X. ZHANG (2013): "Detection and Attribution of Climate Change: From Global to Regional," in *Climate Change 2013: The Physical Science Basis. IPCC Working Group I Contribution to AR5*, Cambridge University Press.

BODEN, T., R. ANDRES, AND G. MARLAND (2017): "Global, Regional, and National Fossil-Fuel CO2 Emissions (1751-2014)," *Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States).*

BREI, M., P. MOHAN, AND E. STROBL (2019): "The Impact of Natural Disasters on the Banking Sector: Evidence from Hurricane Strikes in the Caribbean," *The Quarterly Review of Economics and Finance*, 72, 232–239.

BRETSCHGER, L. AND S. VALENTE (2011): "Climate Change and Uneven Development," *The Scandinavian Journal of Economics*, 113, 825–845.

BUCKLE, R. A., K. KIM, H. KIRKHAM, N. MCLELLAN, AND J. SHARMA (2007): "A Structural VAR Business Cycle Model for a Volatile Small Open Economy," *Economic Modelling*, 24, 990–1017.

BURKE, M., W. M. DAVIS, AND N. S. DIFFENBAUGH (2018): "Large Potential Reduction in Economic Damages Under UN Mitigation Targets," *Nature*, 557, 549–553.

BURKE, M., J. DYKEMA, D. B. LOBELL, E. MIGUEL, AND S. SATYANATH (2015a): "Incorporating Climate Uncertainty Into Estimates of Climate Change Impacts," *Review of Economics and Statistics*, 97, 461–471.

BURKE, M. AND K. EMERICK (2016): "Adaptation to Climate Change: Evidence from US Agriculture," *American Economic Journal: Economic Policy*, 8, 106–40.

BURKE, M., S. M. HSIANG, AND E. MIGUEL (2015b): "Climate and Conflict," *Annual Review of Economics*, 7, 577–617.

——— (2015c): "Global Non-Linear Effect of Temperature on Economic Production," *Nature*, 527, 235–239.

BURKE, M. B., E. MIGUEL, S. SATYANATH, J. A. DYKEMA, AND D. B. LOBELL (2009): "Warming Increases the Risk of Civil War in Africa," *Proceedings of the National Academy of Sciences*, 106, 20670–20674.

CAI, Y., K. L. JUDD, AND T. S. LONTZEK (2013): "The Social Cost of Stochastic and Irreversible Climate Change," *NBER Working Paper 18704*.

CANTELMO, A., G. MELINA, AND C. PAPAGEORGIOU (2019): "Macroeconomic Outcomes in Disaster-Prone Countries," *IMF Working Paper 19/217*.

CARLETON, T. A. AND S. M. HSIANG (2016): "Social and Economic Impacts of Climate," *Science*, 353.

CARTER, M. R., P. D. LITTLE, T. MOGUES, AND W. NEGATU (2007): "Poverty Traps and Natural Disasters in Ethiopia and Honduras," *World Development*, 35, 835–856.

CASHIN, P. AND S. SOSA (2013): "Macroeconomic Fluctuations in the Eastern Caribbean: The Role of Climatic and External Shocks," *The Journal of International Trade & Economic Development*, 22, 729–748.

CAVALLO, E., S. GALIANI, I. NOY, AND J. PANTANO (2013): "Catastrophic Natural Disasters and Economic Growth," *Review of Economics and Statistics*, 95, 1549–1561.

CEBALLOS, F., B. KRAMER, AND M. ROBLES (2019): "The Feasibility of Picture-Based Insurance (PBI): Smartphone Pictures for Affordable Crop Insurance," *Development Engineering*, 4, 100042.

CÉSPEDES, L. F. AND A. VELASCO (2014): "Was This Ttime Different?: Fiscal Policy in Commodity Republics," *Journal of Development Economics*, 106, 92–106.

CHAUVET, L. AND L. JACOLIN (2017): "Financial Inclusion, Bank Concentration, and Firm Performance," *World Development*, 97, 1–13.

CHRISTIAN, C. AND L. ELBOURNE (2018): "Shocks to Military Support and Subsequent Assassinations in Ancient Rome," *Economics Letters*, 171, 79–82.

COLACITO, R., B. HOFFMANN, AND T. PHAN (2019): "Temperature and Growth: A Panel Analysis of the United States," *Journal of Money, Credit and Banking*, 51, 313–368.

COOK, J., N. ORESKES, P. T. DORAN, W. R. ANDEREGG, B. VERHEGGEN, E. W. MAIBACH, J. STUART CARLTON, S. LEWANDOWSKY, A. G. SKUCE, S. A. GREEN, D. NUCCITELLI, P. JACOBS, M. RICHARDSON, B. WINKLER, R. PAINTING, AND K. RICE (2016): "Consensus on Consensus: A Synthesis of Consensus Estimates on Human-Caused Global Warming," *Environmental Research Letters*, 11, 048002.

COPELAND, B. R. AND M. S. TAYLOR (1994): "North-South Trade and the Environment," *The Quarterly Journal of Economics*, 109, 755–787.

COUHARDE, C., O. DAMETTE, R. GENEROSO, AND K. MOHADDES (2019): "The Growth Effects of El Niño and La Niña: Local Weather Conditions Matter," *Cambridge Working Papers in Economics 1992*.

COUHARDE, C. AND R. GÉNÉROSO (2017): "Croissance économique et seuils hydroclimatiques dans les pays en développement," *Mondes en développement*, 179, 67–84.

CENTRE FOR RESEARCH ON THE EPIDEMIOLOGY OF DISASTERS - CRED (2020): "EM-DAT," Online database. Brussels, Belgium, https://www.emdat.be/.

CENTRE FOR RESEARCH ON THE EPIDEMIOLOGY OF DISASTERS (2019): "EM-DAT The International Disaster Database," Online database. Brussels, https://emdat.be/.

DALLMANN, I. AND K. MILLOCK (2017): "Climate Variability and Inter-State Migration in India," *CESifo Economic Studies*, 63, 560–594.

DAMANIA, R., S. DESBUREAUX, AND E. ZAVERI (2020): "Does Rainfall Matter for Economic Ggrowth? Evidence from Global Sub-National Data (1990–2014)," *Journal of Environmental Economics and Management*, 102, 102335.

DAMETTE, O. AND S. GOUTTE (2022): "Beyond Climate and Conflict Relationships: New Evidence from a Copula-Based Analysis on an Historical Perspective," *Journal of Comparative Economics*.

DE BANDT, O., L. JACOLIN, AND T. LEMAIRE (2021): "Climate Change in Developing Countries: Global Warming Effects, Transmission Channels and Adaptation Policies," *Banque de France Working Paper 822*.

DELL, M., B. F. JONES, AND B. A. OLKEN (2012): "Temperature Shocks and Economic Growth: Evidence From the Last Half Century," *American Economic Journal: Macroeconomics*, 4, 66–95.

——— (2014): "What do we Learn From the Weather? The New Climate-Economy Literature," *Journal of Economic Literature*, 52, 740–98.

DESCHÊNES, O. AND M. GREENSTONE (2007): "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather," *American Economic Review*, 97, 354–385.

DEVADAS, S., I. ELBADAWI, AND N. V. LOAYZA (2021): "Growth in Syria: Losses from the War and Potential Recovery in the Aftermath," *Middle East Development Journal*, 13, 215–244.

DIAMOND, J. (1997): *Guns, Germs and Steel: The Fates of Human Societies*, New York: W. W. Norton & Company.

DIETZ, S., F. VAN DER PLOEG, A. REZAI, AND F. VENMANS (2020): "Are Economists Getting Climate Dynamics Right and Does it Matter?" *CESifo Working Paper Series 8122*.

DIFFENBAUGH, N. S. AND M. BURKE (2019): "Global Warming has Increased Global Economic Inequality," *Proceedings of the National Academy of Sciences*, 116, 9808–9813.

DRISCOLL, J. C. AND A. C. KRAAY (1998): "Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data," *Review of economics and statistics*, 80, 549–560.

EASTERLY, W. AND R. LEVINE (2003): "Tropics, Germs, and Crops: How Endowments Influence Economic Development," *Journal of Monetary Economics*, 50, 3–39.

EBERLE, U., D. ROHNER, AND M. THOENIG (2020): "Heat and Hate: Climate Security and Farmer-Herder Conflicts in Africa," *CEPR Discussion Paper 15542*.

EL HADRI, H., D. MIRZA, AND I. RABAUD (2018): "Why Natural Disasters Might Not Lead to a Fall in Exports in Developing Countries?" *Economic Research Department of the University of Orléans Working Paper 2018-09*.

——— (2019): "Natural Disasters and Countries' Exports: New Insights from a new (and an old) Database," *The World Economy*, 42, 2668–2683.

FEENSTRA, R. C., R. INKLAAR, AND M. P. TIMMER (2015): "The Next Generation of the Penn World Table," *American Economic Review*, 105, 3150–3182.

FELBERMAYR, G. AND J. GRÖSCHL (2014): "Naturally Negative: The Growth Effects of Natural Disasters," *Journal of Development Economics*, 111, 92–106.

FENSKE, J. AND N. KALA (2015): "Climate and the Slave Trade," *Journal of Development Economics*, 112, 19–32.

FERNÁNDEZ, A., A. GONZÁLEZ, AND D. RODRÍGUEZ (2018): "Sharing a Ride on the Commodities Roller Coaster: Common Factors in Business Cycles of Emerging Economies," *Journal of International Economics*, 111, 99–121.

FOMBY, T., Y. IKEDA, AND N. V. LOAYZA (2013): "The Growth Aftermath of Natural Disasters," *Journal of Applied Econometrics*, 28, 412–434.

FRIEDLINGSTEIN, P., M. W. JONES, M. O'SULLIVAN, R. M. ANDREW, J. HAUCK, G. P. PETERS, W. PETERS, J. PONGRATZ, S. SITCH, C. LE QUÉRÉ, D. C. E. BAKKER, J. G. CANADELL, P. CIAIS, R. B. JACKSON, P. ANTHONI, L. BARBERO, A. BASTOS, V. BASTRIKOV, M. BECKER, L. BOPP, E. BUITENHUIS, N. CHANDRA, F. CHEVALLIER, L. P. CHINI, K. I. CURRIE, R. A. FEELY, M. GEHLEN, D. GILFILLAN, T. GKRITZALIS, D. S. GOLL, N. GRUBER, S. GUTEKUNST, I. HARRIS, V. HAVERD, R. A. HOUGHTON, G. HURTT, T. ILYINA, A. K. JAIN, E. JOETZJER, J. O. KAPLAN, E. KATO, K. KLEIN GOLDEWIJK, J. I. KORSBAKKEN, P. LANDSCHÜTZER, S. K. LAUVSET, N. LEFÈVRE, A. LENTON, S. LIENERT, D. LOMBARDOZZI, G. MARLAND, P. C. MCGUIRE, J. R. MELTON, N. METZL, D. R. MUNRO, J. E. M. S. NABEL, S.-I. NAKAOKA, C. NEILL, A. M. OMAR, T. ONO, A. PEREGON, D. PIERROT, B. POULTER, G. REHDER, L. RESPLANDY, E. ROBERTSON, C. RÖDENBECK, R. SÉFÉRIAN, J. SCHWINGER, N. SMITH, P. P. TANS, H. TIAN, B. TILBROOK, F. N. TUBIELLO, G. R. VAN DER WERF, A. J. WILTSHIRE, AND S. ZAEHLE (2019): "Global Carbon Budget 2019," *Earth System Science Data*, 11, 1783–1838.

GALLIC, E. AND G. VERMANDEL (2020): "Weather Shocks," *European Economic Review*, 124, 103409.

GENEROSO, R., C. COUHARDE, O. DAMETTE, AND K. MOHADDES (2020): "The Growth Effects of El Niño and La Niña: Local Weather Conditions Matter," *Annals of Economics and Statistics*, 83–126.

GIOVANIS, E. AND O. OZDAMAR (2021): "The Transboundary Effects of Climate Change and Global Adaptation: The Case of the Euphrates-Tigris Water Basin in Turkey and Iraq," *ERF Working Paper No. 1517*.

GOLLIN, D., S. L. PARENTE, AND R. ROGERSON (2007): "The Food Problem and the Evolution of International Income Levels," *Journal of Monetary Economics*, 54, 1230–1255.

GRUSS, B. AND S. KEBHAJ (2019): "Commodity Terms of Trade: A New Database," *IMF Working Paper 19/21*.

HAGERTY, N. (2020): "Adaptation to Water Scarcity in Irrigated Agriculture," *Unpublished Manuscript*.

HEAL, G. (2017): "The Economics of the Climate," *Journal of Economic Literature*, 55, 1046–1063.

——— (2020): "The Economic Case for Protecting Biodiversity," *NBER Working Paper 27963*.

HOEKSTRA, A. Y. AND P. Q. HUNG (2005): "Globalisation of Water Resources: International Virtual Water Flows in Relation to Crop Trade," *Global Environmental Change*, 15, 45–56.

HSIANG, S. (2016): "Climate Econometrics," *Annual Review of Resource Economics*, 8, 43–75.

HSIANG, S., R. KOPP, A. JINA, J. RISING, M. DELGADO, S. MOHAN, D. RASMUSSEN, R. MUIR-WOOD, P. WILSON, AND M. OPPENHEIMER (2017): "Estimating Economic Damage from Climate Change in the United States," *Science*, 356, 1362–1369.

HSIANG, S. AND R. E. KOPP (2018): "An Economist's Guide to Climate Change Science," *Journal of Economic Perspectives*, 32, 3–32.

HSIANG, S. M. AND M. BURKE (2014): "Climate, Conflict, and Social Stability: What Does the Evidence Say?" *Climatic Change*, 123, 39–55.

HSIANG, S. M., M. BURKE, AND E. MIGUEL (2013): "Quantifying the Influence of Climate on Human Conflict," *Science*, 341, 1235367.

HSIANG, S. M., K. C. MENG, AND M. A. CANE (2011): "Civil Conflicts are Associated with the Global Climate," *Nature*, 476, 438–441.

HUNJRA, A. I., T. TAYACHI, M. I. CHANI, P. VERHOEVEN, AND A. MEHMOOD (2020): "The Moderating Effect of Institutional Quality on the Financial Development and Environmental Quality Nexus," *Sustainability*, 12, 3805.

IBN KHALDUN (1377): *Muqaddimah*, Tunisia.

INTERNATIONAL MONETARY FUND (2020): "International Financial Statistics," Online database. Washington, D.C., https://data.imf.org/IFS.

JACOLIN, L., J. KENECK MASSIL, AND A. NOAH (2021): "Informal Sector and Mobile Financial Services in Emerging and Developing Countries: Does Financial Innovation Matter?" *The World Economy*.

JANVRY, A. D., E. RAMIREZ RITCHIE, AND E. SADOULET (2016): "Weather Index Insurance and Shock Coping: Evidence from Mexico's CADENA Program," *World Bank Policy Research Working Paper 7715*.

JORDÀ, Ò. (2005): "Estimation and Inference of Impulse Responses by Local Projections," *American Economic Review*, 95, 161–182.

KAHN, M. E. (2005): "The Death Toll from Natural Disasters: The Role of Income, Geography, and Institutions," *Review of Economics and Statistics*, 87, 271–284.

KAHN, M. E., K. MOHADDES, R. N. C. NG, M. H. PESARAN, M. RAISSI, AND J.-C. YANG (2021): "Long-Term Macroeconomic Effects of Climate Change: A Cross-Country Analysis," *Energy Economics*, 104, 105624.

KALKUHL, M. AND L. WENZ (2020): "The Impact of Climate Conditions on Economic Production. Evidence from a Global Panel of Regions," *Journal of Environmental Economics and Management*, 103, 102360.

KARAHASAN, B. C. AND M. PINAR (2021): "Climate Change and Spatial Agricultural Development in Turkey," *ERF Working Paper No. 1524*.

KEEN, S. (2020): "The Appallingly Bad Neoclassical Economics of Climate Change," *Globalizations*, 1–29.

KEERTHIRATNE, S. AND R. S. TOL (2017): "Impact of Natural Disasters on Financial Development," *Economics of Disasters and Climate Change*, 1, 33–54.

——— (2018): "Impact of Natural Disasters on Income Inequality in Sri Lanka," *World Development*, 105, 217–230.

KIM, J., A. LEE, AND M. ROSSIN-SLATER (2019): "What to Expect When it Gets Hotter: The Impacts of Prenatal Exposure to Extreme Heat on Maternal and Infant Health," *NBER Working Paper 26384*.

KLOMP, J. (2014): "Financial Fragility and Natural Disasters: An Empirical Analysis," *Journal of Financial Stability*, 13, 180–192.

——— (2017): "Flooded With Debt," *Journal of International Money and Finance*, 73, 93–103.

——— (2020): "Do Natural Disasters Affect Monetary Policy? A Quasi-Experiment of Earthquakes," *Journal of Macroeconomics*, 64, 103164.

KLOMP, J. AND K. VALCKX (2014): "Natural Disasters and Economic Growth: A Meta-Analysis," *Global Environmental Change*, 26, 183–195.

KOMPAS, T., V. H. PHAM, AND T. N. CHE (2018): "The Effects of Climate Change on GDP by Country and the Global Economic Gains from Complying with the Paris Climate Accord," *Earth's Future*, 6, 1153–1173.

KOTZ, M., L. WENZ, A. STECHEMESSER, M. KALKUHL, AND A. LEVERMANN (2021): "Day-to-day Temperature Variability Reduces Economic Growth," *Nature Climate Change*, 11, 319–325.

KOUSKY, C. (2014): "Informing Climate Adaptation: A Review of the Economic Costs of Natural Disasters," *Energy Economics*, 46, 576–592.

LAMPERTI, F., V. BOSETTI, A. ROVENTINI, AND M. TAVONI (2019): "The Public Costs of Climate-Induced Financial Instability," *Nature Climate Change*, 9, 829–833.

LAMPERTI, F., G. DOSI, M. NAPOLETANO, A. ROVENTINI, AND A. SAPIO (2018): "Faraway, So Close: Coupled Climate and Economic Dynamics in an Agent-Based Integrated Assessment Model," *Ecological Economics*, 150, 315–339.

LANCESSEUR, N., C. LABROUSSE, M. VALDENAIRE, AND M. NAKAA (2020): "Impact économique du changement climatique : revue des méthodologies d'estimation, résultats et limites," *Document de Travail de la DG Trésor 2020/4*.

LAZZARONI, S. AND P. A. G. VAN BERGEIJK (2014): "Natural Disasters' Impact, Factors of Resilience and Development: A Meta-Analysis of the Macroeconomic Literature," *Ecological Economics*, 107, 333–346.

LEMAIRE, T. (2021): "Civil Conflicts and Exchange Rate Misalignment: Evidence from MENA and Arab League Members," *ERF Working Paper No. 1495*.

——— (2022): "Drought and Growth in Arab League Members, Iran and Turkey," *ERF 28th Annual Conference Paper*.

LIS, E. M. AND C. NICKEL (2010): "The Impact of Extreme Weather Events on Budget Balances," *International Tax and Public Finance*, 17, 378–399.

LOAYZA, N. V., E. OLABERRIA, J. RIGOLINI, AND L. CHRISTIAENSEN (2012): "Natural Disasters and Growth: Going Beyond the Averages," *World Development*, 40, 1317–1336.

MATSUURA, K. AND C. J. WILLMOTT (2019): "Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series (1900–2017)," *University of Delaware*, v.5.01.

MCGUIRK, E. F. AND N. NUNN (2020): "Nomadic Pastoralism, Climate Change, and Conflict in Africa," *NBER Working Paper 28243*.

MCKEE, T. B., N. J. DOESKEN, AND J. KLEIST (1993): "The Relationship of Drought Frequency and Duration to Time Scales," *Proceedings of the 8th Conference on Applied Climatology*, 17, 179–183.

MOHAN, P. S., B. OUATTARA, AND E. STROBL (2018): "Decomposing the Macroeconomic Effects of Natural Disasters: A National Income Accounting Perspective," *Ecological Economics*, 146, 1–9.

MONTESQUIEU (1748): *De l'Esprit des Lois*, Geneva, Switzerland.

NEWELL, R. G., B. C. PREST, AND S. E. SEXTON (2021): "The GDP-Temperature Relationship: Implications for Climate Change Damages," *Journal of Environmental Economics and Management*, 108, 102445.

NORDHAUS, W. D. (1977): "Economic Growth and Climate: the Carbon Dioxide Problem," *The American Economic Review*, 67, 341–346.

——— (1992): "An Optimal Transition Path for Controlling Greenhouse Gases," *Science*, 258, 1315–1319.

——— (2008): *A Question of Balance: Weighing the Options on Global Warming Policies*, Yale University Press.

NOY, I. (2009): "The Macroeconomic Consequences of Disasters," *Journal of Development Economics*, 88, 221–231.

NOY, I. AND W. DUPONT IV (2016): "The Long-Term Consequences of Natural Disasters: A Summary of the Literature," *SEF Working Paper 02/2016*.

ORTIZ-BOBEA, A., T. R. AULT, C. M. CARRILLO, R. G. CHAMBERS, AND D. B. LOBELL (2021): "Anthropogenic Climate Change has Slowed Global Agricultural Productivity Growth," *Nature Climate Change*, 11, 306–312.

OUATTARA, B. AND E. STROBL (2013): "The Fiscal Implications of Hurricane Strikes in the Caribbean," *Ecological Economics*, 85, 105–115.

PALMER, W. C. (1965): "Meteorological Drought," *US Department of Commerce, Research Paper No.*, 65.

PINDYCK, R. S. (2013): "Climate Change Policy: What Do the Models Tell Us?" *Journal of Economic Literature*, 51, 860–72.

RAMEY, V. A. AND S. ZUBAIRY (2018): "Government Spending Multipliers in Good Times and in Bad: Evidence from US Historical Data," *Journal of Political Economy*, 126, 850–901.

RANSON, M. (2014): "Crime, Weather, and Climate Change," *Journal of Environmental Economics and Management*, 67, 274–302.

REZAI, A., D. K. FOLEY, AND L. TAYLOR (2012): "Global Warming and Economic Externalities," *Economic theory*, 49, 329–351.

RODRIK, D. (2016): "Premature Deindustrialization," *Journal of Economic Growth*, 21, 1–33.

RODRIK, D., A. SUBRAMANIAN, AND F. TREBBI (2004): "Institutions Rule: The Primacy of Institutions Over Geography and Integration in Economic Development," *Journal of Economic Growth*, 9, 131–165.

SACHS, J. D. (2003): "Institutions Don't Rule: Direct Effects of Geography on Per Capita Income," *NBER Working Paper 9490*.

SCHULTZ, T. W. (1953): *Economic Organization of Agriculture*, New York: McGraw-Hill Book Company Inc.

SINDING BENTZEN, J. (2019): "Acts of God? Religiosity and Natural Disasters across Subnational World Districts," *The Economic Journal*, 129, 2295–2321.

SKIDMORE, M. AND H. TOYA (2002): "Do Natural Disasters Promote Long-Run Growth?" *Economic Inquiry*, 40, 664–687.

STROBL, E. (2012): "The Economic Growth Impact of Natural Disasters in Developing Countries: Evidence from Hurricane Strikes in the Central American and Caribbean Regions," *Journal of Development Economics*, 97, 130–141.

SUN, Q., C. MIAO, M. HANEL, A. G. BORTHWICK, Q. DUAN, D. JI, AND H. LI (2019): "Global Heat Stress on Health, Wildfires, and Agricultural Crops Under Different Levels of Climate Warming," *Environment International*, 128, 125–136.

Svartzman, R., E. Espagne, J. Gauthey, P. Hadji-Lazaro, M. Salin, T. Allen, J. Berger, J. Calas, A. Godin, and A. Vallier (2021): “A ”Silent Spring” for the Financial System? Exploring Biodiversity-Related Financial Risks in France,” *Banque de France Working Paper 826*.

Taraz, V. (2018): “Can Farmers Adapt to Higher Temperatures? Evidence from India,” *World Development*, 112, 205–219.

Tol, R. S. (2002): “Estimates of the Damage Costs of Climate Change, Part II. Dynamic Estimates,” *Environmental and Resource Economics*, 21, 135–160.

——— (2018): “The Economic Impacts of Climate Change,” *Review of Environmental Economics and Policy*, 12, 4–25.

——— (2020): “The Economic Impacts of Weather and Climate,” *Unpublished Manuscript*.

Toya, H. and M. Skidmore (2007): “Economic Development and the Impacts of Natural Disasters,” *Economics Letters*, 94, 20–25.

United Nations Development Programme (2019): “Human Development Index Data,” Online database. New York, N.Y., http://hdr.undp.org/en/data.

United States Department of Agriculture Economic Research Service (2019): “International Agricultural Productivity,” Online database. Washington, D.C., https://www.ers.usda.gov/data-products/international-agricultural-productivity/.

Vicente-Serrano, S. M., S. Beguería, J. I. López-Moreno, M. Angulo, and A. El Kenawy (2010): “A New Global 0.5 Gridded Dataset (1901–2006) of a Multiscalar Drought Index: Comparison With Current Drought Index Datasets Based on the Palmer Drought Severity Index,” *Journal of Hydrometeorology*, 11, 1033–1043.

Weitzman, M. L. (2009): “On Modeling and Interpreting the Economics of Catastrophic Climate Change,” *The Review of Economics and Statistics*, 91, 1–19.

——— (2010): “What Is The "Damages Function" For Global Warming — And What Difference Might It Make?” *Climate Change Economics*, 1, 57–69.

The World Bank (2019): “World Development Indicators,” Online database. Washington, D.C., https://databank.worldbank.org/source/world-development-indicators.

——— (2020): "World Development Indicators," Online database. Washington, D.C., https://databank.worldbank.org/source/world-development-indicators.

Xu, C., T. A. Kohler, T. M. Lenton, J.-C. Svenning, and M. Scheffer (2020): "Future of the Human Climate Niche," *Proceedings of the National Academy of Sciences*.

Yüksel, E., H. Ikizler, and A. E. Mutlu (2021): "Potential Impact of Climate Change on Food Consumption Through Price Channel: Case for Turkey," *ERF Working Paper No. 1516*.