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Essays on the Macroeconomic Effects of Climate Change in Developing Countries

Thibault Lemaire

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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

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**ESSAIS SUR LES EFFETS MACROÉCONOMIQUES DU
CHANGEMENT CLIMATIQUE DANS LES PAYS EN
DÉVELOPPEMENT**

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PHD THESIS

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

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**ESSAYS ON THE MACROECONOMIC EFFECTS OF CLIMATE
CHANGE IN DEVELOPING COUNTRIES**

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Table of Contents

Acknowledgements	vii
List of Figures	xvi
List of Tables	xviii
Glossary	xix
General Introduction	1
1 Climate Change and the Macroeconomy	1
2 Some Stylized Facts About Climate Change	2
3 Quantifying the Impacts of Climate Change: Empirical Issues	6
4 Contribution of this Dissertation	8
4.1 Chapter 1	8
4.2 Chapter 2	8
4.3 Chapter 3	9
4.4 Chapter 4	9
4.5 Chapter 5	10
I Macroeconomic Effects of Climate Change	11
1 Climate Change in Developing Countries: Global Warming Effects, Transmission Channels and Adaptation Policies	13
1 Introduction	14
2 Review of the Literature	17
2.1 Structural Macroeconomic Models	17
2.2 Calibration of the Damage Function	18
2.3 Empirical Macroeconomic Approaches	19
2.4 Distinguishing Climate Change from Weather Shocks	21
2.5 Contribution to the Literature	22
3 Data and Stylized Facts	22
3.1 Socio-Economic data	23

Table of Contents

3.2	Climate data	23
3.3	Carbon Dioxide Emissions	24
3.4	Climate Change: A Descriptive Analysis	25
4	Empirical Framework	30
5	Macroeconomic Effects of Global Warming	32
5.1	Main Results	32
5.2	Cumulative Effects of Past Climate Change on Actual Income per Capita	38
5.3	Robustness	40
6	Transmission Channels	43
6.1	A Shift in the Composition of Demand	43
6.2	Distinct Sectoral Effects	46
7	The Role of Structural Policies	48
8	Conclusion	52
	Appendix	54
1.A	Country List, Classification and Data Sources	54
1.B	Additional Results and Robustness Checks	56
1.C	Additional Transmission Channels	61
1.D	Additional Policy Results	66
2	Drought and Growth in the Middle East and North Africa	67
1	Introduction	68
2	Review of the Literature	70
3	Data and Stylized Facts	71
4	Empirical Framework	75
5	Results	77
6	Robustness Tests	82
7	Transmission Channels	85
8	Conclusion	89
	Appendix	92
2.A	Data, Sources and Descriptive Statistics	92
2.B	Additional Robustness Checks	94
II	Climate Change, Weather Shocks and Finance	101
3	Climate-Related Natural Disasters and the Exchange Rate in Developing Countries	103

1	Introduction	104
2	Real Exchange Rate Misalignment	106
3	Data and Stylized Facts	109
3.1	Real Exchange Rate Misalignment	109
3.2	Climate-related Natural Disasters	109
3.3	Other Socio-economic Variables	114
4	Empirical Framework	114
5	Results	115
5.1	Main Results	115
5.2	Dynamic Approach	117
5.3	Heterogenous Effects	119
6	Transmission Channels	122
7	Conclusion	124
	Appendix	126
3.A	Sample and Data Sources	126
3.B	Robustness Tests	129
4	Climate-Related Natural Disasters and Financial Stability in Developing Countries	133
1	Introduction	134
2	Data and Stylized Facts	135
2.1	Climate-related Natural Disasters	136
2.2	Financial Stability Variables	137
3	Empirical Framework	137
4	Results	138
5	Robustness	142
6	Conclusion	144
	Appendix	145
4.A	Sample and Data Sources	145
5	Climate Variability and International Migrations From Low-Income Countries: Does Financial Inclusion Matter?	147
1	Introduction	148
2	Review of the Literature	150
3	Data and Stylized Facts	153
3.1	Migration Data	153
3.2	Climate Data	154

Table of Contents

3.3	Financial Inclusion Data	155
3.4	Socio-Economic Data	155
3.5	Stylized Facts	156
4	Empirical Framework	157
5	Results	159
6	Conclusion	164
	Appendix	166
5.A	Data Sources	166
5.B	Additional Results	168
6	Résumé de la thèse	171
1	Changement climatique et macroéconomie	171
2	Faits stylisés sur le changement climatique	172
3	Quantifier les effets du changement climatique : défis empiriques	177
4	Contribution de cette thèse	179
4.1	Chapitre 1	179
4.2	Chapitre 2	183
4.3	Chapitre 3	185
4.4	Chapitre 4	187
4.5	Chapitre 5	189

List of Figures

1	Global Mean Annual Temperature	2
2	Global Atmospheric CO ₂ Concentration	3
3	Temperature Deviation, by Region	4
4	Precipitations Deviation, by Region	5
5	Global Average Temperature Increase Relative to Pre-Industrial Era . . .	6
1.1	Yearly Temperature difference: 2001-2017 Vs. 1900-1950	25
1.2	Temperature Dynamics (1900 - 2017), by Region	26
1.3	Yearly Precipitations difference: 2001-2017 Vs. 1900-1950	27
1.4	Precipitations Dynamics (1900 - 2017), by Region	28
1.5	Global Carbon Dioxide Emissions, 1751 - 2014	29
1.6	Share of Total Historical Carbon Dioxide Emissions, in 2014	29
1.7	Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, Using Temperatures of the Full Sample	33
1.8	Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, Using Temperatures of the Full Sample Period	35
1.9	Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP in Lowest Income Countries, Using Recent Temperatures	37
1.10	Cumulative Real GDP per Capita Loss due to Global Warming (1960–2017)	38
1.11	Real GDP per Capita Loss due to Global Warming, by Income Category	39
1.12	Cumulative Effect of Temperatures Deviations from their Historical Norms on the Share of Private Consumption in GDP	44
1.13	Cumulative Effect of Temperatures Deviations from their Historical Norms on the Share of Investment in GDP	44
1.14	Cumulative Effect of Temperatures Deviations from their Historical Norms on Trade Balance	45

1.15 Cumulative Effect of Temperatures Deviations from their Historical Norms on the Share of Industrial Value Added in GDP	47
1.16 Cumulative Effect of Temperatures Deviations from their Historical Norms on the Share of Agricultural Value Added in GDP	48
1.17 Cumulative Effect of Temperatures Deviations from their Historical Norms on Agricultural Output	49
1.18 Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, According to Policy Levels	50
1.A.1 Country Classification	55
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	57
1.B.2 Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP	58
1.B.3 Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP	59
1.C.1 Cumulative Effect of Temperatures Deviations from their Historical Norms on Demand Components of GDP	61
1.C.2 Cumulative Effect of Temperatures Deviations from their Historical Norms on Sectoral Components of GDP	62
1.C.3 Cumulative Effect of Temperatures Deviations from their Historical Norms on Sectoral Components of GDP	63
1.C.4 Cumulative Effect of Temperatures Deviations from their Historical Norms on Agriculture	64
1.D.1 Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, According to Policy Levels	66
2.1 Water stress index (2018)	68
2.1 Standardized Precipitation-Evapotranspiration Index Deviation from Historical Norm	73
2.2 Standardized Precipitation-Evapotranspiration Index Deviation from its Historical Norm	74
2.1 Cumulative Response of GDP Growth to Cumulative Drought	77
2.2 Impulse Response of GDP Growth to Drought	79
2.3 Impulse Responses of GDP Growth to Drought, by Income Level	81
2.1 Impulse Responses of Agricultural Sector Growth to Drought	86

2.2	Impulse Responses of Civil Violence, Labour Productivity Growth and Oil/NGL Production Growth to Drought	89
2.B.1	Cumulative Response of GDP Growth to Cumulative Drought (3-Month SPEI)	94
2.B.2	Cumulative Response of GDP Growth to Cumulative Drought (12-Month SPEI)	94
2.B.3	Impulse Response of GDP Growth to Drought (inverse of the SPEI6 index)	95
2.B.4	Impulse Response of GDP Growth to Drought (3-Month SPEI)	95
2.B.5	Impulse Response of GDP Growth to Drought (12-Month SPEI)	95
2.B.6	Impulse Response of GDP Growth to Drought (Controls Include One Lag)	96
2.B.7	Impulse Response of GDP Growth to Drought (Controls Include Country-Specific Linear and Quadratic Time Trend)	96
2.B.8	Impulse Response of GDP Growth to Drought (Driscoll and Kraay Standard Errors)	97
2.B.9	Impulse Response of GDP Growth to Drought (Controls Include Temperature and Precipitations Deviations from their Historical Norms) . .	97
2.B.10	Impulse Response of GDP Growth to Drought (Controls Include Temperature and Precipitations Levels)	98
2.B.11	Impulse Response of GDP Growth to Drought (Controls Include Climate-Related Natural Disasters Occurrences)	98
2.B.12	Impulse Response of GDP Growth to Drought (Controls Include Commodity Terms of Trade)	99
2.B.13	Impulse Response of GDP Growth to Drought (Controls Include Civil Conflict Intensity)	99
3.1	Climate-Related Natural Disaster Occurrences, by Continent	110
3.2	Climate-Related Natural Disaster Occurrences, by Continent	113
3.1	RER Misalignment's Response to a Climate-Related Natural Disaster . .	119
3.A.1	Country Classification	126
3.B.1	RER Misalignment's Response to a Climate-Related Natural Disaster - Additional Control Variables	129
3.B.2	RER Misalignment's Response to a Climate-Related Natural Disaster - Driscoll-Kraay Standard Errors	129
3.B.3	RER Misalignment's Response to a Climate-Related Natural Disaster - Driscoll-Kraay Standard Errors	131
4.1	Climate-Related Natural Disasters Occurrences	137
4.1	Non-performing Loans, in Percent	138

List of Figures

4.2	Non-performing Loans, in Local Currency	139
4.3	Provisions to Non-performing Loans	140
4.1	Non-performing Loans, in Percent	142
4.2	Non-performing Loans, in Local Currency	143
4.3	Provisions to Non-performing Loans	143
5.1	Temperatures Variability, by Continent	156
5.2	Precipitations Variability, by Continent	157
6.1	Température moyenne annuelle mondiale	173
6.2	Concentration atmosphérique mondiale de CO ₂	174
6.3	Écarts de température, par région	175
6.4	Écarts de précipitations, par région	176
6.5	Augmentation de la température moyenne mondiale par rapport à l'ère préindustrielle	177

List of Tables

1.1	Macroeconomic Effects of Temperature Deviations from their Historical Norms in Low- and Middle-Income Countries	32
1.2	Distribution of Temperatures Deviations from Their Historical Norms	34
1.3	Macroeconomic Effects of Temperature Deviations from their Historical Norms in Low- and Middle-Income Countries: Main Results and Robustness Checks	41
1.A.1	List of Countries Included in the Main Regression Analysis	54
1.A.2	Data Sources	55
1.B.1	Macroeconomic Effects of Temperature Deviations from their Historical Norms in Low-Income Countries	56
2.1	Summary Statistics	76
2.1	Cumulative Response of GDP Growth to Cumulative Drought	78
2.2	Impulse Response of GDP Growth to Drought	80
2.1	Impulse Response of GDP Growth to Drought (Robustness Checks)	83
2.1	Agricultural Sector Contemporary Response to Drought	88
2.A.1	List of Countries Included in the Sample	92
2.A.2	Data Sources	92
2.A.3	Summary Statistics (Oil Exporters)	93
2.A.4	Summary Statistics (Oil Importers)	93
2.B.1	Contemporary Response of GDP Growth to Drought, Excluding Countries One by One	100
3.1	Real Exchange Rate Long- and Short-Run Determinants	107
3.1	Effects of Climate-Related Natural Disasters on RER Misalignment	116
3.2	Effects of Climate-Related Natural Disasters based on Meteorological Observations	118
3.3	Heterogenous Effects of Climate-Related Natural Disasters on RER Misalignment	121

3.1	Impact of Climate-Related Natural Disasters on RER Misalignment: What Are the Channels?	123
3.A.1	List of Countries Included in the Main Regression Analysis	127
3.A.2	Data Sources	128
3.A.3	List of Small Island Developing States	128
3.B.1	Effects of Climate-Related Natural Disasters based on Meteorological Observations: Additional Results	130
4.1	Effects of Climate-Related Natural Disasters on RER Misalignment	141
4.A.1	List of Countries Included in the Main Regression Analysis	145
4.A.2	Data Sources	145
5.1	Climate Variability and International Migrations	159
5.2	Financial Inclusion, Temperatures Variability and Migrations	161
5.3	Relation Between Precipitations Variability and Migrations	163
5.A.1	List of Variables and Sources	166
5.A.2	Correlation between our migration rate and variables in Abel et al. (2019)	167
5.B.1	Financial Inclusion, Temperatures Variability and Migrations	168
5.B.2	Financial Inclusion, Temperatures Variability and Migrations	169

Glossary

AR6	Sixth Assessment Report
ARDL	Autoregressive distributed lag
CBDR	Common But Differentiated Responsibilities
DFE	Dynamic fixed effects
DSGE	Dynamic stochastic general equilibrium
ECCAS	Economic Community of Central African States
FDI	Foreign direct investments
FSI	Financial Soundness Indicators
GDP	Gross Domestic Product
GHG	Greenhouse gas
IAM	Integrated Assessment Models
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
MAT	Mean Annual Temperature
MENA	Middle-East and North Africa
MG	Mean group
NDC	Nationally Determined Contribution
NGL	natural gas liquids
OECD	Organisation for Economic Co-operation and Development
PDSI	Palmer Drought Severity Index
PMG	Pooled mean group
RER	Real Exchange Rate

List of Tables

SDG	Sustainable Development Goals
SIDS	Small Island Developing States
SPEI	Standardized Precipitation-Evapotranspiration Index
SPI	Standardized Precipitation Index
SSP	Shared Socioeconomic Pathways
TFP	Total Factor Productivity
UNFCCC	United Nations Framework Convention on Climate Change
VAR	Vector auto-regressive
WAEMU	West African Economic and Monetary Union

General Introduction

1 Climate Change and the Macroeconomy

It is now scientifically uncontested that the climate is changing. The causes of climate change, or climate change attribution, have been more debated until recently, but it is now established as a fact that human activity is a powerful force that drive these changes. According to the Intergovernmental Panel on Climate Change (IPCC)'s Sixth Assessment Report (AR6) from Working Group I (Masson-Delmotte et al., 2021): "It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred." The report adds: "Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years".¹

This fact has major consequences for the economy, and particularly for the economy of developing countries (*i.e.* those classified as low-income and middle-income by the World Bank²). On the one hand, changes in climate conditions affect the economy. This is capture by the damage functions, which are core functions in Integrated Assessment Models (IAM) pioneered by Nordhaus (1977). On the other hand, economic activity matters for the climate due to the Greenhouse gas (GHG) emissions resulting from energy use during the process of production, among other causes (such as changes in land use).

Climate change consequences are even more important for developing countries. The notion of Common But Differentiated Responsibilities (CBDR) is at the center of international negotiations on climate change since the United Nations Framework Convention on Climate Change (UNFCCC) of Earth Summit in Rio de Janeiro, 1992. In the Paris Agreement (2015),³ this principle allowed developing countries to set longer horizons to reach net-zero emissions in their Nationally Determined Contribution (NDC).

¹The Summary for Policymakers is available at: <https://www.ipcc.ch/report/ar6/wg1/chapter/summary-for-policymakers/>.

²The current and historical classifications are available at: <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>

³The Paris Agreement is available at: <https://www.un.org/en/climatechange/paris-agreement>

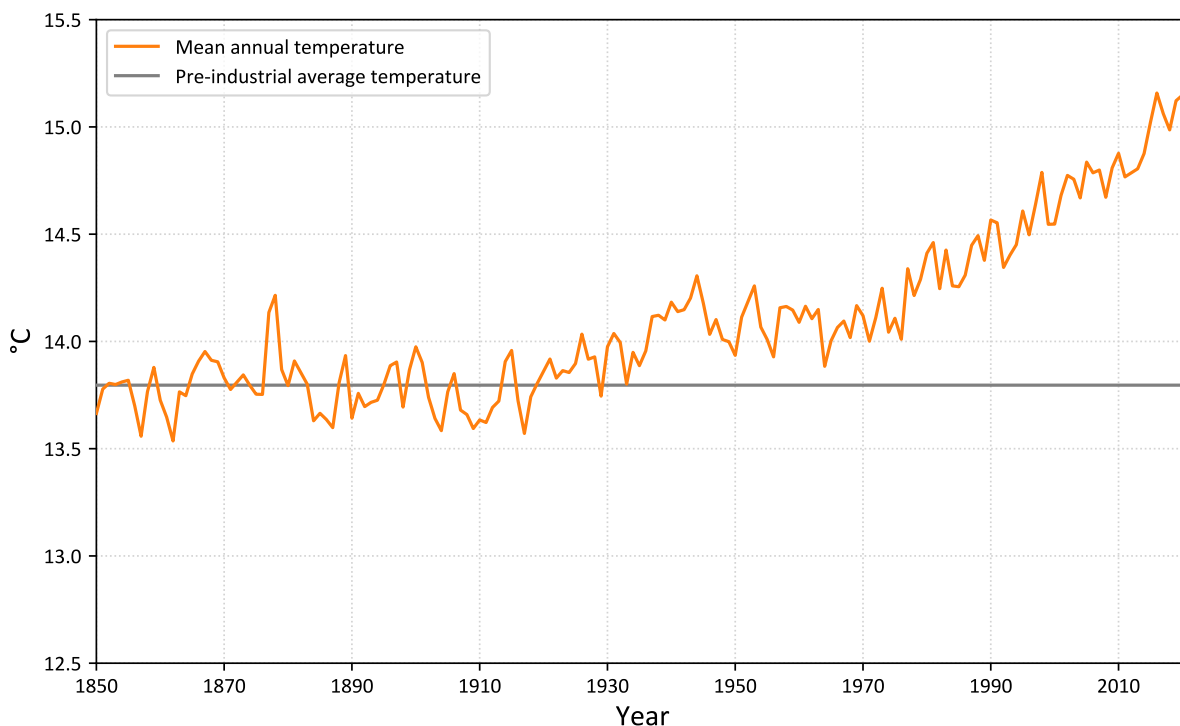
However, as climate conditions continue to evolve, fast-growing developing countries are likely to face increasing pressures both from the international community and from within to shift towards greener development agendas. With the existing technologies, the objective of limiting GHG emissions might enter into conflict with other of the Sustainable Development Goals (SDG).

The relation between the climate and the economy has long captured scholars' interest. [Ibn Khaldun \(1377\)](#) and [Montesquieu \(1748\)](#) are two examples, but the reflections on this relation have started much earlier. Recently, global warming triggered a renewed interest and major contributions were made in the literature, both theoretical ([Nordhaus, 1977](#), among others) and empirical ([Dell et al., 2012](#), among others). Chapter 1 contains a more detailed discussion of these contributions.

2 Some Stylized Facts About Climate Change

Before discussing how climate change affects the economy, this section introduces some stylized facts about this phenomenon.

Figure 1 – Global Mean Annual Temperature



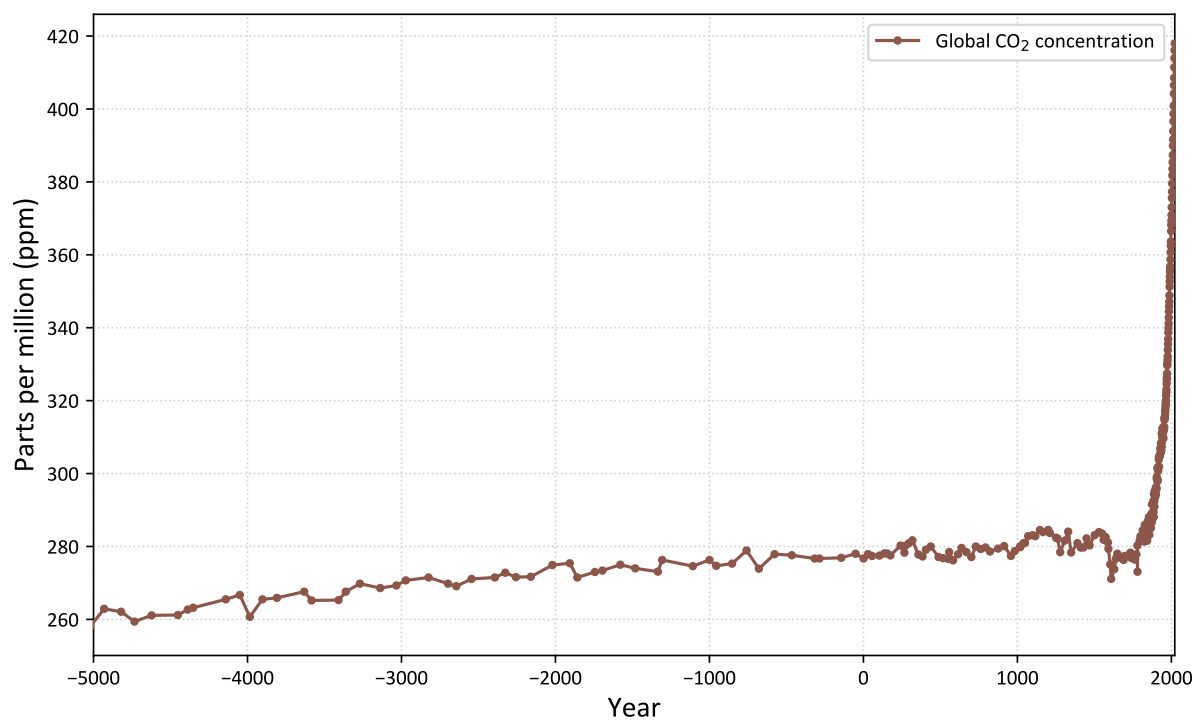
Note: [Rohde and Hausfather \(2020\)](#), elaboration by the author. Pre-industrial average temperature corresponds to the period 1850–1900.

Global warming is arguably the most widely known materialisation of climate

change. Figure 1 shows the evolution of global Mean Annual Temperature (MAT) between 1850 and 2021. Temperatures remain broadly constant up to the 1930s and started to increase markedly around the beginning of the 1970s. According to Berkeley Earth, the global MAT was 1.2°C higher in 2021 than the average during the period 1950–1980.⁴

This increase in MAT results from higher atmospheric concentration of CO₂ and other GHG, which itself results from high and still increasing CO₂ and other GHG emissions. Hsiang and Kopp (2018) provide a sound introduction to the physics underlying climate change. Figure 2 shows that the current Global atmospheric CO₂ concentration is roughly 55% higher than the average between 5000 BC and 1000 AD. It also evidences that a major shift occurred at the beginning of the industrial era, around the beginning of the nineteenth century.

Figure 2 – Global Atmospheric CO₂ Concentration



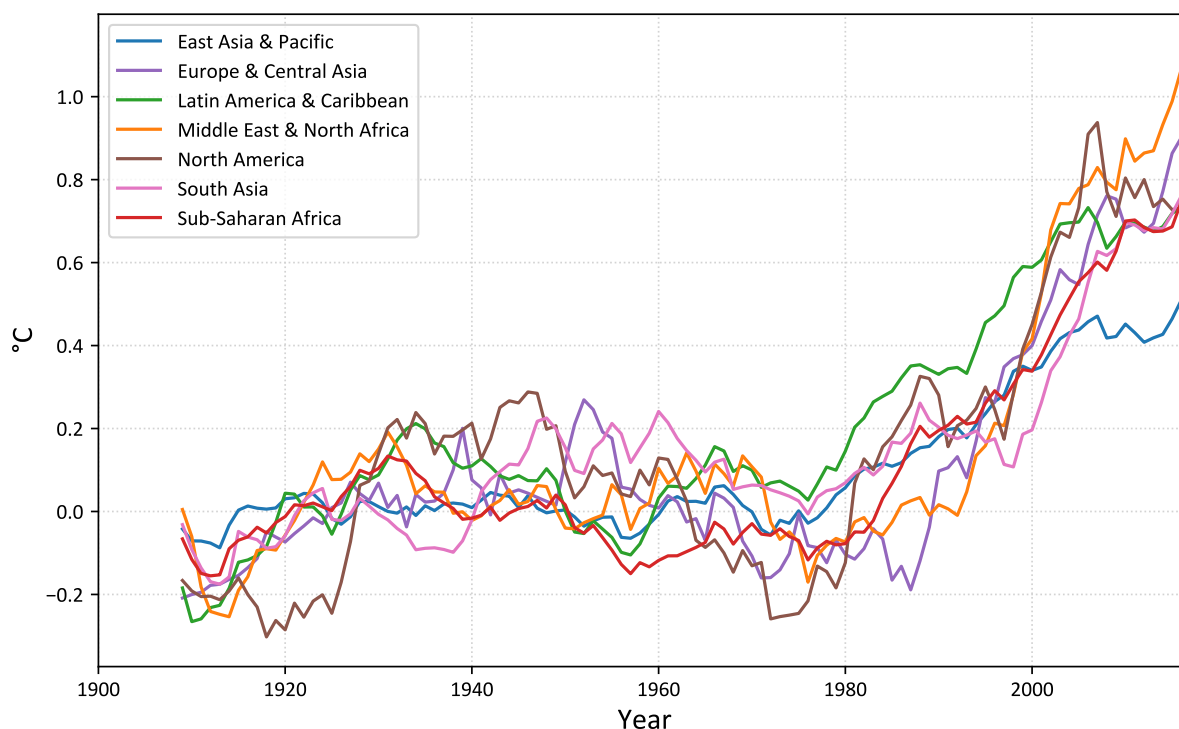
Source: Our World in Data, elaboration by the author.

The national GHG emissions that explain the sharp increase in global GHG concentration are far from being evenly distributed. Up to 2017, the main contributors to cumulative global CO₂ emissions were the USA (25%), the EU-28 (22%) and China (12.7%). The entire African continent and South America each contributed to less than

⁴This number corresponds to Land-Surface temperature. The entire time series covering the period 1750–2021 is publicly available at: https://berkeley-earth-temperature.s3.us-west-1.amazonaws.com/Global/Complete_TAVG_summary.txt

3% of total historical CO₂ emissions.⁵ Chapter 1 includes more detailed stylized facts at the country-level using data from [Boden et al. \(2017\)](#). This unequal distribution of historical GHG is the main explanation behind the emergence of the notion of Common But Differentiated Responsibilities. Heterogeneity matters for climate change attribution.

Figure 3 – Temperature Deviation, by Region



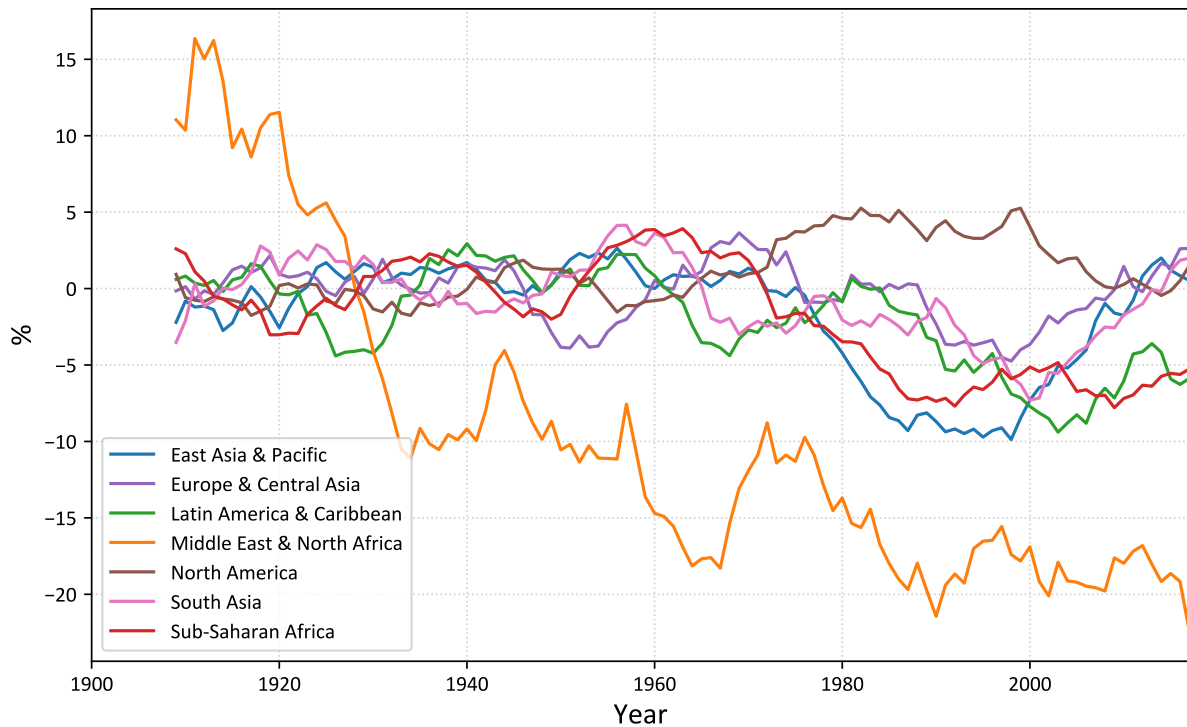
Note: [Matsuura and Willmott \(2019a\)](#), calculations and elaboration by the author. The series show for each region the temperature (10-year moving average) deviation from average temperature during the period 1900–1950. Regional temperatures calculated by the authors using the unweighted average of country mean annual temperature.

Heterogeneity also characterises the materialisation of climate change. As shown in Figure 3, MAT across regions follow a similar trend but with varying intensity. MAT at the end of the 2010s were more than 1°C higher than their historical norm in the Middle-East and North Africa (MENA), while the increase was of the order of +0.5°C in East Asia and the Pacific. The historical norm is defined as the average during the period 1900–1950, here and in the rest of this dissertation unless otherwise stated. Heterogeneity in the materialisation of climate change is more marked when considering annual precipitations. Figure 4 shows total annual precipitations deviations from their historical norm, expressed in percent. No common trends appear and diverging pat-

⁵The underlying data is available from Our World in Data at: <https://ourworldindata.org/co2-emissions>

terns are visible during the period 1980–2000. The MENA region has experienced a marked decline in annual precipitations since the beginning of the twentieth century, from an already low level, which combined with the highest temperature hikes, from already high levels, to alter drought conditions in the region. Chapter 2 focuses on the macroeconomic consequences of this pattern.

Figure 4 – Precipitations Deviation, by Region

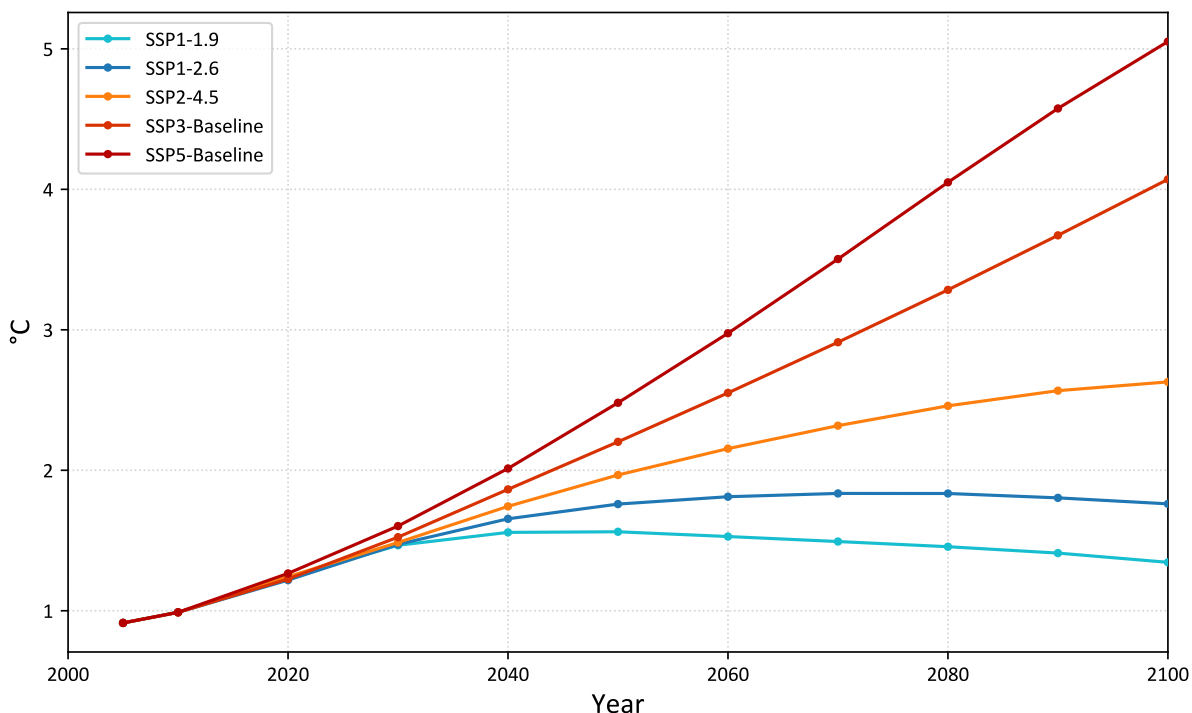


Note: [Matsuura and Willmott \(2019a\)](#), calculations and elaboration by the author. The series show for each region the precipitations (10-year moving average) percentage deviation from average precipitations during the period 1900–1950. Regional precipitations calculated by the authors using the unweighted average of country yearly total precipitations.

The previous figures contain historical data that show that climate change is already a reality and that its effects are likely to be already felt. Future projections are at the core of IPCC's work. Their reports feature climate scenarios that describe likely temperatures trajectories under sets of assumptions. Figure 5 reports some of the scenarios, or Shared Socioeconomic Pathways (SSP), extensively discussed in IPCC's AR6 ([Masson-Delmotte et al., 2021](#)). The scenarios relying on the lowest future levels of GHG emissions anticipate that global MAT will peak at +1.5 to +2.0°C above pre-industrial levels around 2050 to 2070.⁶ These correspond to scenarios SSP1-1.9 and SSP1-2.6. On the

⁶Pre-industrial levels correspond to year 1750 in Figure 5. The data is publicly available from the SSP Database version 2.0, at: <https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10>.

Figure 5 – Global Average Temperature Increase Relative to Pre-Industrial Era



Source: [Riahi et al. \(2017\)](#), elaboration by the author. SSP corresponds to Shared Socioeconomic Pathways, the scenarios used by IPCC. Pre-industrial era corresponds to year 1750.

contrary, Baseline scenarios SPP3 and SPP5, in which energy use remains highly emitting, anticipate a continued increase in MAT up to 2100, with temperatures at that time 4 to 5°C above the pre-industrial era.

These projections highlight the scope for, and the importance of mitigation policy, *i.e.* the policies that aim at curbing GHG emissions. In all scenarios, but particularly in SSP3 and SSP5, adaptation policies will be fundamental for economies to flourish, and even more so in developing countries. These policies must rely on sound economic evidence on the effects of climate change, which must overcome several challenges.

3 Quantifying the Impacts of Climate Change: Empirical Issues

The abundance of high quality observational and modelled data from climate science has allowed the empirical literature on the economic consequences of climate change to flourish recently. High frequency geolocalized data, primarily on temperatures and precipitations, are strong assets to build robust empirical strategies since they can be considered as exogenous, random shocks. However, these data denote weather con-

ditions, as opposed to climate conditions which are defined as changes in weather conditions over the long run (usually 30 years or more). One contribution of this dissertation is to introduce a novel identification strategy that relies on sustained changes in weather conditions in Chapters 1 and 2.

Another challenge associated with the notion of climate change is the diversity of its materialisation, which cannot be captured in a single variable. Instead, this dissertation aims at exploring the macroeconomic effects of several aspects of climate change. Climate change comprises an increase in global (and local) MAT, also known as Global warming, and variations in precipitations patterns. These precipitations patterns are highly localized and their aggregation at the country level is problematic (Damania et al., 2020). Chapter 1 explores this dimension of climate change. The combined modifications in temperatures and precipitations patterns affect drought patterns, which have received little attention in the macroeconomic literature. Chapter 2 focuses on this aspect of climate change in the MENA region.

Climate change affects not only temperatures and precipitations levels, but also their volatility. This higher volatility is expected to increase economic uncertainty and might make adaptation policies more difficult to implement. Chapter 5 explores the effects of temperatures and precipitations volatility on international migrations originating from developing countries. Changing frequency and intensity of climate-related extreme events, often referred to as (climate-related) natural disasters or rapid onset events, is another consequence of climate change. Chapters 3 and 4 explore the consequences of these events on exchange rates and financial stability.

Another challenge faced when identifying the effects of climate change is the aggregation of microeconomic results, also known as the enumerative approach. The enumerative approach has two main limitations. First, aggregating microeconomic, *i.e.* sectoral, results implies that the effects on some sectors will not be covered and the assessment will not be exhaustive. Second, aggregating microeconomic results will leave out potential general equilibrium effects. These limitations justify a macroeconomic approach. The literature review in Chapter 1 provides a more detailed discussion of this topic.

Finally, this dissertation refrains from covering two dimensions of, or closely tied to climate change. First, because climate change is a highly complex and nonlinear process with unanticipated tipping points, empirical work that rely on historical data have a relatively little capacity to be informative about the effects of future climate change, especially for higher-emissions scenarios. Therefore, this dissertation does not contain nor works with projections. Second, climate change is only one aspect of broader environmental issues which include, among others, contamination and biodiversity loss.

These issues, interlinked with climate change, are out of the scope of this dissertation despite their undisputable importance.

4 Contribution of this Dissertation

This section presents each chapter's contribution, based on the previous discussion.

4.1 Chapter 1

The first chapter shows that global warming has negative macroeconomic consequences in developing countries. Using panel data covering 126 low- and middle-income countries between 1960 and 2017, it finds that sustained positive temperature deviations from their historical norms have a non-linear negative effect on per capita real output growth: the 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, the results indicate 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, the results suggest that global warming will reinforce development traps, hindering further adaptation to climate change in developing countries.

4.2 Chapter 2

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, the second chapter 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.

4.3 Chapter 3

Climate-related natural disasters have recently had dramatic effects on developing countries' real sector and populations. The monetary and financial consequences of these events have received less attention however, despite their importance in a context in which climate change will alter the frequency and intensity of these natural disasters. The third chapter uses macroeconomic, natural disasters and climatic panel data for 109 countries during the period 1960–2019 to assess the effects of climate-related natural disasters on the real exchange rate (RER) misalignment. It constructs a country-specific RER misalignment index and several measures of climate-related natural disasters based on climatic data to show that such events lead to RER overvaluations in developing countries: one disaster occurrence leads to a 0.015 unit increase in the RER misalignment index. This effect tends to increase when using measures of natural disasters based on climatic data and is mostly explained by middle-income countries, small countries, and small island developing states. The results indicate that remittances and net capital flows act as transmission channels.

4.4 Chapter 4

Climate-related natural disasters have monetary and financial consequences in developing countries, but these have received relatively little attention. The fourth chapter uses macroeconomic data of the financial sector and data on natural disasters for 22 countries during the period 2005m3–2018m12 to assess the effects of climate-related natural disasters on financial stability in developing countries. The results show that such events lead to an increase in non-performing loans: one disaster occurrence leads to a 1.93 percentage point increase in the non-performing loans ratio. This effect materializes after four months and lasts for two periods. Provisions to non-performing loans also temporarily increase after ten months. These results evidence a higher fragility of the banking sector following climate-related natural disasters, in a context in which climate change will alter these natural disasters' frequency and intensity.

4.5 Chapter 5

The relation between climate change or weather shocks and migration is complex and has been extensively studied by the literature. However, the effects of climate variability on migration have received much less attention. Using migration, climate and macroeconomic panel data for 114 low- and middle-income countries during the period 1986–2020, the fifth chapter finds that temperatures variability increases migration from low-income countries to neighbouring countries, while migration to OECD countries remains unaffected. In addition, the results indicate that access to domestic credit decreases the migration response to temperatures variability. This suggests that financial inclusion can constitute an adaptation policy in low-income countries.

Part I

**Macroeconomic Effects of Climate
Change**

Chapter 1

Climate Change in Developing Countries: Global Warming Effects, Transmission Channels and Adaptation Policies¹

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.

Keywords: Climate Change, Economic Growth, Adaptation, Developing Countries.

JEL Classification: C33, E20, O11, O13, Q54.

¹Joint 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 Gross Domestic Product (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 6 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 IAM. 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 cli-

mate 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 Généros \(2017\)](#) 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 fictitious 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, 2014a](#)), 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 3.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 4.A.1. The dataset covers three dimensions: socio-economic variables, climate-related disaster and climate variables, and carbon emissions and consumption. Appendix Table 5.A.1 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, 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 Total Factor Productivity (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, 2019b). 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 its 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 Arctic 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 CO₂ 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.

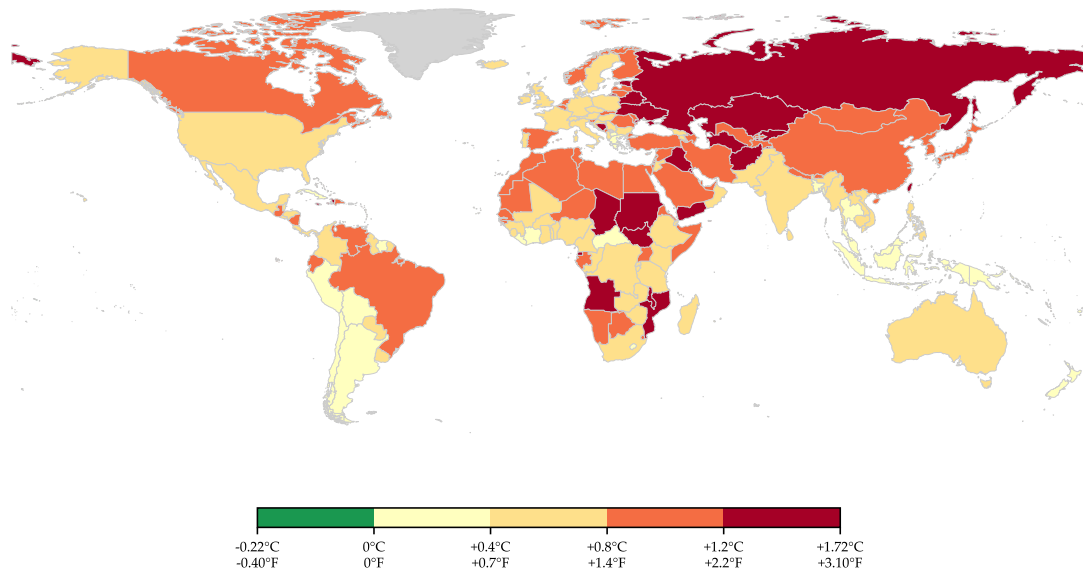
²As evidenced in https://www.dhn.mil.pe/Archivos/Oceanografia/ENFEN/nota_tecnica/01-2017.pdf.

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

Country territorial CO₂ emissions and transfers, corresponding to the difference between CO₂ consumption and territorial emissions, are retrieved from [Friedlingstein et al. \(2019\)](#) and allow to expand the time coverage of CO₂ emissions until 2017.

3.4 Climate Change: A Descriptive Analysis

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



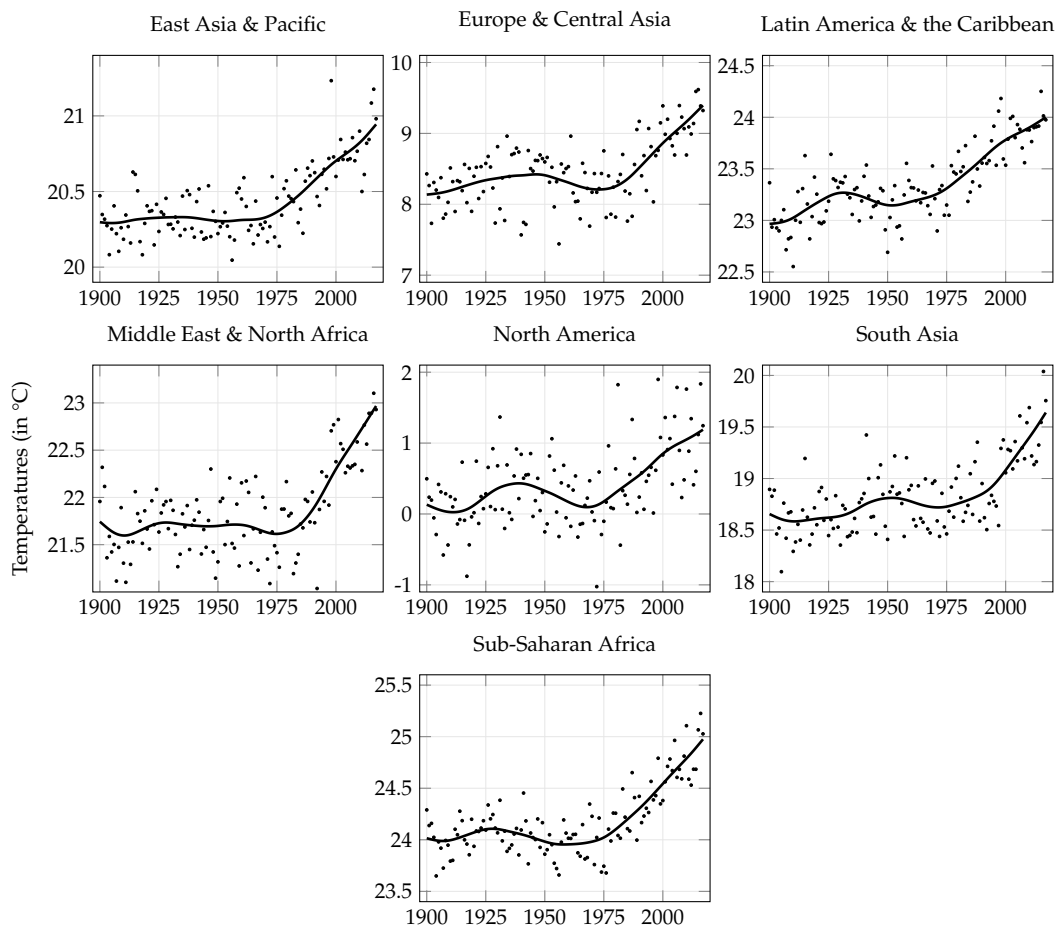
Source: [Matsuura and Willmott \(2019b\)](#), calculation and elaboration by the authors.

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.

⁴Mean 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

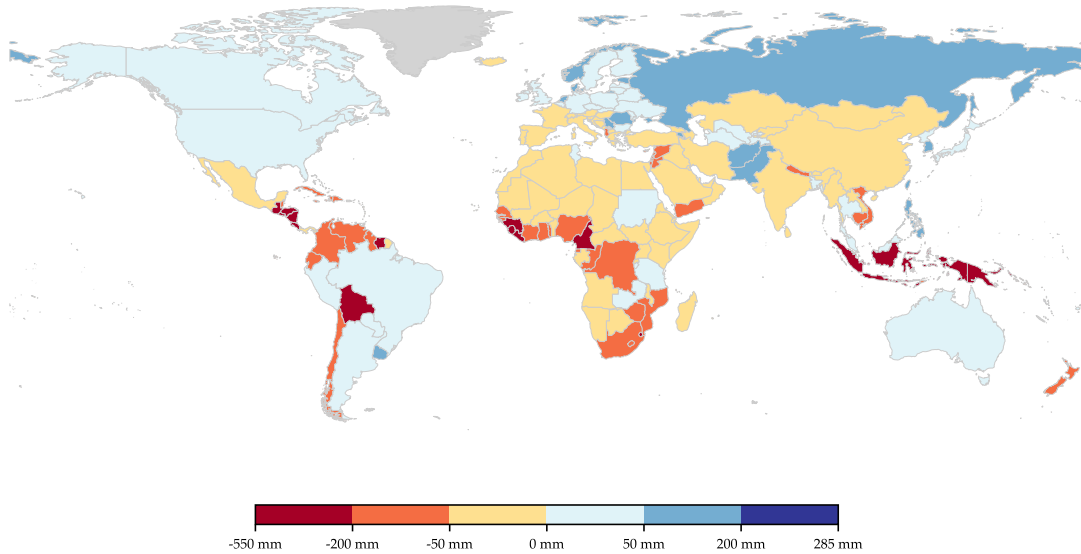


Source: [Matsuura and Willmott \(2019b\)](#), calculations of regional temperatures by the authors using the unweighted average of country yearly mean temperatures and smoothing by the Hodrick–Prescott filter ($\lambda = 1600$).

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



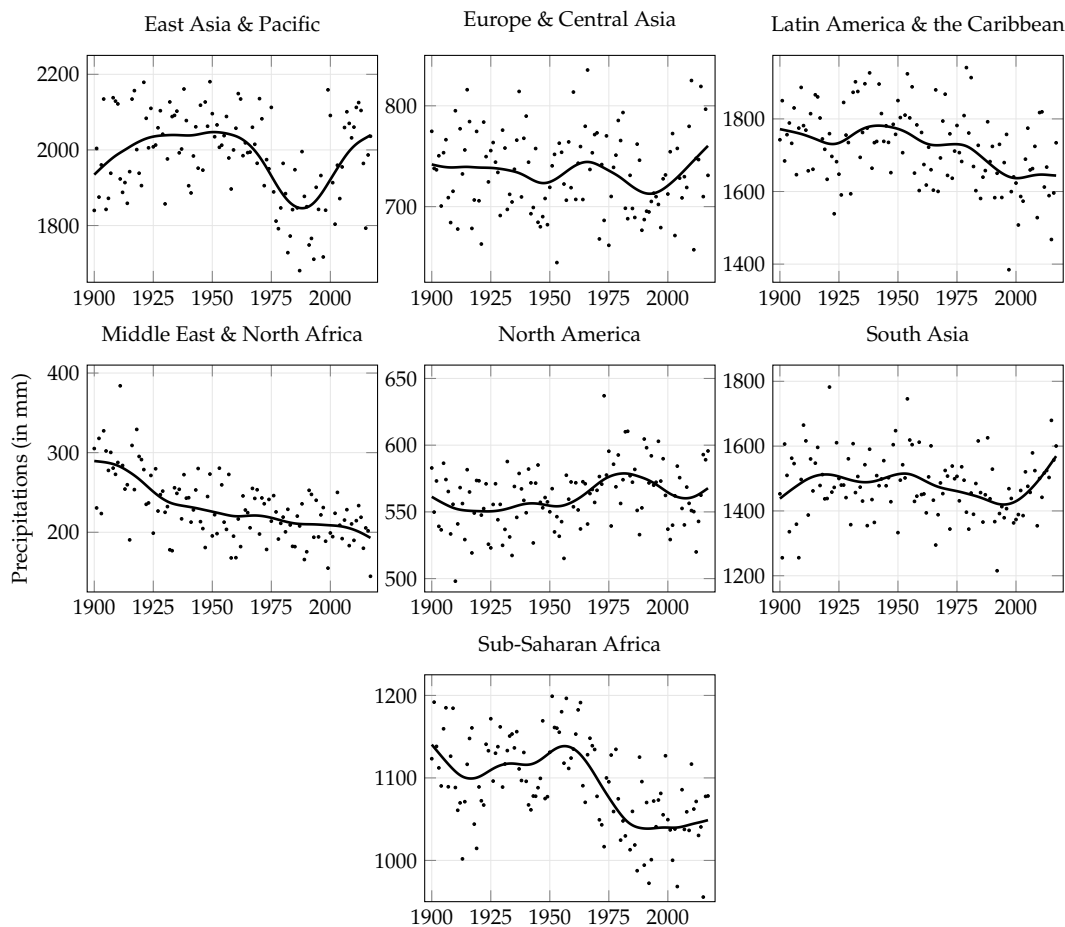
Source: [Matsuura and Willmott \(2019b\)](#), elaborated by the authors. Units are in Millimeters.

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 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 emissions at

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



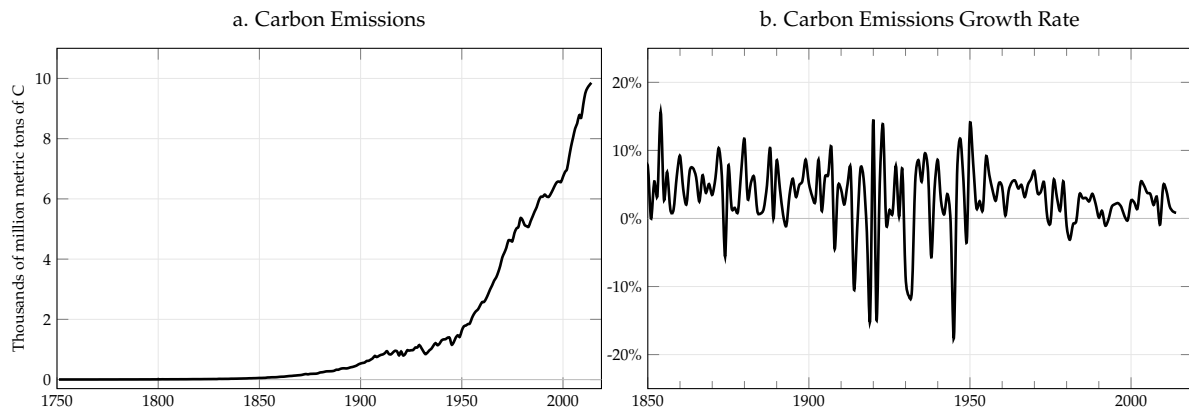
Source: [Matsuura and Willmott \(2019b\)](#), calculations of regional precipitations by the authors using the unweighted average of country yearly total precipitations and smoothing by the Hodrick–Prescott filter ($\lambda = 1600$).

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.

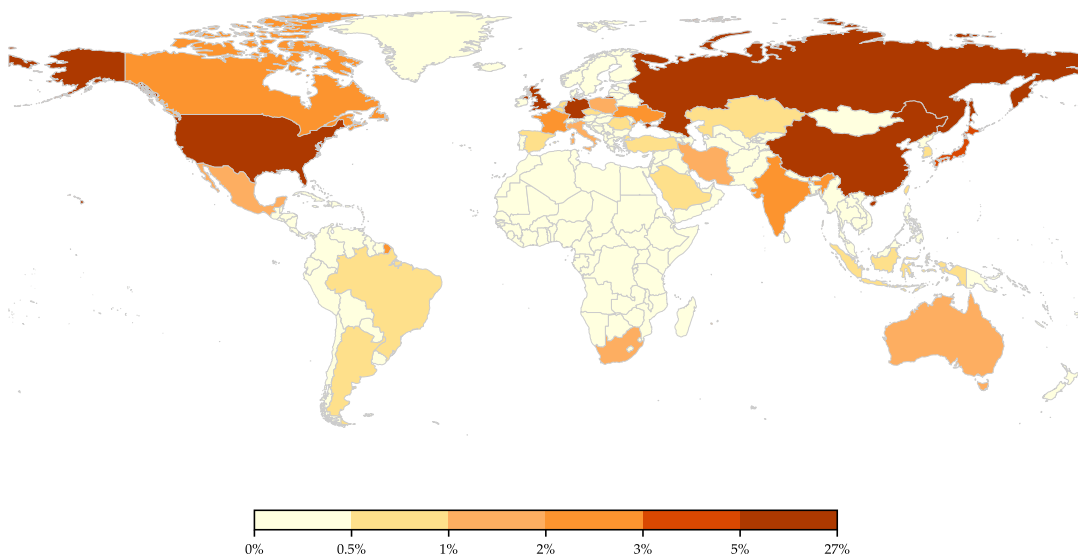
Third, while weather shocks seem to be relatively exogenous, econometric assessments of the effects of sustained climate deviations from historical norms may be biased due to reverse causality issues: economic growth, which lead to CO_2 emissions, does positively affect temperatures.

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 (3.1) for horizons $h = 0, 1, \dots, 5$:

$$y_{i,t+h} - y_{i,t-1} = \theta_h \sum_{p=t}^{t+h} \widetilde{T}_{i,p} + \phi_h \sum_{p=t}^{t+h} \widetilde{P}_{i,p} + \vartheta_h \sum_{p=t}^{t+h} \widetilde{T}_{i,p}^2 + \varphi_h \sum_{p=t}^{t+h} \widetilde{P}_{i,p}^2 + \lambda \mathbf{X}'_{i,t} + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h \quad (1.1)$$

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 ($^{\circ}\text{C}$), 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

	$h = 0$	$h = 1$	$h = 2$	$h = 3$	$h = 4$	$h = 5$
<i>Panel A: Dependent variable is Real GDP per capita growth</i>						
\tilde{T}	-0.002 (0.003)	0.005 (0.003)	0.008*** (0.003)	0.010*** (0.003)	0.010*** (0.003)	0.011*** (0.003)
\tilde{T}^2	-0.002 (0.002)	-0.005*** (0.002)	-0.008*** (0.002)	-0.009*** (0.002)	-0.009*** (0.002)	-0.010*** (0.002)
\tilde{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)
\tilde{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
<i>Panel B: Dependent variable is Real GDP growth</i>						
\tilde{T}	-0.003 (0.003)	0.003 (0.003)	0.007** (0.003)	0.008*** (0.003)	0.009*** (0.003)	0.010*** (0.003)
\tilde{T}^2	-0.002 (0.002)	-0.005*** (0.002)	-0.007*** (0.002)	-0.008*** (0.002)	-0.008*** (0.002)	-0.008*** (0.002)
\tilde{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)
\tilde{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 (3.1) 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.

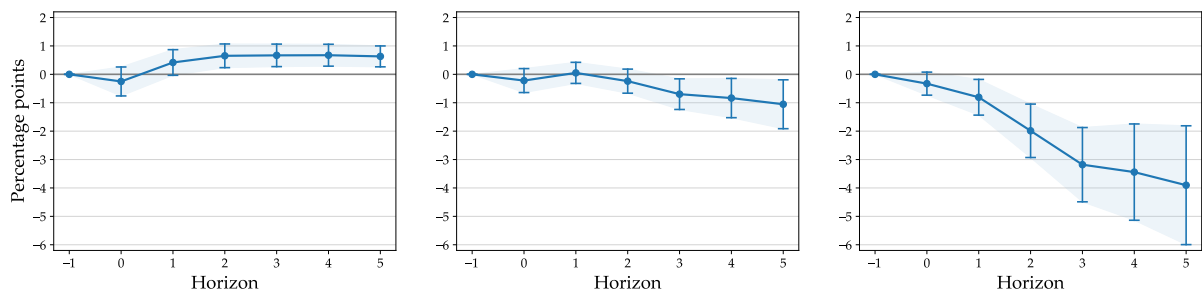
Equation (3.2) indicates the total, non-linear effect of temperatures deviations from their historical norms on real GDP per capita growth for a given year t and horizon $h \in [0, 5]$:

$$\frac{\partial (y_{i,t+h} - y_{i,t-1})}{\partial \widetilde{T}_{i,t,h}} = \theta_h + 2\vartheta_h \widetilde{T}_{i,t,h} \quad (1.2)$$

Equation (3.2) is obtained by partially differentiating equation (3.1) 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) 25th percentile: +0.00°C at $h = 0$ (b) 50th percentile: +0.34°C at $h = 0$ (c) 75th 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 25th, 50th and 75th percentiles, respectively, at $h = 0$, and +0.27°C, +1.83°C and +3.93°C for the 25th, 50th and 75th 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 25th percentile, the median and the 75th 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 25th 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 75th 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:	<i>A. Full Sample of Estimations</i>			<i>B. Early 21st Century</i>		
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

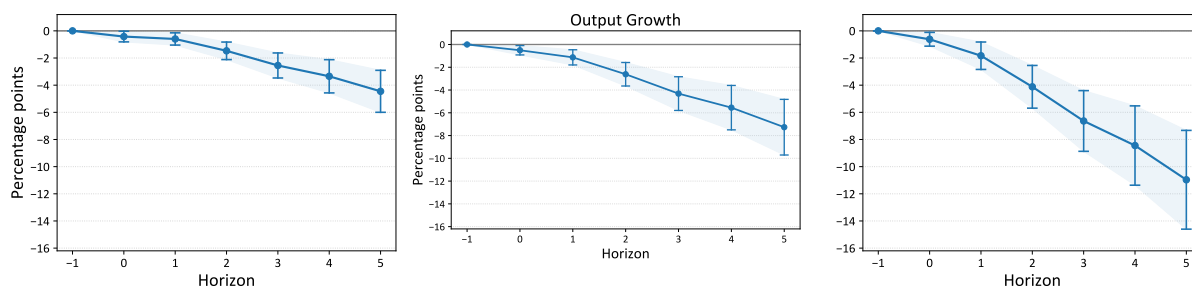
Note: All temperature changes are in °C. To convert into °F, multiply by nine-fifth. \widetilde{T}_h denotes the deviation in mean temperature from its historical values during horizon h . Panel A indicates for horizons $h = 0, \dots, 5$ the 25th, 50th and 75th percentiles of the distribution of yearly 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 $h = 0, \dots, 5$ the 25th, 50th and 75th 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 75th 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) 25th percentile: +0.49°C at $h = 0$ (b) 50th percentile: +0.74°C at $h = 0$ (c) 75th percentile: +1.06°C at $h = 0$



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 25th, the 50th and the 75th 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 (3.1) using the full sample, but the temperature deviations from their historical values correspond to the 25th percentile, the median and the 75th 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 representative of each country's recent and ongoing experience, 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

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

⁶Taking 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 25th percentile, the median and the 75th 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 25th percentile, the median and the 75th percentile of the distribution. The country at the 25th 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 75th 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 25th percentile, the median and the 75th 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).

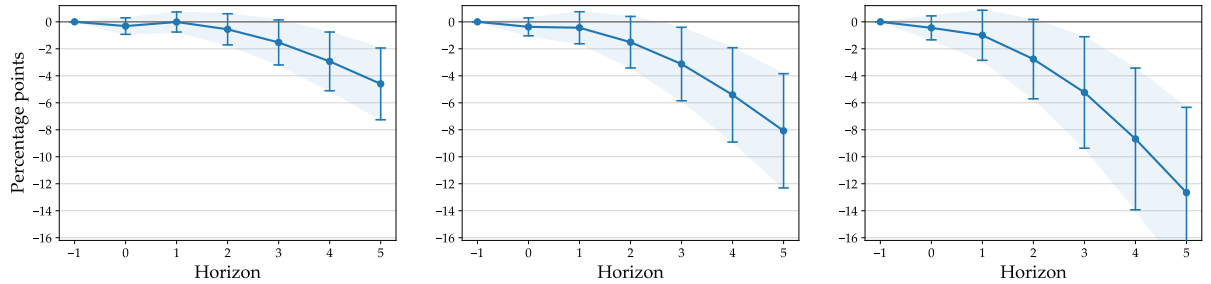
The fact that none of the coefficients are statistically significant at horizon $h = 0$ while all are at horizon $h = 5$ evidences that sustained changes in weather conditions, *i.e.* a variable that captures more closely the materialization of climate change, impact economic output beyond the short-term 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 (3.1) 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 International Monetary Fund (IMF) lists of countries. After this modification, equation (3.1) is transformed as indicated in equation (3.3):

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

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



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 25th, the 50th and the 75th 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.

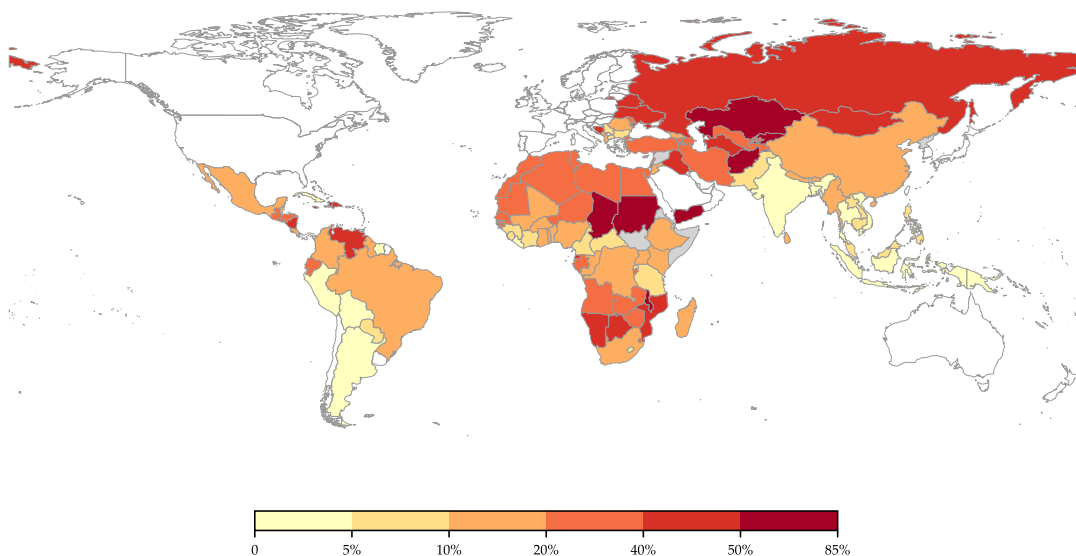
Equation (3.4) indicates the total, non-linear effect of temperatures deviations from their historical norms on real GDP per capita growth in countries with the lowest level of income per capita for a given year t and horizon $h \in [0, 5]$:

$$\frac{\partial (y_{i,t+h} - y_{i,t-1})}{\partial \widetilde{T}_{i,t,h}} = (\theta_h + \zeta_h) + 2(\vartheta_h + \kappa_h) \widetilde{T}_{i,t,h} \quad (1.4)$$

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).

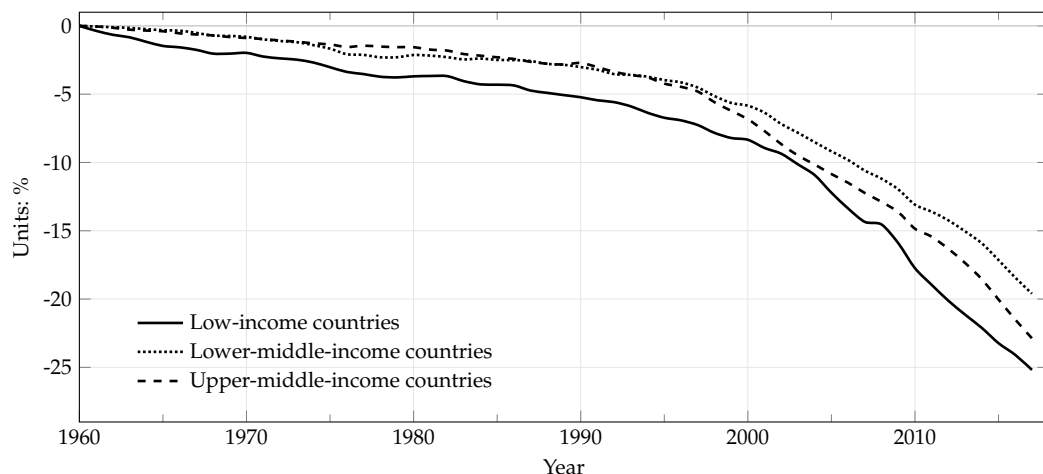
Estimates reported in Table 1.1 allow to compute for each country and each year the loss in real GDP per capita growth due to temperature deviations from their historical norms and build a counterfactual growth rate corresponding to a scenario in which temperature levels equal to historical norms. We 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 distributed, reflecting differences in temperature hikes across countries. The most 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 [Differbaugh 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 (3.1) and the bottom part of each panel indicates the effects at the 25th, the 50th and the 75th percentiles of the distribution of country average mean temperature deviations between the periods 2001–2017 and 1900–1950, using equation (3.2). 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 25th percentile and from horizon $h = 1$ at the median and the 75th 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

⁷Including the quadratic terms for temperature and precipitations levels leads to similar results,

5. Macroeconomic Effects of Global Warming

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)
<i>Panel A: Contemporary effects (h = 0)</i>								
\tilde{T}	-0.250 (0.311)	-0.267 (0.315)	-0.250 (0.320)	-0.697** (0.326)	-0.250 (0.311)	-0.061 (0.181)	-0.312 (0.312)	0.141 (0.296)
\tilde{T}^2	-0.174 (0.187)	-0.193 (0.191)	-0.174 (0.237)	0.003 (0.193)	-0.174 (0.187)	-0.096 (0.118)	-0.169 (0.187)	-0.371* (0.190)
\tilde{P}	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.001)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)
\tilde{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 percentile	-0.421* (0.238)	-0.456* (0.243)	-0.421** (0.202)	-0.694*** (0.244)	-0.421* (0.238)	-0.155 (0.158)	-0.479** (0.239)	-0.223 (0.228)
At 50 th percentile	-0.506** (0.250)	-0.551** (0.256)	-0.506** (0.224)	-0.692*** (0.252)	-0.506** (0.250)	-0.203 (0.176)	-0.562** (0.250)	-0.405* (0.245)
At 75 th percentile	-0.619** (0.309)	-0.676** (0.317)	-0.619* (0.323)	-0.690** (0.309)	-0.619** (0.309)	-0.266 (0.222)	-0.672** (0.310)	-0.646** (0.313)
<i>Panel B: Cumulative effects (h = 5)</i>								
\tilde{T}	1.148*** (0.279)	1.165*** (0.282)	1.148** (0.525)	0.759*** (0.277)	1.345*** (0.303)	0.254 (0.164)	0.975*** (0.281)	3.120*** (0.310)
\tilde{T}^2	-0.951*** (0.188)	-0.937*** (0.190)	-0.951** (0.371)	-0.990*** (0.182)	-0.959*** (0.187)	-0.264** (0.111)	-0.845*** (0.189)	-2.057*** (0.238)
\tilde{P}	-0.001** (0.000)	-0.001** (0.000)	-0.001 (0.001)	-0.001 (0.000)	-0.001** (0.000)	-0.001** (0.000)	-0.001* (0.000)	-0.000 (0.000)
\tilde{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 percentile	-4.453*** (0.939)	-4.352*** (0.956)	-4.453** (2.019)	-5.071*** (0.909)	-4.300*** (0.944)	-1.300** (0.603)	-4.002*** (0.946)	-8.992*** (1.244)
At 50 th percentile	-7.265*** (1.485)	-7.122*** (1.510)	-7.265** (3.095)	-7.998*** (1.439)	-7.134*** (1.487)	-2.081** (0.926)	-6.501*** (1.496)	-15.074*** (1.939)
At 75 th percentile	-10.967*** (2.210)	-10.768*** (2.247)	-10.967** (4.525)	-11.851*** (2.143)	-10.865*** (2.210)	-3.108** (1.356)	-9.791*** (2.226)	-23.080*** (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 25th, 50th and 75th percentiles are obtained as indicated in equation (3.2). * 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 CO₂ 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 (3.1) 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,

available from the authors upon request.

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 phenomenon, 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 (3.1) 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 (3.1) 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 (3.1) 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 (3.2).

6.1 A Shift in the Composition of Demand

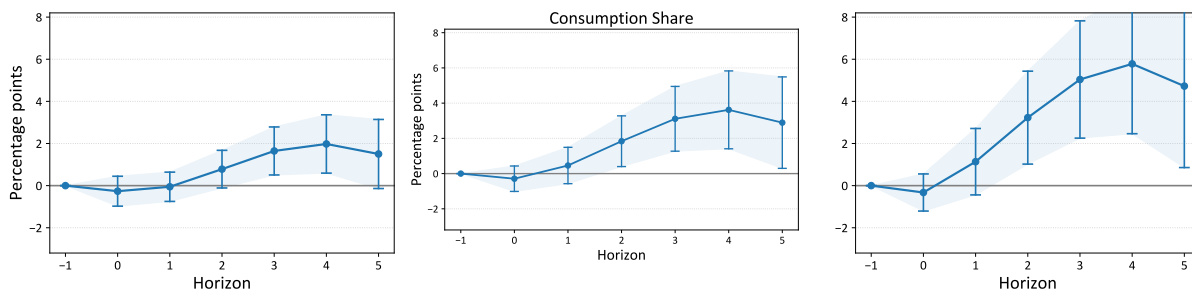
The results presented in Figure 1.12 show that the share of private consumption in GDP tends to increase when temperatures rise with respect to their historical norms. Furthermore, appendix Figure 1.C.1 panel A shows also a slightly positive effect of temperature hikes on the public consumption share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

⁸Results available from the authors upon request.

⁹Results 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) 25th percentile: +0.49°C at $h = 0$ (b) 50th percentile: +0.74°C at $h = 0$ (c) 75th percentile: +1.06°C at $h = 0$

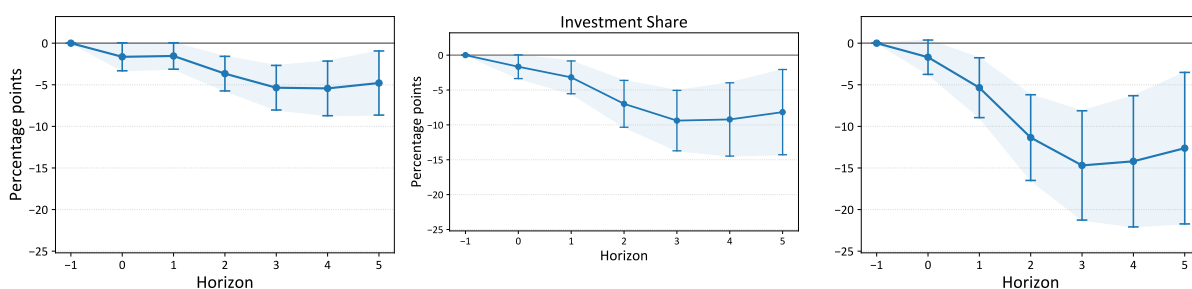


Note: The three panels show the cumulative response of the ratio of Private Consumption over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017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

consumption share in GDP (Appendix Figure 1.C.1 panel B). These results suggest 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) 25th percentile: +0.49°C at $h = 0$ (b) 50th percentile: +0.74°C at $h = 0$ (c) 75th percentile: +1.06°C at $h = 0$



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.

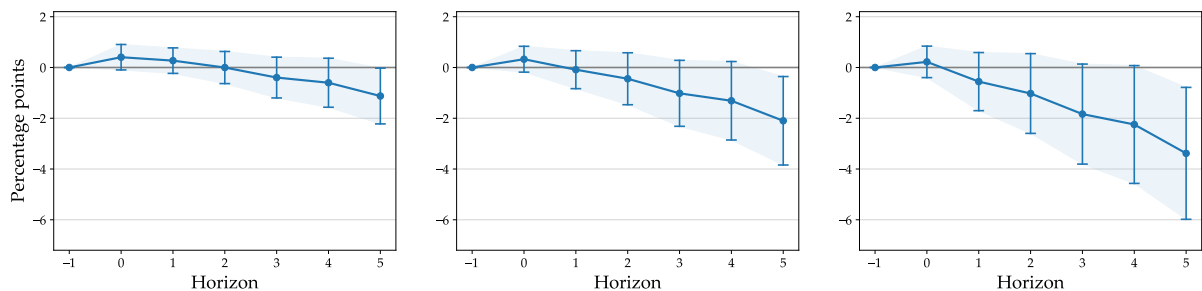
Conversely, Figure 1.13 shows that the share of investment in GDP declines as temperatures rise. Appendix Figure 1.C.1 panel C confirms the negative impact on investment since the share of fixed investments also respond negatively to positive tempera-

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



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 (3.1) 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 (3.1), 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 $h = 0, \dots, 5$ 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 (3.1).

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.

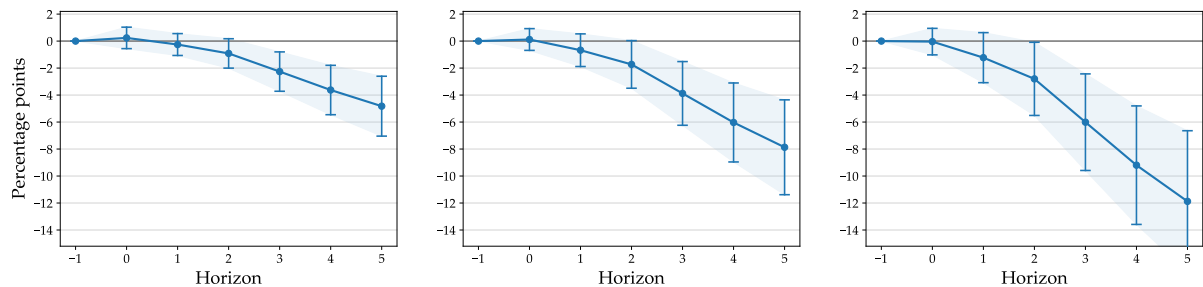
While the potential increase in Foreign direct investments (FDI) inflows is also expected to positively affect economic outcomes through spillovers on subcontractors in the manufacturing sector and higher demand for high-quality services, Appendix Figure 1.C.3 panel C shows that the service sector does 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

¹⁰Results 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) 25th percentile: +0.49°C at $h = 0$ (b) 50th percentile: +0.74°C at $h = 0$ (c) 75th percentile: +1.06°C at $h = 0$



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.

subsistence requirements, developing countries tend to devote a higher share of their resources to food production and consumption (see Gollin et al., 2007; Schultz, 1953).

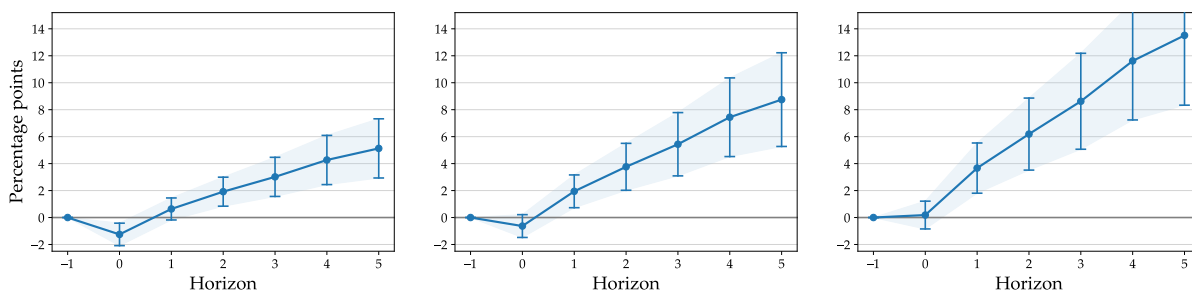
This challenges the common view that agriculture is that most affected sector by temperature hikes: in spite of large effects of temperature hikes and weather shocks on the agricultural sector shocks (see Ortiz-Bobea et al., 2021, for a recent example), the decline of the agricultural sector is outpaced 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 coun-

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

(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 $h = 0$



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.

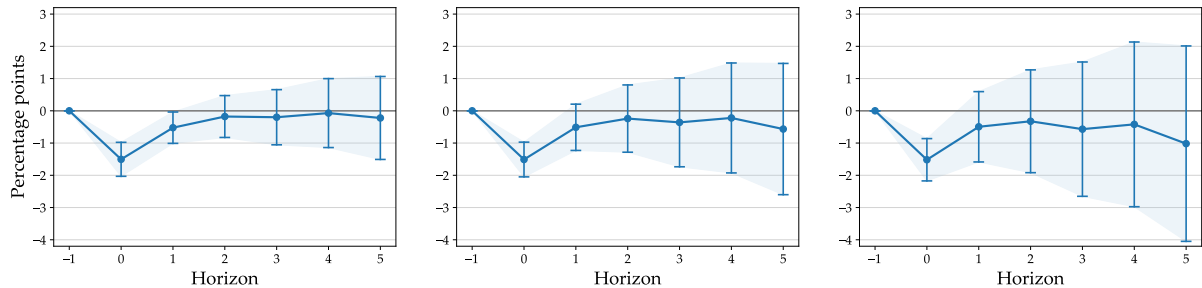
tries. Aggregate demand shifts from investment to consumption, increased outsourcing does not appear to be sufficient to maintain the trade balance, the share of industrial output declines while the economy becomes more dependent on agriculture, and agricultural inputs, fertilizers and livestock substitute 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 (3.1) 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 (3.2) and present them for each subsample.

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

(a) 25th percentile: +0.49°C at (b) 50th percentile: +0.74°C at (c) 75th 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.

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

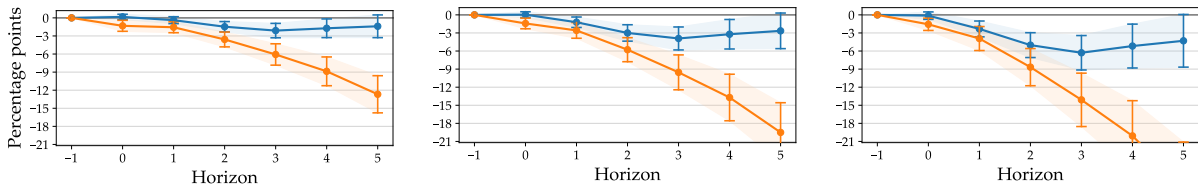
Access to electricity is also associated with a reduced impact, but the evidence is less robust since this effect appears when comparing the country-year observations above the 75th percentile to those below the 25th (Appendix Figure 1.D.1 panel C) but disappears when the threshold is set at the median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

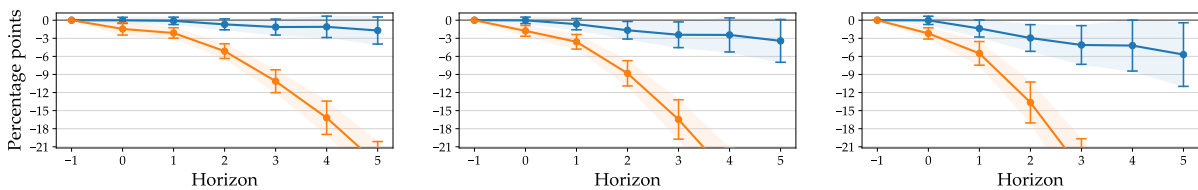
Figure 1.18 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, According to Policy Levels

Panel A. Institutional Quality

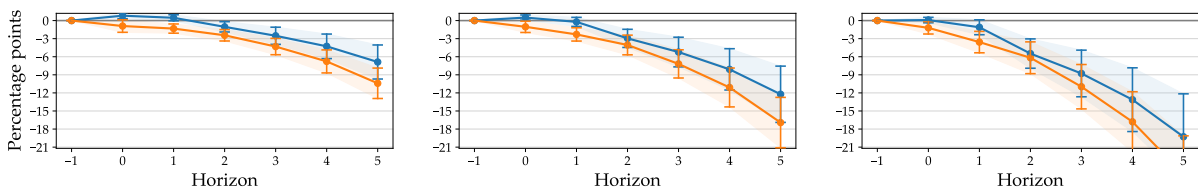
(a) 25th percentile: +0.49°C at $h = 0$ (b) 50th percentile: +0.74°C at $h = 0$ (c) 75th percentile: +1.06°C at $h = 0$



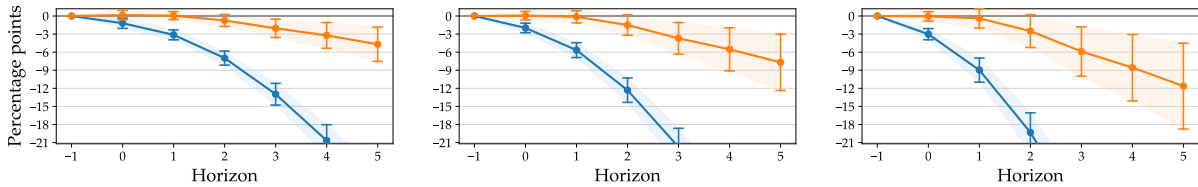
Panel B. Mobile Cellular Subscriptions



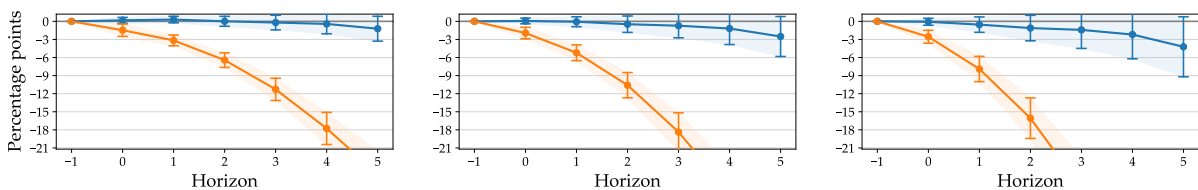
Panel C. Access to Electricity



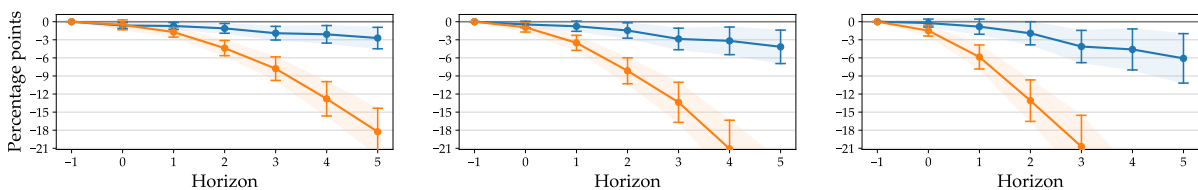
Panel D. Deforestation



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.

of their effectiveness in preventing soil erosion, in protecting agricultural output in the 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

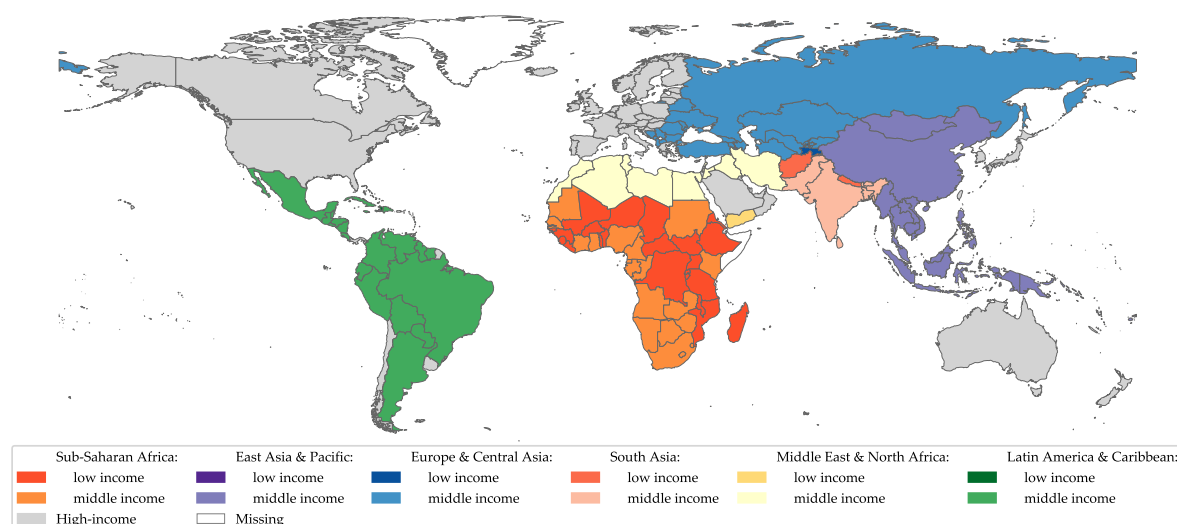
Low-Income Countries	Afghanistan, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Democratic Republic of the Congo, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Liberia, Madagascar, Malawi, Mali, Mozambique, Nepal, Niger, Rwanda, Sierra Leone, South Sudan, Tajikistan, Tanzania, 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 \(2019b\)](#).

Table 1.A.2 – Data Sources

Variable:	Source:
<i>Socio-Economic Variables:</i>	
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)
<i>Climate Variables:</i>	
Terrestrial Temperature and Precipitation	University of Delaware: Matsuura and Willmott (2019b)
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

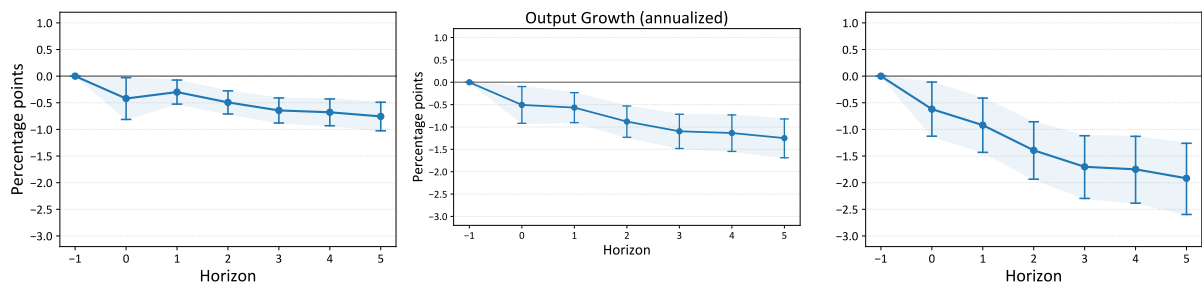
Table 1.B.1 – Macroeconomic Effects of Temperature Deviations from their Historical Norms in Low-Income Countries

<i>Dependent variable is Real GDP per capita growth</i>						
	<i>h = 0</i>	<i>h = 1</i>	<i>h = 2</i>	<i>h = 3</i>	<i>h = 4</i>	<i>h = 5</i>
\tilde{T}	-0.002 (0.003)	0.004 (0.003)	0.007** (0.003)	0.008*** (0.003)	0.008*** (0.003)	0.009*** (0.003)
$\tilde{T} \times \mathbb{1}_{(low\ inc.)}$	0.000 (0.005)	0.005 (0.005)	0.007 (0.005)	0.009* (0.005)	0.012*** (0.005)	0.015*** (0.005)
\tilde{T}^2	-0.002 (0.002)	-0.006*** (0.002)	-0.008*** (0.002)	-0.009*** (0.002)	-0.008*** (0.002)	-0.009*** (0.002)
$\tilde{T}^2 \times \mathbb{1}_{(low\ inc.)}$	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)	0.001 (0.004)	-0.002 (0.004)	-0.003 (0.004)
\tilde{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)
$\tilde{P} \times \mathbb{1}_{(low\ inc.)}$	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
\tilde{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)
$\tilde{P}^2 \times \mathbb{1}_{(low\ inc.)}$	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: $\mathbb{1}_{(low\ inc.)}$ 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) 25th percentile: +0.49°C at $h = 0$ (b) 50th percentile: +0.74°C at $h = 0$ (c) 75th percentile: +1.06°C at $h = 0$

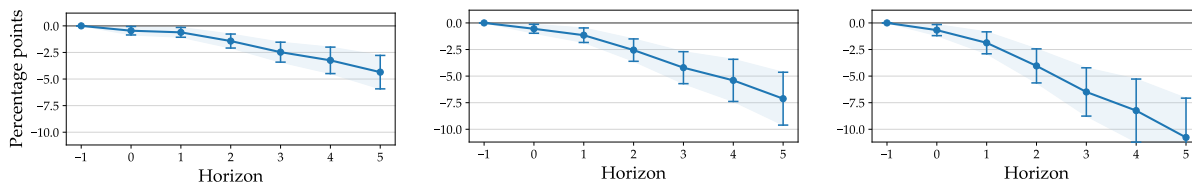


Note: The three panels show the annualized response of per capita real GDP growth rate to a 1 °C increase in temperatures deviation from their historical norms. Annualized growth rates are computed from the results reported in Figure 1.8. The distribution of these temperatures deviations refers to the 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 25th, the 50th and the 75th 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.

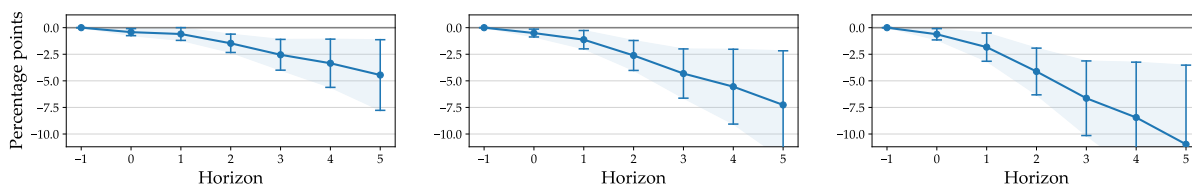
Figure 1.B.2 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP

Panel A. Excluding China, India and Russia

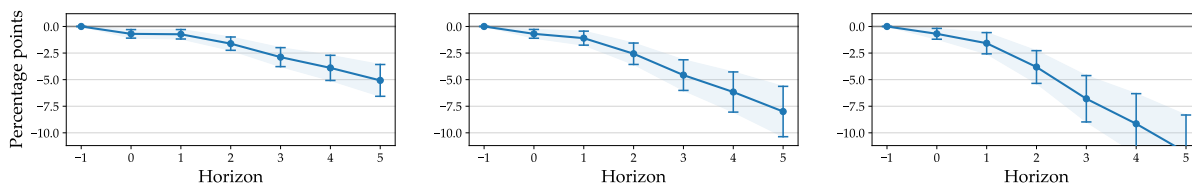
(a) 25th percentile: +0.49°C at (b) 50th percentile: +0.74°C at (c) 75th percentile: +1.06°C at $h = 0$



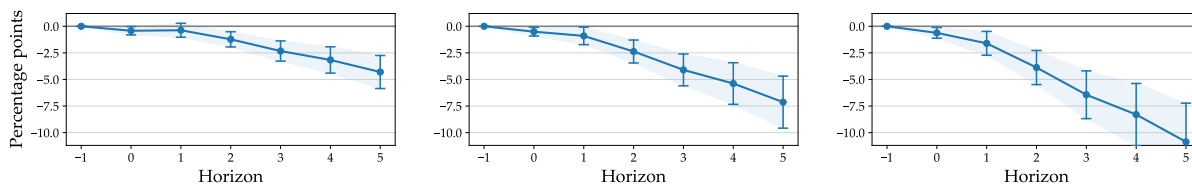
Panel B. Driscoll-Kraay Standard Errors



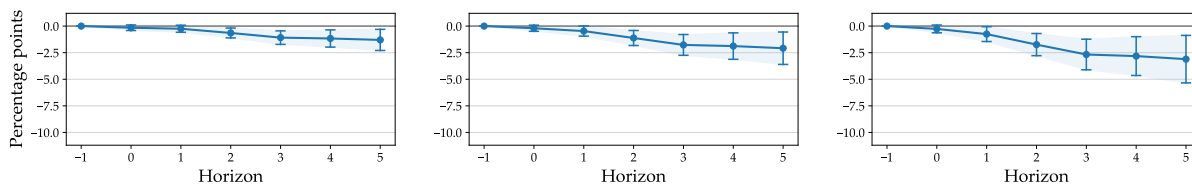
Panel C. Controlling for Commodity Exports Value



Panel D. Controlling for Temperatures and Precipitations Levels



Panel E. Sample includes High Income Countries

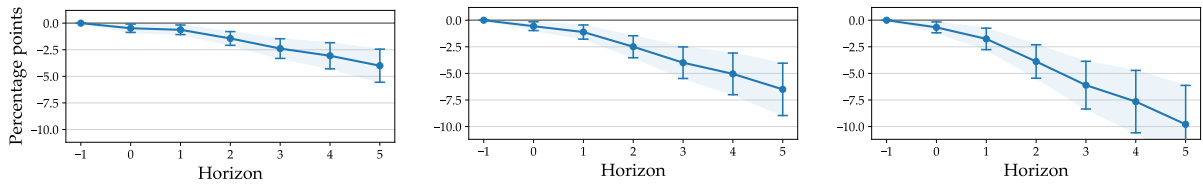


Note: Each panel shows the cumulative response of per capita real GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in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

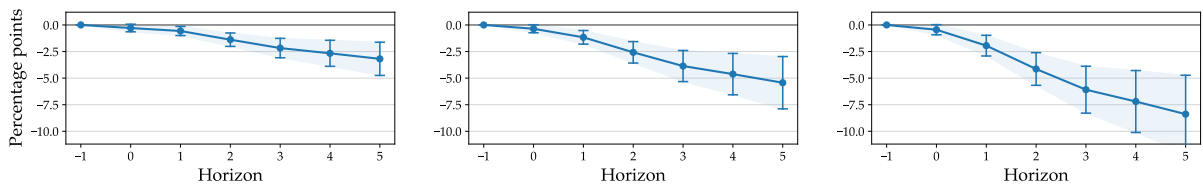
Figure 1.B.3 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP

Panel A. Real GDP as dependent variable

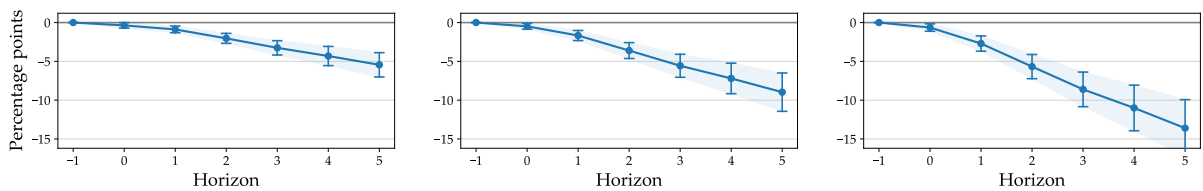
(a) 25th percentile: +0.49°C at $h = 0$ (b) 50th percentile: +0.74°C at $h = 0$ (c) 75th percentile: +1.06°C at $h = 0$



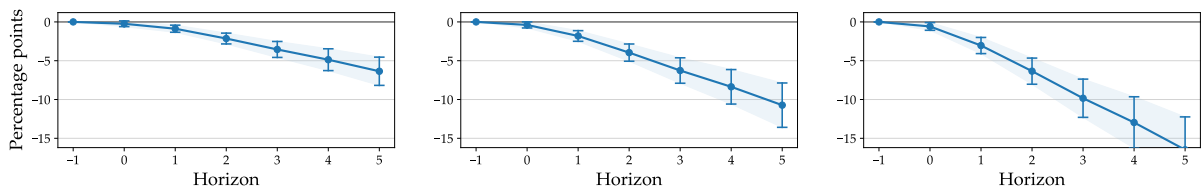
Panel B. Including a Linear Time Trend



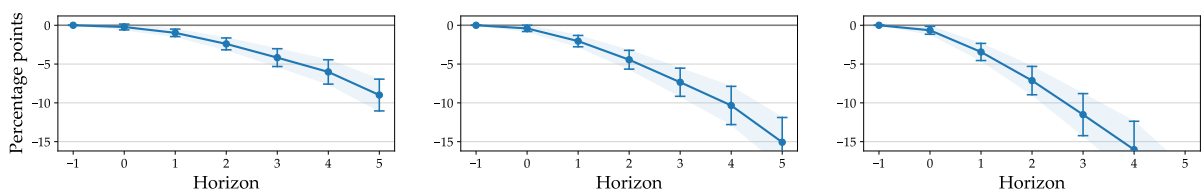
Panel C. Including a Linear and Quadratic Time Trends



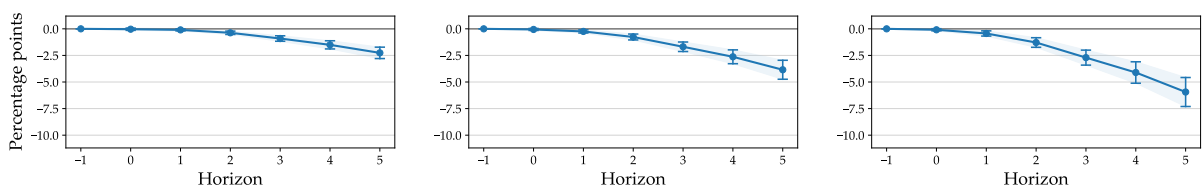
Panel D. Including a Country-Specific Linear Time Trend



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



Panel F. Human Development Index as dependent variable



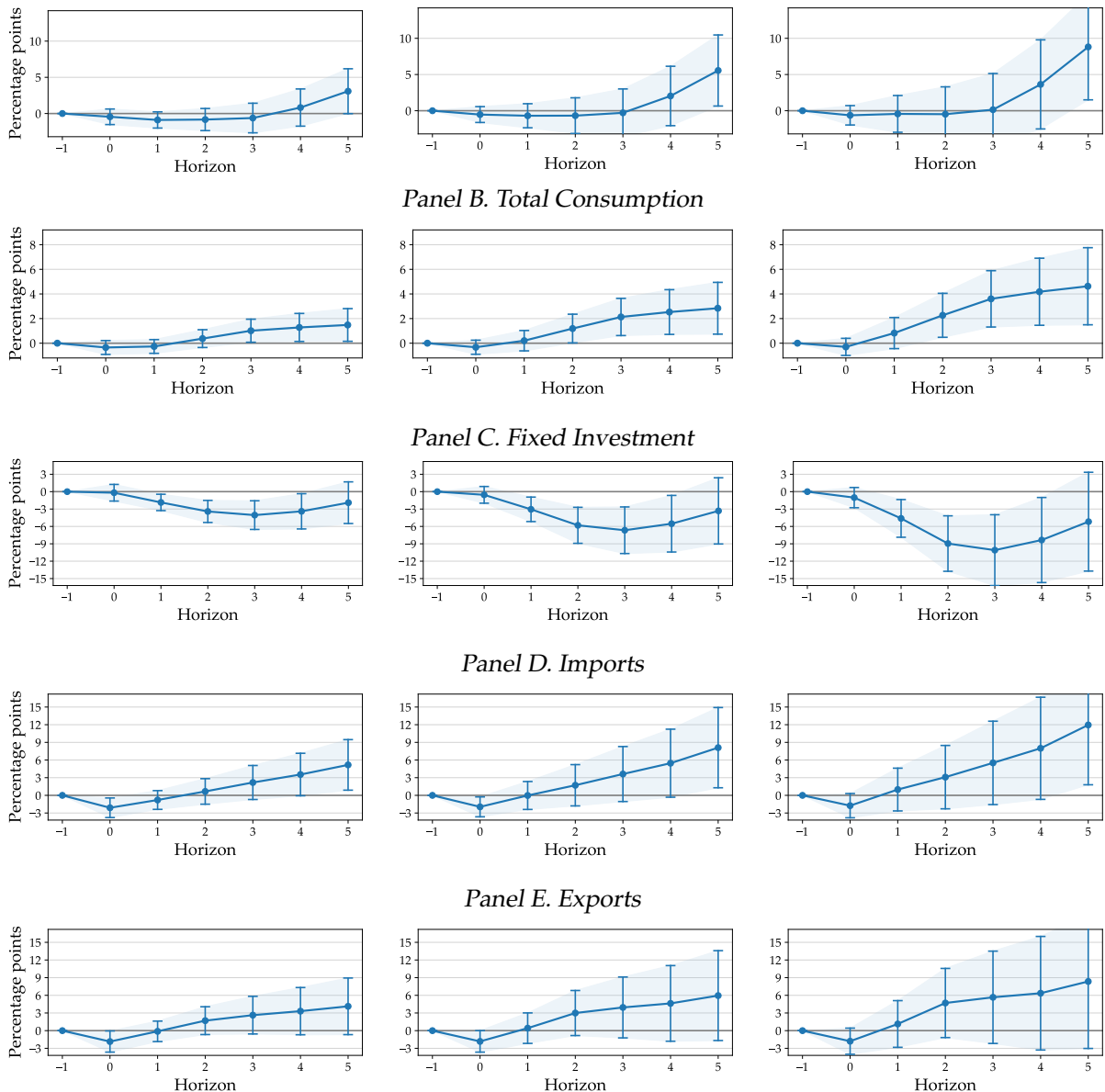
Note: Each panel shows the cumulative response of per capita real GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown in 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) 25th percentile: +0.49°C at (b) 50th percentile: +0.74°C at (c) 75th percentile: +1.06°C at
 $h = 0$ $h = 0$ $h = 0$



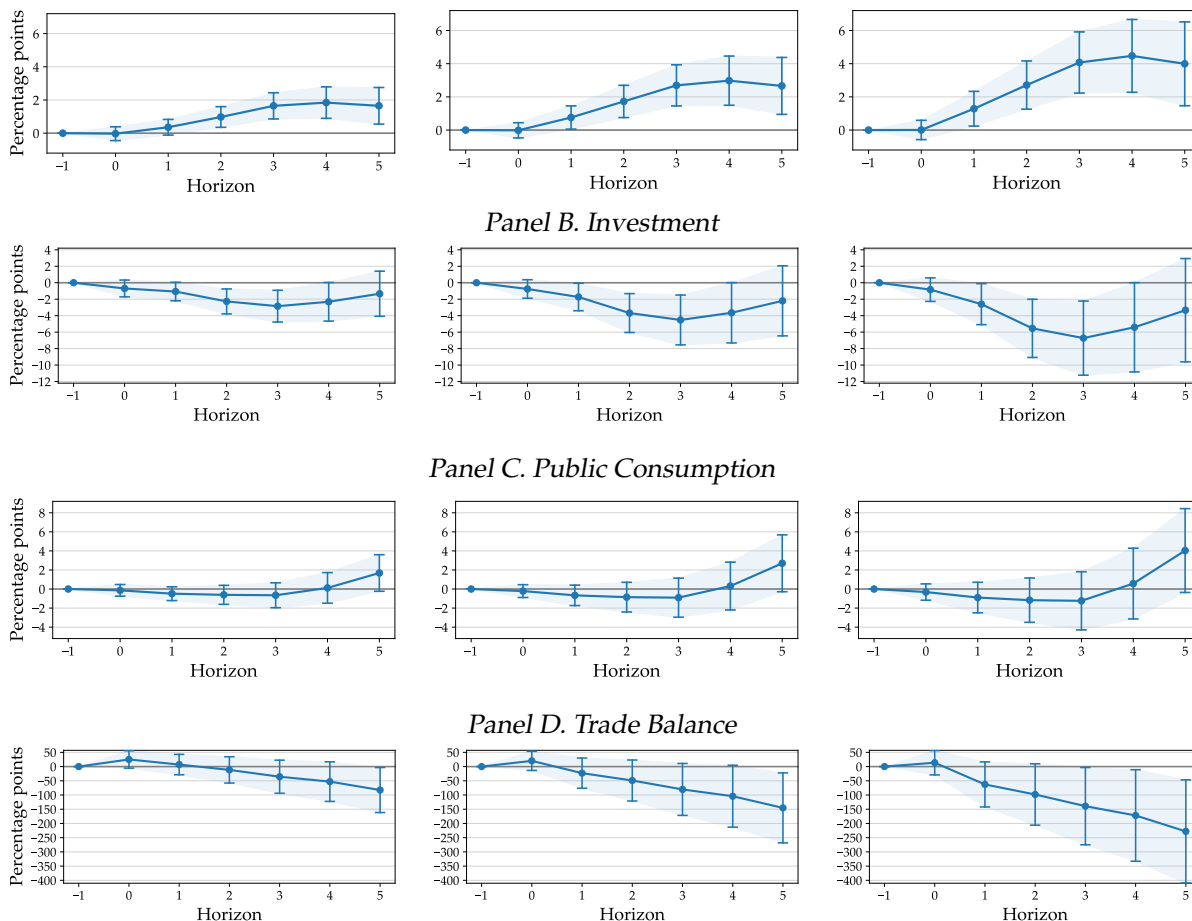
Note: Each panel shows the cumulative response of the ratio of the respective demand component over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 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.

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

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 $h = 0$

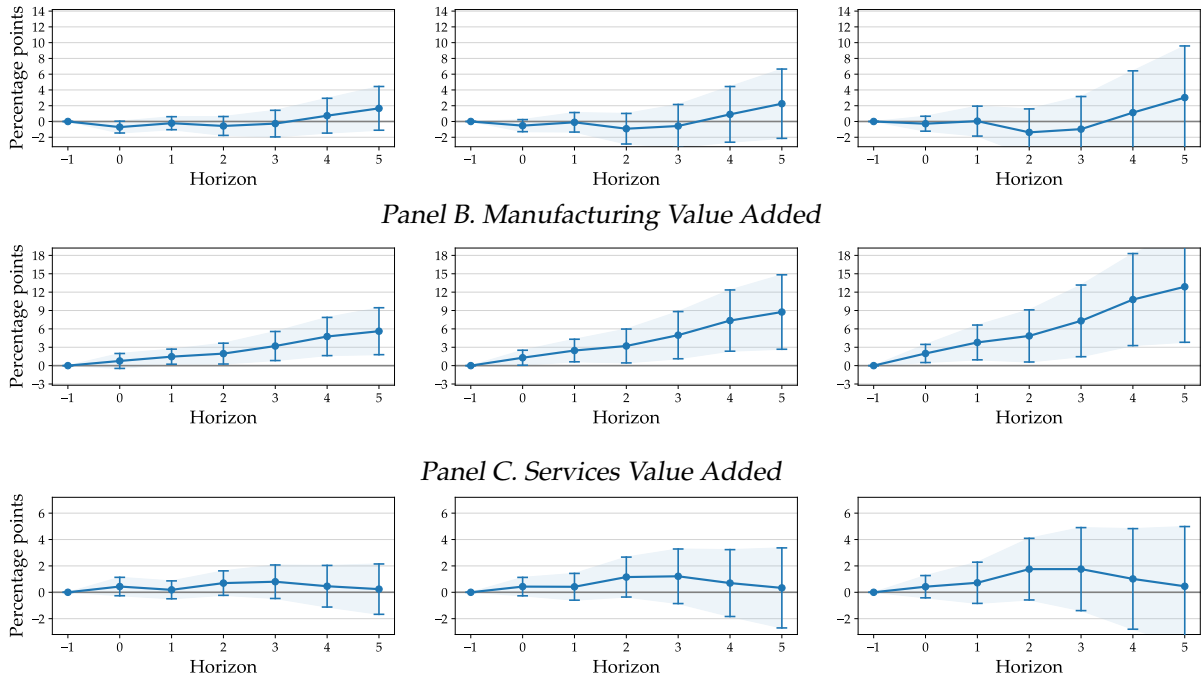


Note: Each panel shows the cumulative response of the ratio of the respective sectoral component over GDP to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 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

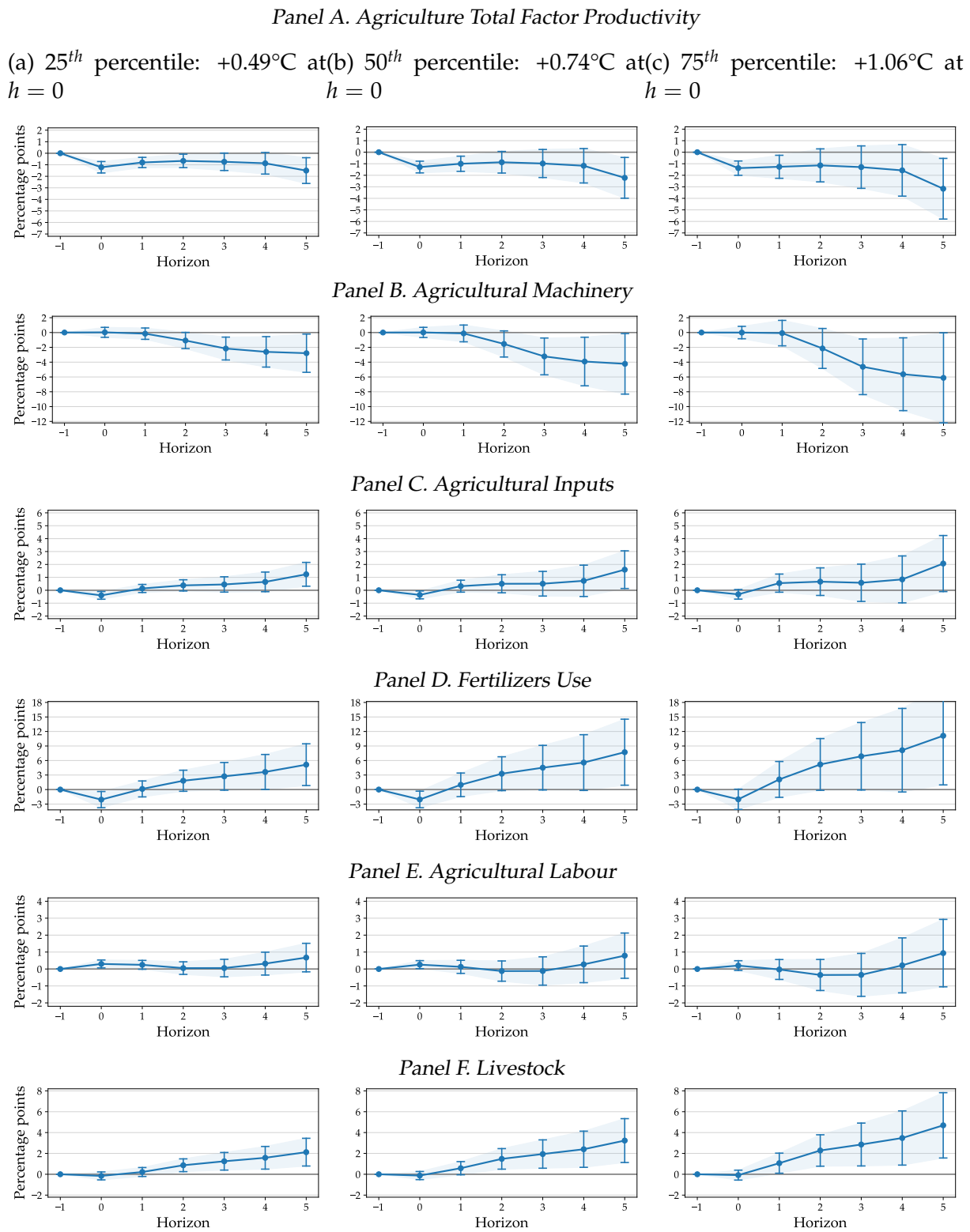
Panel A. Total Factor Productivity

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



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



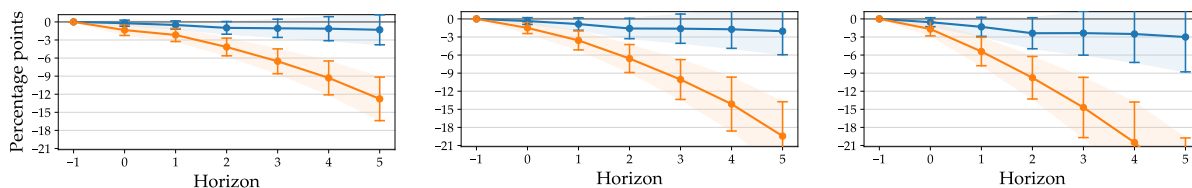
Note: Each panel shows the cumulative response of the respective variable to a 1 °C increase in temperatures deviation from their historical norms. The distribution of these temperatures deviations refers to the difference in average mean temperature between the periods 2001–2017 and 1900–1950, shown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

1.D Additional Policy Results

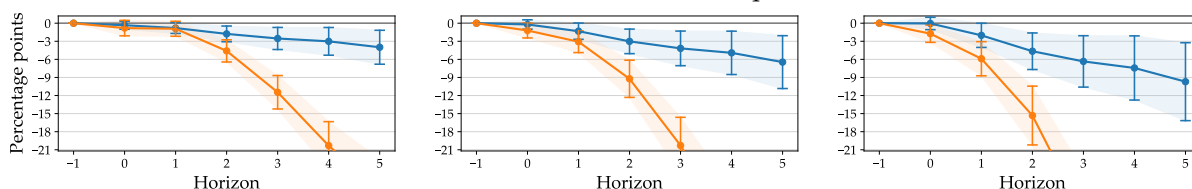
Figure 1.D.1 – Cumulative Effect of Temperatures Deviations from their Historical Norms on per Capita Real GDP, According to Policy Levels

Panel A. Institutional Quality

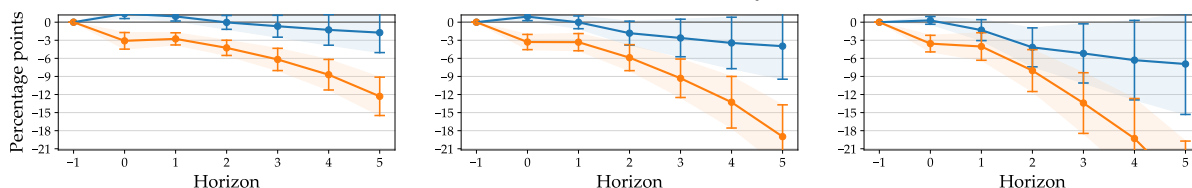
(a) 25th percentile: +0.49°C at $h = 0$ (b) 50th percentile: +0.74°C at $h = 0$ (c) 75th percentile: +1.06°C at $h = 0$



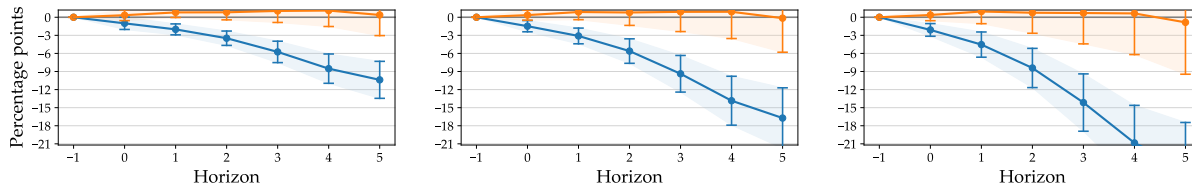
Panel B. Mobile Cellular Subscriptions



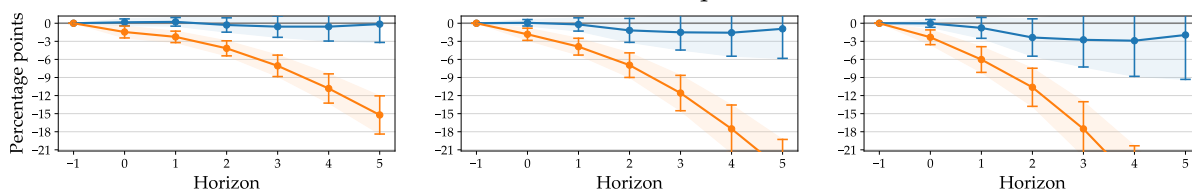
Panel C. Access to Electricity



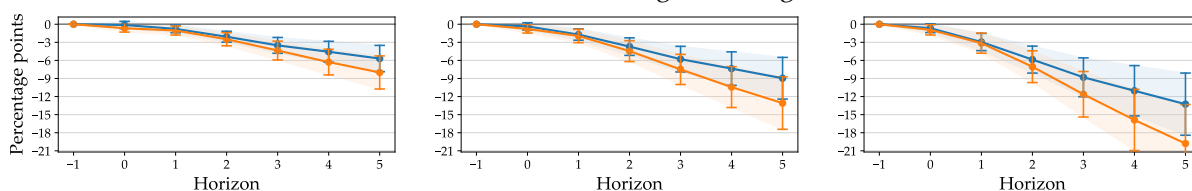
Panel D. Deforestation



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 75th percentile, while light orange colour includes observations below the 25th 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.

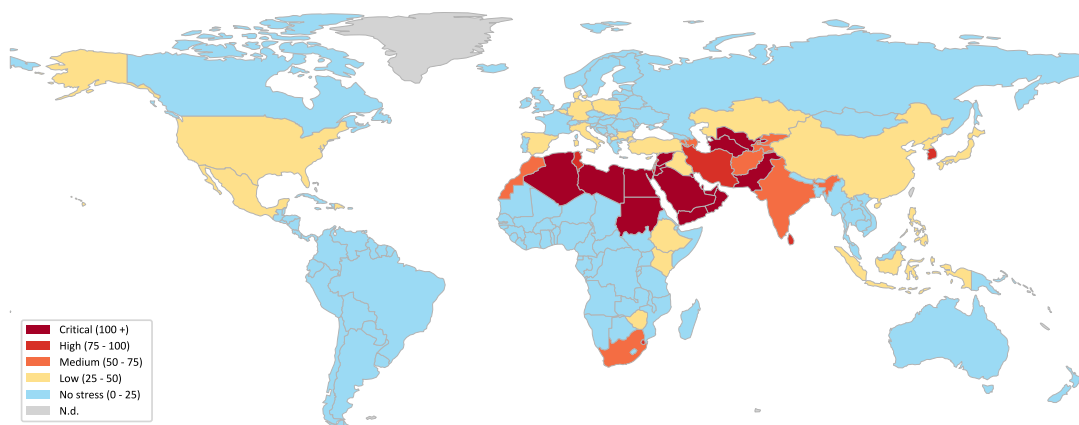
Keywords: Climate Change, Drought, Economic Growth, Business Fluctuations, Developing Countries, Middle East and North Africa.

JEL Classification: E32, O11, O13, O40, Q54.

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 acute 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 maintenance 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 countries 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 output 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 CO₂ emissions (4.4 % of global historical CO₂ 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 \(2021\)](#) and [IMF - IFS \(2020\)](#) datasets and the 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 5 discusses robustness checks. Section 7 analyses transmission channels and Section 6 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 controlling 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. (2020a) is an exception: 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 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 controlling 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 4.A.1 contains the

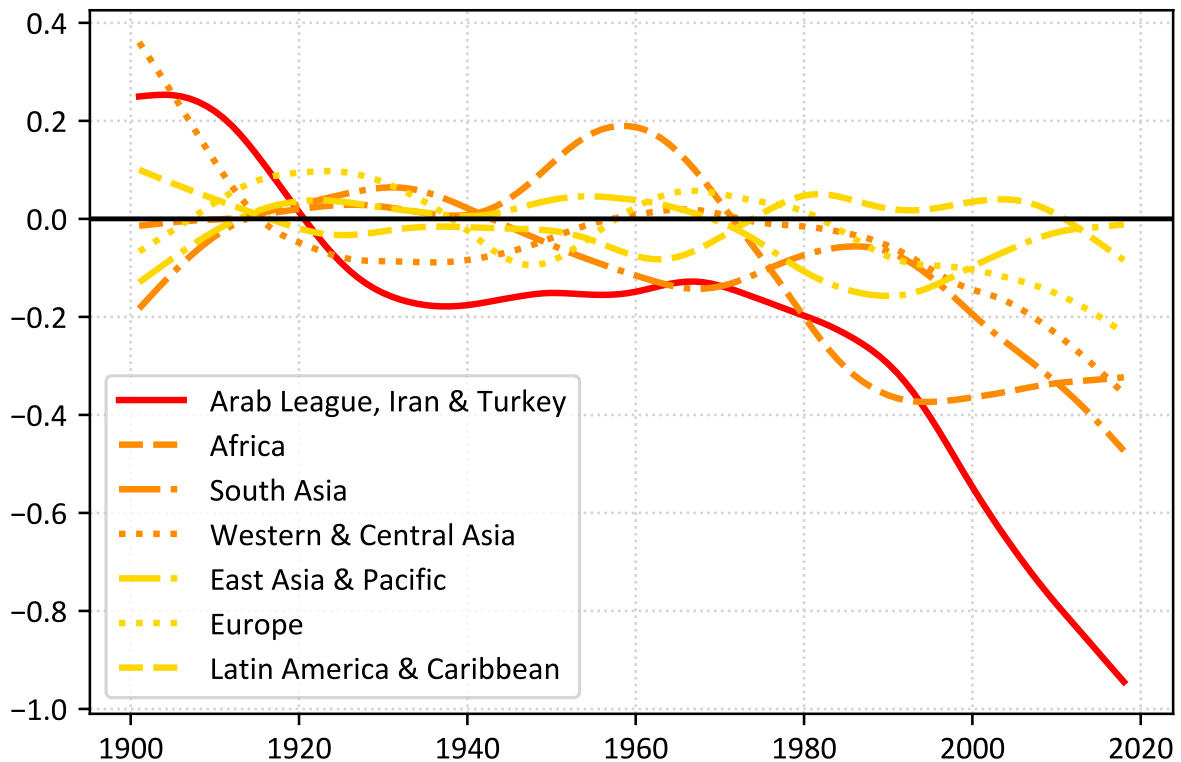
list of the countries included in the sample, and Appendix Table 5.A.1 lists all the data sources used in this paper.

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, defined as its average during the period 1901–1950. The global dataset is gridded with a 0.5° latitude \times 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 Standardized Precipitation Index (SPI), developed 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 Palmer Drought Severity Index (PDSI), developed 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 across regions. Arab League members, Iran and Turkey correspond to the region where climate conditions dry 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.

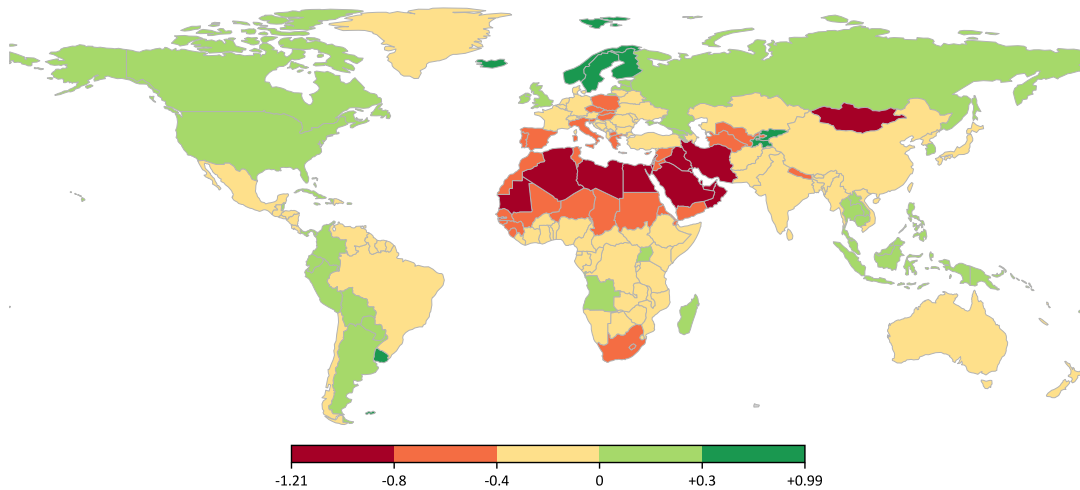
This paper uses the SPEI deviation from its historical norm, to assess the effects of one dimension of climate change, namely changing drought patterns, instead of just drought episodes. The historical norm is defined as the period 1901–1950, *i.e.* after the pre-industrial period often considered by the IPCC 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 for all coun-

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

tries 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:

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

with:

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

²Robustness checks presented in section 5 ensure that the results are not driven by the indicator’s construction.

Other climate and weather data are used as control variables. Terrestrial mean annual temperatures and total annual precipitations are obtained from [Matsuura and Willmott \(2019b\)](#). 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 \(2021\)](#) 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 natural gas liquids (NGL) production from the International Energy Agency (IEA) Oil Information Statistics through Organisation for Economic Co-operation and Development (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 $h = 0, 1, \dots, 5$:

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

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 . $\mathbf{X}'_{i,t}$ 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 respond 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):

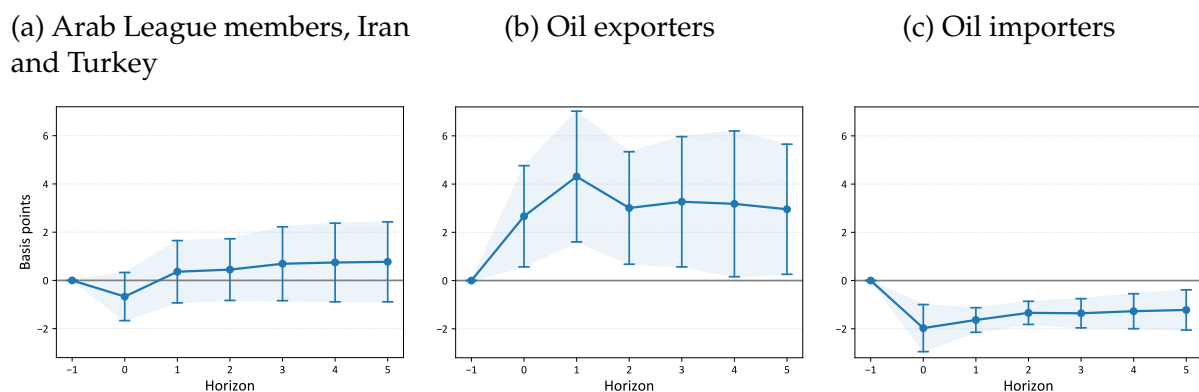
$$y_{i,t+h} = \theta^h \widetilde{Drought}_{i,t} + \Theta^h \widetilde{X}'_{i,t} + \delta_i^h + \gamma_t^h + \varepsilon_{i,t}^h \quad (2.4)$$

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 $h = 0, 1, \dots, 5$ 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 $h = 0, 1, \dots, 5$. 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



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 $h = 0, 1, \dots, 5$. 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-

³The division of the sample between oil exporters and oil importers follows that of the IMF and is indicated in Appendix Table 4.A.1.

Table 2.1 – Cumulative Response of GDP Growth to Cumulative Drought

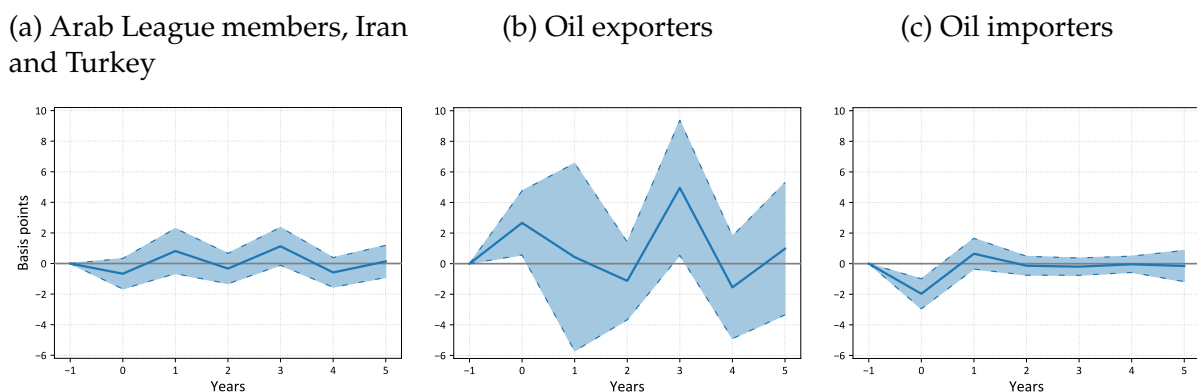
Dependent Variable:	Real GDP Growth					
	$h = 0$	$h = 1$	$h = 2$	$h = 3$	$h = 4$	$h = 5$
<i>Panel A: Sample includes Arab League Members, Iran and Turkey</i>						
$\widetilde{Drought}_h$	-0.007 (0.006)	0.004 (0.008)	0.004 (0.008)	0.007 (0.009)	0.007 (0.010)	0.008 (0.010)
Observations	912	888	864	840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



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 $h = 0, 1, \dots, 5$. 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 per-

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

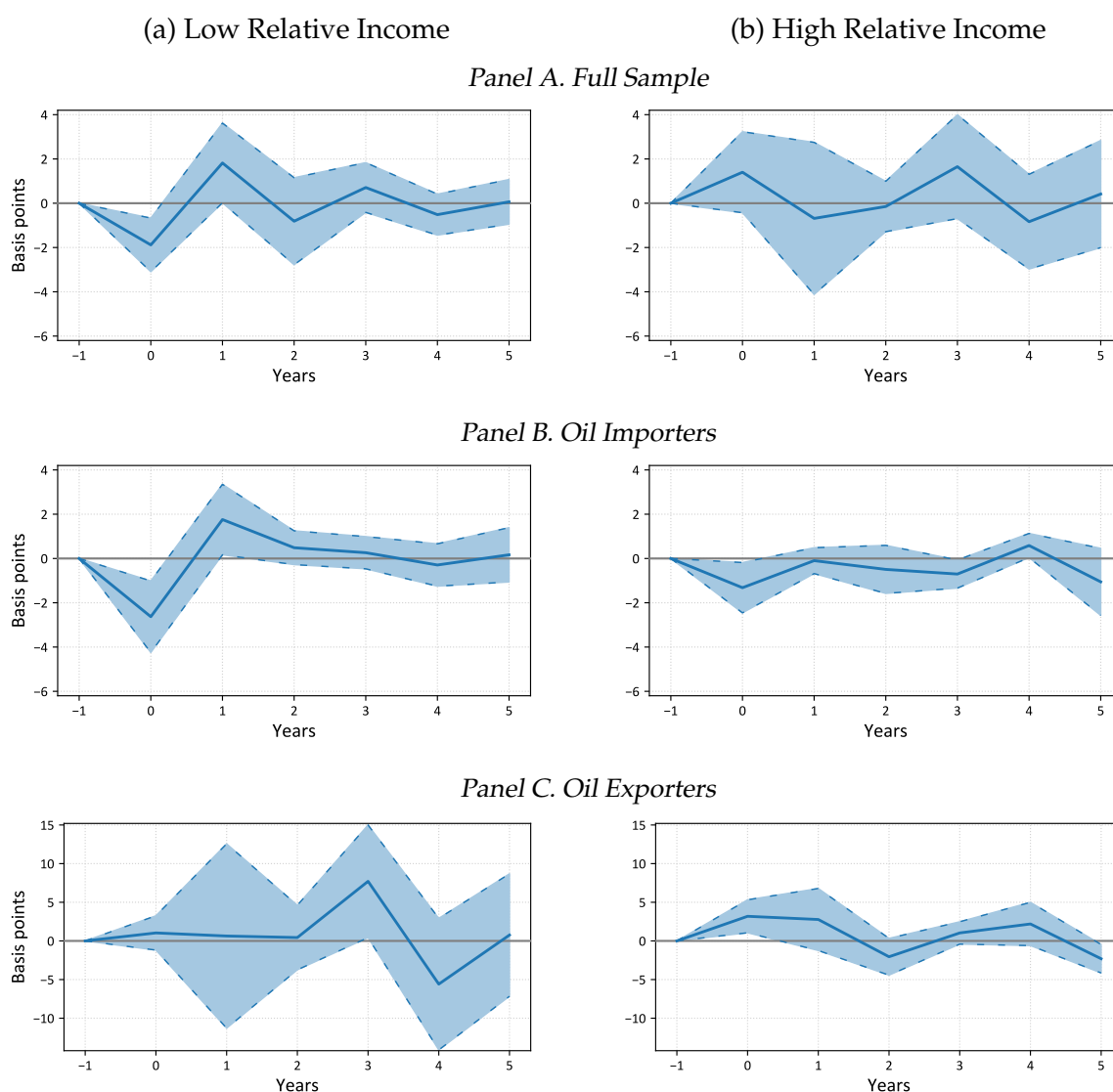
Note: The estimates are in percentage points. Standard errors in parentheses are clustered at the country level. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

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 and 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 heterogeneous.

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 $h = 0, 1, \dots, 5$. 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., 2020a). 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 SPEI6 indicator (i.e. the variable $\widetilde{Drought}_t$), instead of the inverse of the deviation of SPEI6 to its historical norm ($Drought_t$). 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) reports 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:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	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
$\widehat{Drought}_t$	-0.002 (0.008)	-0.008 (0.006)	-0.004 (0.006)	-0.013* (0.007)	-0.007 (0.005)	-0.004 (0.007)	-0.004 (0.007)	-0.007 (0.006)	-0.005 (0.006)	-0.008 (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
<i>Panel A: Sample includes Arab League Members, Iran and Turkey</i>										
$\widehat{Drought}_t$	0.045* (0.023)	0.013 (0.013)	0.027 (0.015)	-0.007 (0.014)	0.027 (0.016)	0.028 (0.018)	0.028 (0.018)	0.026* (0.012)	0.026* (0.013)	0.026 (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
<i>Panel B: Sample includes oil exporters</i>										
$\widehat{Drought}_t$	-0.020** (0.007)	-0.016** (0.005)	-0.018** (0.006)	-0.017** (0.008)	-0.020*** (0.006)	-0.016** (0.006)	-0.016** (0.006)	-0.020*** (0.006)	-0.019** (0.006)	-0.020*** (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
<i>Panel C: Sample includes oil importers</i>										

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 5.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 known 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

⁴These 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 $\tilde{\mathbf{X}}'_{i,t}$ is modified accordingly to include two lags of the dependent variable.

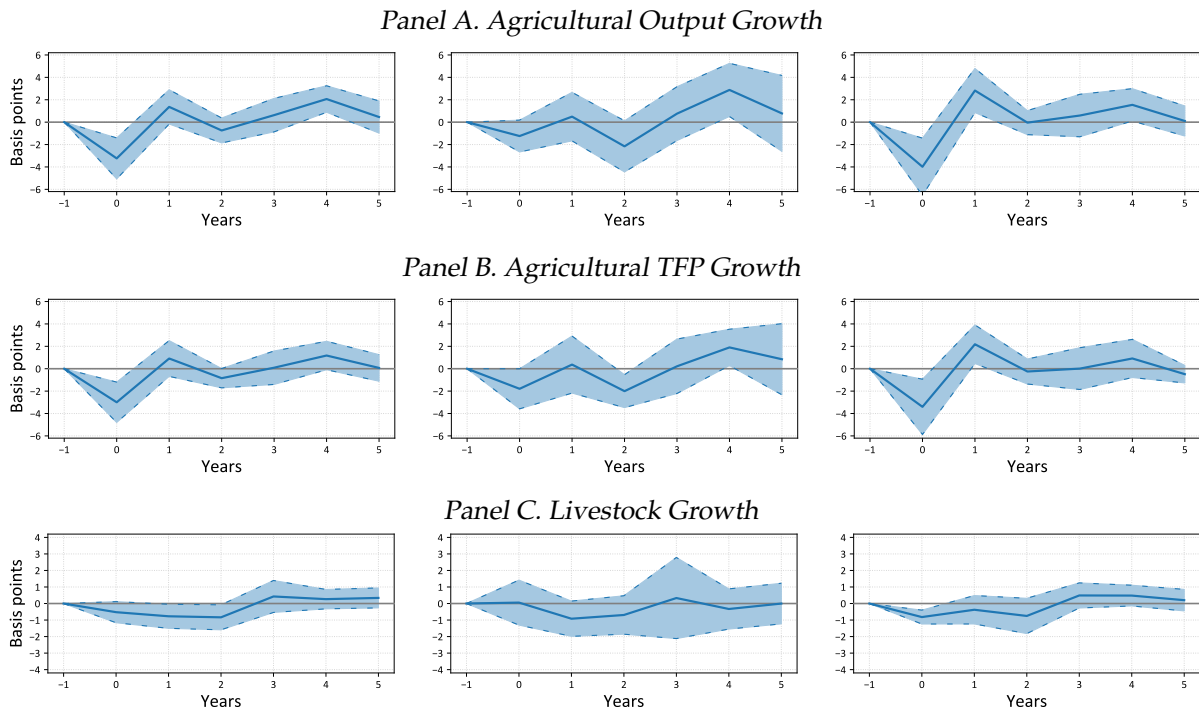
The results for the agricultural sector show that agricultural output growth, agricultural total factor productivity growth and livestock growth all significantly decrease when droughts occur in oil-importing countries. Contrary to the aggregate results, the negative contemporary effect appears to be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

Figure 2.1 – Impulse Responses of Agricultural Sector Growth to Drought

(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 agricultural sector growth for each horizon $h = 0, 1, \dots, 5$. 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 $h = 0, 1, \dots, 5$:

$$y_{i,t+h} = \theta^h Drought_{i,t} + \alpha^h Irrigation_{i,t} + \beta^h Drought_{i,t} \times Irrigation_{i,t} + \Theta^h \tilde{\mathbf{X}}'_{i,t} + \delta_i^h + \gamma_t^h + \varepsilon_{i,t}^h \quad (2.5)$$

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 (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 replacing 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 $\tilde{\mathbf{X}}'_{i,t}$ 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 a 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 mechanisms 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	Agricultural TFP	Livestock
	<i>Growth</i>	<i>Growth</i>	<i>Growth</i>
	(1)	(2)	(3)
$\widetilde{Drought}_t$	-0.045** (0.017)	-0.038** (0.016)	-0.008** (0.003)
$Irrigation_t$	-0.002 (0.001)	-0.002 (0.001)	0.000 (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** (0.010)	0.015* (0.007)	-0.001 (0.006)
$\widetilde{Drought}_{t-2}$	0.009 (0.011)	0.005 (0.011)	-0.004 (0.006)
<i>Agricultural Output Growth</i> _{t-1}	-0.402*** (0.065)	-	-
<i>Agricultural Output Growth</i> _{t-2}	-0.071* (0.038)	-	-
<i>Agricultural TFP Growth</i> _{t-1}	-	-0.426*** (0.071)	-
<i>Agricultural TFP Growth</i> _{t-2}	-	-0.079 (0.048)	-
<i>Livestock Growth</i> _{t-1}	-	-	0.127 (0.091)
<i>Livestock Growth</i> _{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

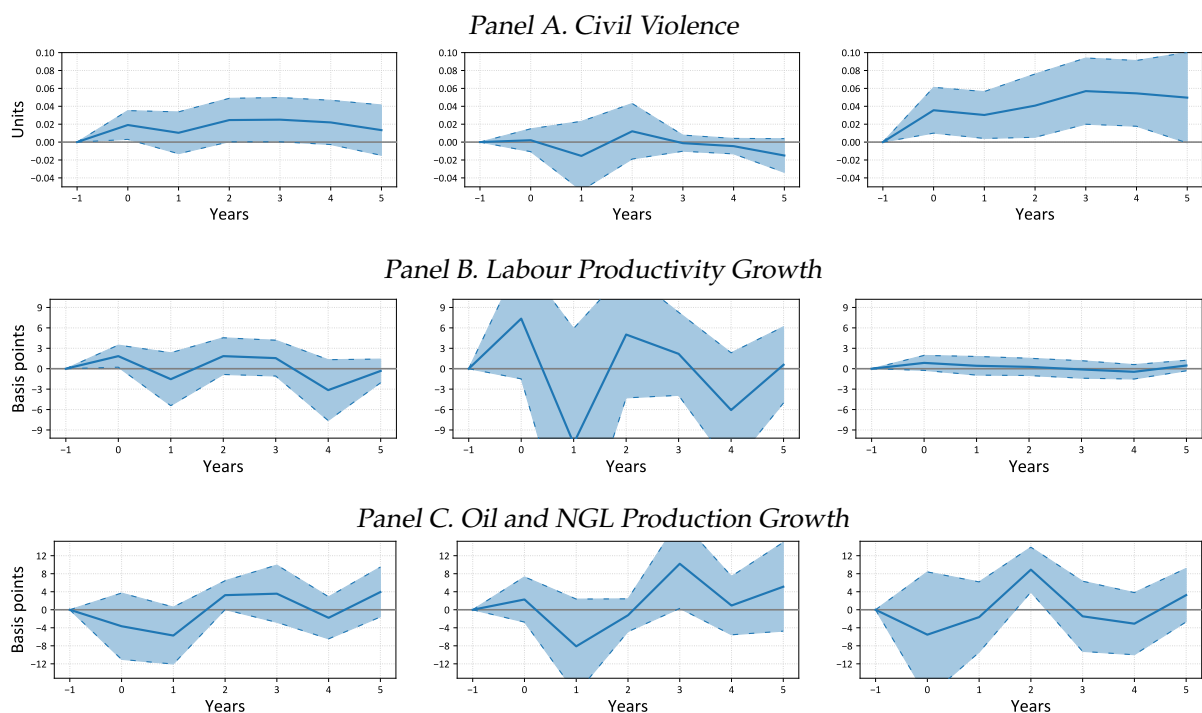
potential transmission mechanisms are active in the region. Labour productivity growth does not respond to droughts, and oil output growth does not increase in oil-exporting countries in response such events.

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 $h = 0, 1, \dots, 5$. 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 acute 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 diversify their economies away from oil production and reduce their dependence on this sector, with heterogeneous 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:
<i>Socio-Economic Variables:</i>	
Real GDP growth rate	World Bank - WDI (2021) ; 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
<i>Climate Variables:</i>	
Standardized Precipitations-Evapotranspiration Index	Vicente-Serrano et al. (2010)
Terrestrial temperature and precipitation	Matsuura and Willmott (2019b)
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)

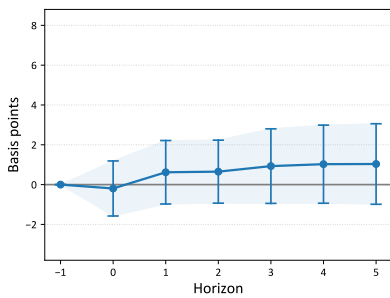
Variable	Obs.	Mean	Std. Dev.	Min.	Max.
GDP growth rate	581	4.23	6.10	-42.45	49.45
Drought index deviation ^a	754	0.26	0.67	-1.93	2.20
Temperatures deviation ^a	741	0.32	0.67	-1.62	2.95
Precipitations deviation ^a	741	-42.70	111.40	-920.03	553.77
Temperatures	741	21.31	5.18	9.34	29.03
Precipitations	741	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.

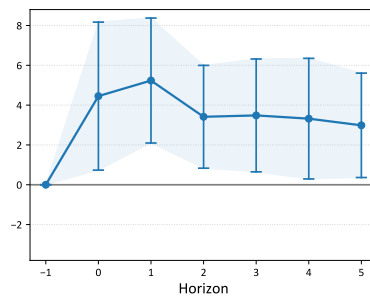
2.B Additional Robustness Checks

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

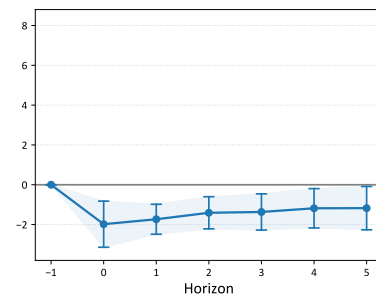
(a) Arab League members, Iran and Turkey



(b) Oil exporters



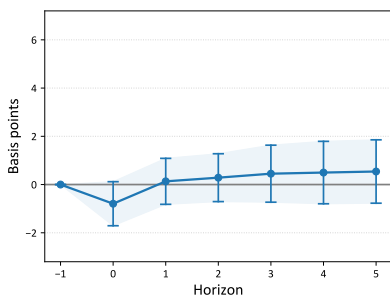
(c) Oil importers



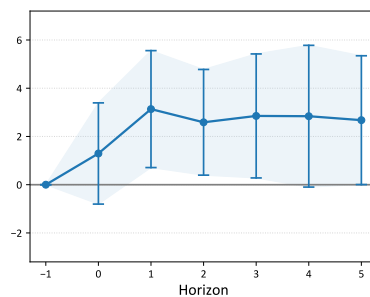
Note: The estimates are in percentage points. Standard errors in parentheses are clustered at the country level. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

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

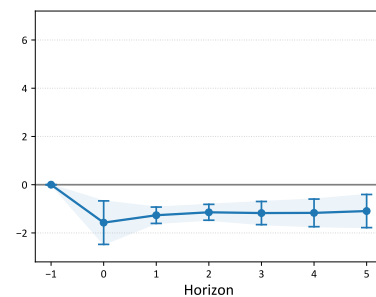
(a) Arab League members, Iran and Turkey



(b) Oil exporters



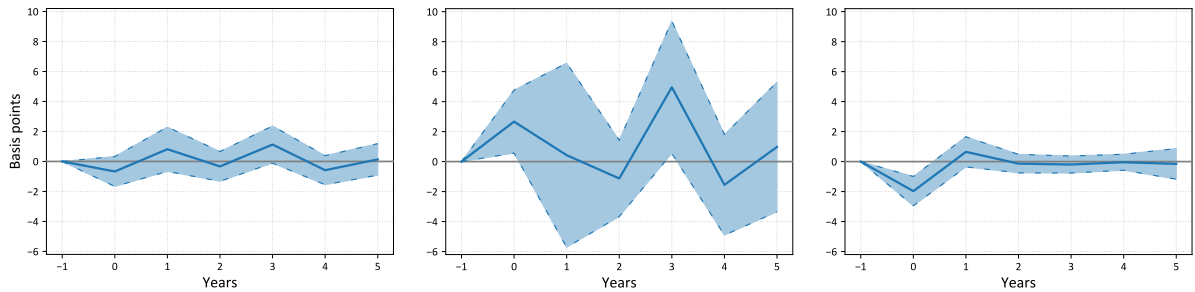
(c) Oil importers



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)

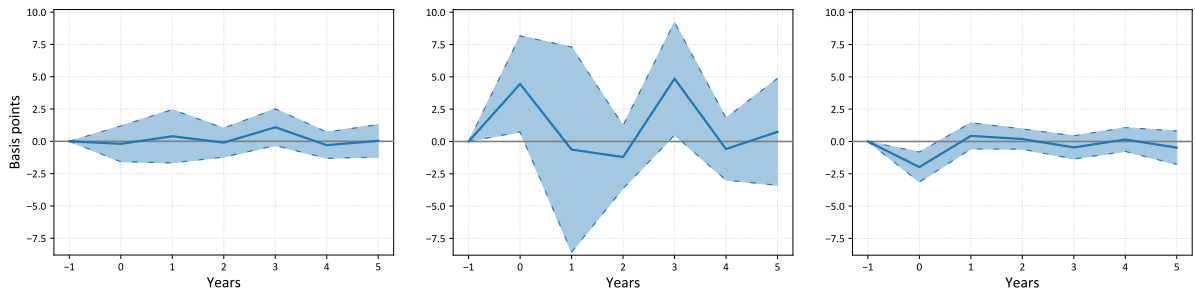
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



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

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

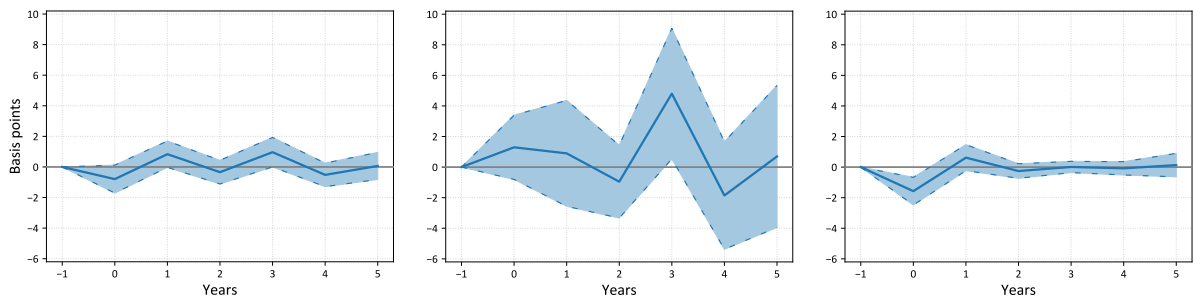
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



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 $h = 0, 1, \dots, 5$. 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



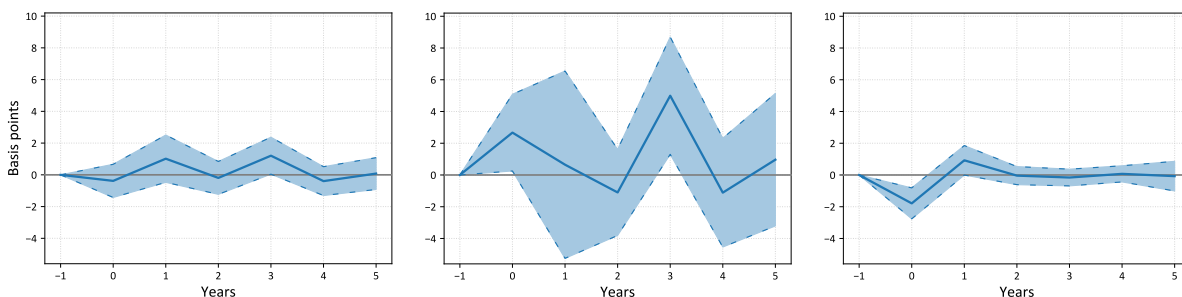
Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, \dots, 5$. Confidence intervals correspond to the 10 % level.

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



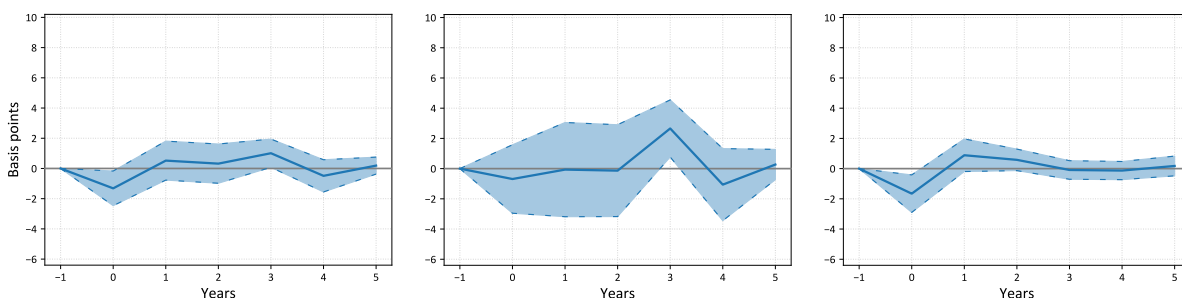
Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, \dots, 5$. Confidence intervals correspond to the 10 % level.

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

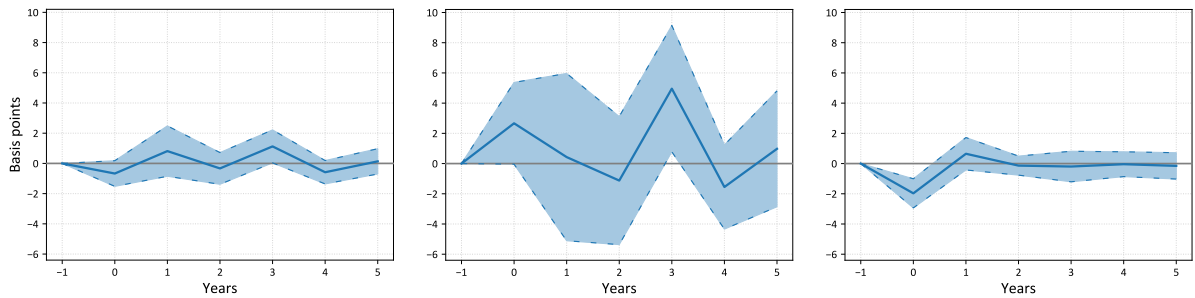
(c) Oil importers



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 $h = 0, 1, \dots, 5$. Confidence intervals correspond to the 10 % level.

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

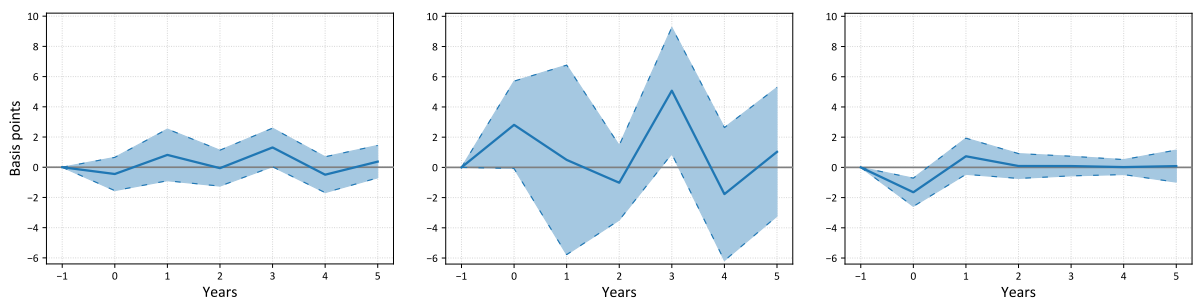
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



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 $h = 0, 1, \dots, 5$. 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



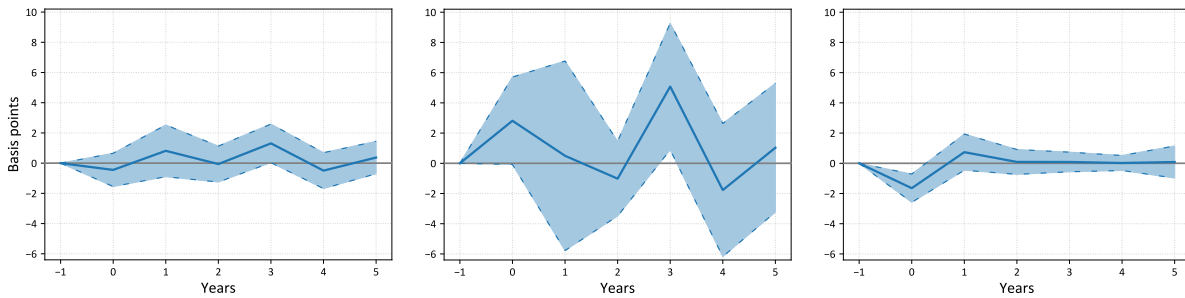
Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, \dots, 5$. Confidence intervals correspond to the 10 % level.

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



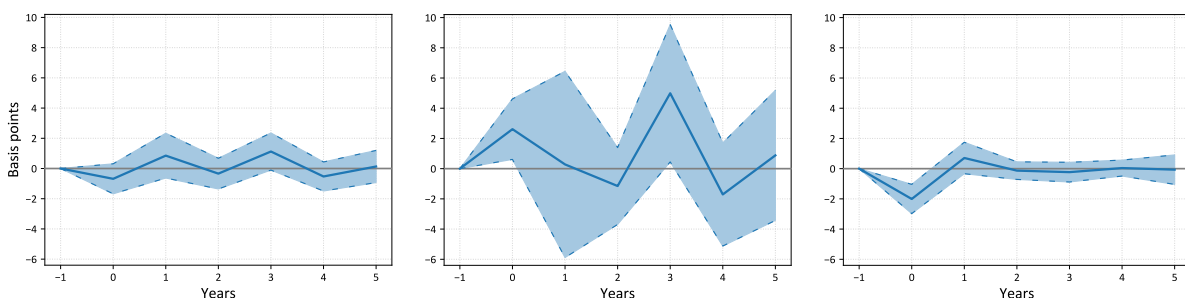
Note: The estimates are in basis points and show the effects of a drought index deviations from its historical norm on annual GDP growth for each horizon $h = 0, 1, \dots, 5$. Confidence intervals correspond to the 10 % level.

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

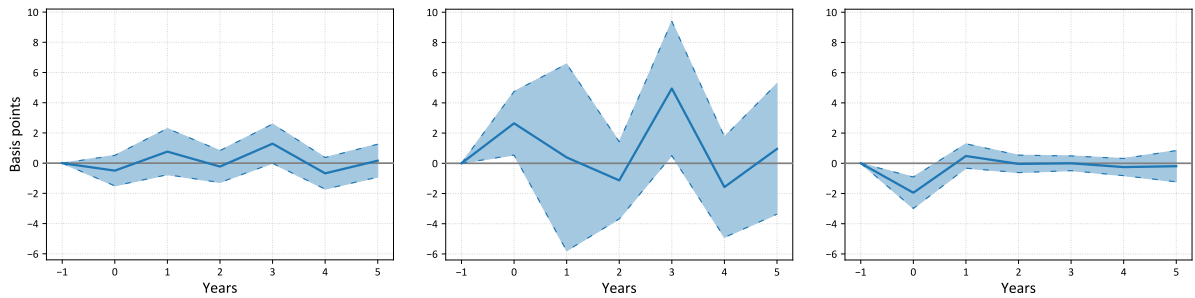
(c) Oil importers



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 $h = 0, 1, \dots, 5$. Confidence intervals correspond to the 10 % level.

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

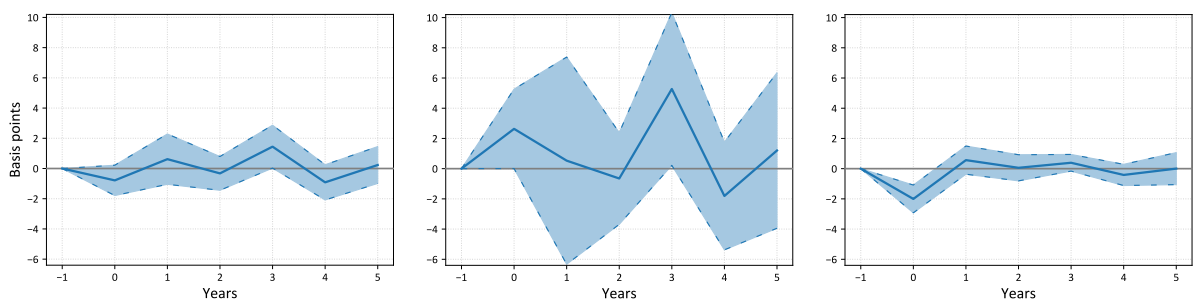
(a) Arab League members, Iran and Turkey (b) Oil exporters (c) Oil importers



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 $h = 0, 1, \dots, 5$. 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 $h = 0, 1, \dots, 5$. 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
<i>Panel A: Sample includes oil importers</i>				
<i>Baseline</i>	-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
<i>Panel B: Sample includes oil exporters</i>				
<i>Baseline</i>	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.

Part II

**Climate Change, Weather Shocks and
Finance**

Chapter 3

Climate-Related Natural Disasters and the Exchange Rate in Developing Countries

Abstract

Climate-related natural disasters have recently had dramatic effects on developing countries' real sector and populations. The monetary and financial consequences of these events have received less attention however, despite their importance in a context in which climate change will alter the frequency and intensity of these natural disasters. This paper uses macroeconomic, natural disasters and climatic panel data for 109 countries during the period 1960–2019 to assess the effects of climate-related natural disasters on the real exchange rate (RER) misalignment. It constructs a country-specific RER misalignment index and several measures of climate-related natural disasters based on climatic data to show that such events lead to RER overvaluations in developing countries: one disaster occurrence leads to a 0.015 unit increase in the RER misalignment index. This effect tends to increase when using measures of natural disasters based on climatic data and is mostly explained by middle-income countries, small countries, and small island developing states. The results indicate that remittances and net capital flows act as transmission channels.

Keywords: Exchange rate misalignment, natural disasters, business cycles, developing countries.

JEL Classification: C23, E32, F31, F41, Q54.

1 Introduction

Climate-related natural disasters have recently had dramatic and increasing effects on developing countries' real sector and populations. These effects are well documented and identified by a rich literature, but the monetary and financial consequences of these events have received much less attention, despite their importance for macroeconomic stability and post-disaster reconstruction and sustainable development. This occurs in a context in which climate change will alter the frequency and intensity of these natural disasters while reducing income and adaptation capacity in developing countries (de Bandt et al., 2021).

This paper combines macroeconomic data with primary meteorological data to build an index of Real Exchange Rate (RER) misalignment and assess how RER misalignment is affected by climate-related natural disasters. Large RER misalignment would create or reinforce macroeconomic imbalances and threaten the post-disaster recovery. From a theoretical standpoint, the effects of climate-related natural disasters on RER misalignment are ambiguous. Several potential consequences of such events can lead to RER depreciations due to a relative shortage of foreign currency: higher imports to compensate domestic supply disruptions and obtain inputs for reconstruction, lower foreign direct investment inflows, and lower agricultural output and exports, among other potential effects. On the contrary, several effects of climate-related natural disasters can lead to RER appreciation: increased exports due to higher foreign demand and increased remittances (diaspora effect), official development assistance and capital inflows for reconstruction, as well as inflation due to shortages. These potentially conflicting effects make an empirical approach appropriate.

The empirical literature on the economic effects of natural disasters has mainly focused on the real sector and found adverse effects on output growth (Felbermayr and Gröschl, 2014; Noy, 2009; Strobl, 2012), capital stock (Acevedo, 2016), trade flows (El Hadri et al., 2018, 2019) and public finances (Acevedo, 2014; Klomp, 2017), among others. Klomp (2020) and Parker (2018) have assessed the monetary effects focusing on inflation, but the effects of natural disasters on the exchange rate have received little attention. Another strand of the literature has focused on estimating RER misalignment indexes. The behavioural approach was pioneered in Edwards (1989) and further developed in ElBadawi (1994) and Clark and MacDonald (1998), among others. Alternative approaches are discussed in Noureldin (2018), including their drawbacks in the case of developing countries. These RER misalignment indices have been used to assess how currency misalignment affect a series of variables, including output growth (ElBadawi et al., 2012), export diversification (Sekkat, 2016) and civil conflicts (Ambaw

and Sim, 2019), among others.

This paper contributes to the literature in several ways. First, it studies the monetary and financial consequences of climate-related natural disasters in developing countries, an essential dimension of macroeconomic stability that has been relatively overlooked in the empirical literature on natural disasters. Second, it provides country-specific estimations of RER misalignment over a long period (1960–2019) based on the behavioural approach. Third, while the macroeconomic effects of RER misalignment have been widely studied, this paper adds to a still scarce literature on the determinants of RER misalignment.

This paper tests the hypothesis that RER misalignment is affected by climate-related natural disasters in developing countries. To do so, it uses real effective exchange rate data from Darvas (2012) and macroeconomic data from the World Development Indicators and the International Financial Statistics databases, complemented by several other sources. Data on climate-related natural disasters are from EMDAT (CRED, 2020) and ifo GAME, and this paper builds additional natural disasters measures from primary meteorological datasets. The panel dataset covers 109 low- and middle-income countries at an annual frequency during the period 1960–2019. The empirical strategy relies on a panel model with fixed effects, complemented by the local projections method introduced in Jordà (2005) which allows to evidence the dynamic effects of climate-related natural disasters on RER misalignment.

The results show that climate-related natural disasters lead to temporary real currency overvaluation in developing countries: One occurrence produces a 0.015 unit increase in the RER misalignment index. This effect tends to increase when using measures of natural disasters based on primary climatic data and is mostly explained by middle-income, small and disaster-prone countries, as well as small island developing states. An assessment of the transmission channels points towards an increase in inflation, although the evidence is incomplete, as well as an increase in remittances and net capital inflows. These results underline the importance of well-calibrated policy responses in order not to affect further macroeconomic stability after being hit by climate-related natural disasters.

The remainder of the article is organized as follows. Section 2 details the construction of the real exchange rate misalignment index, Section 3 presents the data and Section 4 introduces the empirical strategy. Section 5 presents and discusses the main results and Section 6 assesses the transmission channels. Finally, Section 6 concludes.

2 Real Exchange Rate Misalignment

This section details the construction of the real exchange rate misalignment index, following a behavioural approach in the tradition of [Edwards \(1989\)](#), [ElBadawi \(1994\)](#), [Clark and MacDonald \(1998\)](#) and [Goldfajn and Valdés \(1999\)](#), among others. Alternative approaches, namely the fundamentals and the external sustainability approaches, are possible but are associated with drawbacks since they are based on assumptions about the level of capital inflows and net foreign assets that are consistent with internal and external balance. These assumptions are country-specific and likely more problematic in the case of developing countries. [Noureldin \(2018\)](#) discusses the limitations associated with the fundamentals and the external sustainability approaches.

The behavioural approach, based on theoretical foundations, links a theoretical long-term real exchange rate equilibrium to net foreign assets, terms of trade and a Balassa-Samuelson effect, as well as other determinants of the real exchange rate. The misalignment is then defined as the difference between the observed real exchange rate and the estimated equilibrium real exchange rate. The main advantages of this approach is to incorporate the Balassa-Samuelson effect, instead of the relative prices of traded goods only, and not to rely on normative, judgement-based country-specific current account targets. The behavioural approach identifies instead the equilibrium exchange rate and the misalignment based on an econometric specification that links the real exchange rate to its determinants. The full procedure is detailed below. [Bénassy-Quéré \(2015\)](#) offers a textbook treatment of this notion and its theoretical foundations.

The first step to estimate the equilibrium RER consists in specifying an empirical model that expresses the RER as a function of a vector of its fundamentals. Equation (3.1) details the specification:

$$RER_{i,t} = \alpha_i + \mathbf{\Omega}\mathbf{X}'_{i,t} + \varepsilon_{i,t} \quad (3.1)$$

where t denotes the time and i the country, α_i a country-specific intercept, RER the real exchange rate (in log), $\mathbf{\Omega}$ a vector of parameters and \mathbf{X}' a vector of fundamental RER determinants comprising the commodity terms of trade (in log), productivity differential with respect to OECD countries, proxied by the ratio of real per capita GDP over that of OECD countries (in log), to capture the Balassa-Samuelson effect, trade openness, government consumption and net foreign assets. $\varepsilon_{i,t}$ is the error term.

Equation (3.1) is estimated following three econometric methods that allow for an error-correction mechanism when using panel data. The Dynamic fixed effects (DFE)

estimator restricts all short- and long-run parameters to be equal across countries, except for the intercept which is country-specific, and the Mean group (MG) estimator allows both the short- and long-run parameters to be country-specific. The Pooled mean group (PMG) estimator assumes that all countries share common long-run parameters but allows short-term parameters to differ across countries, and therefore offers the best compromise between consistency and efficiency. ElBadawi et al. (2012) offer a detailed description of each estimator and the trade-offs involved.

Table 3.1 – Real Exchange Rate Long- and Short-Run Determinants

	(1) Pooled Mean Group	(2) Mean Group	(3) Dynamic Fixed Effects
<i>Long-Run Coefficients:</i>			
Commodity Terms of Trade (ln)	0.304 (0.489)	0.668 (1.425)	0.501 (0.339)
Productivity (ln)	0.434** (0.201)	0.745*** (0.184)	0.383*** (0.081)
Net Foreign Assets	0.678 (0.668)	0.866* (0.511)	0.958*** (0.114)
Public Consumption	2.009*** (0.461)	0.826 (0.979)	1.905*** (0.346)
Trade Openness	-0.967*** (0.243)	-0.117 (1.041)	-0.896*** (0.174)
<i>Short-Run Coefficients:</i>			
Error Correction Term	-0.078 (0.230)	-0.395*** (0.029)	-0.103*** (0.007)
D.Commodity Terms of Trade (ln)	0.032 (0.198)	-0.006 (0.216)	-0.005 (0.080)
D.Productivity (ln)	0.264*** (0.066)	-0.027 (0.088)	0.035 (0.046)
D.Net Foreign Assets	-0.227*** (0.081)	-0.227*** (0.077)	-0.055*** (0.010)
D.Public Consumption	0.739*** (0.252)	0.239 (0.221)	0.662*** (0.088)
Countries	109	109	109
Observations	4369	4369	4369

Note: Standard errors in parentheses. * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

Table 3.1 presents the results of the estimation of equation (3.1) using the DFE, MG and PMG estimators. The signs of coefficients are consistent with the theory. Increases in productivity, public consumption and net foreign assets are associated with a RER appreciation, while increased trade openness is associated with a RER depreciation.

After estimating equation (3.1), the equilibrium exchange rate is computed as indicated in equation (3.2):

$$RER_{i,t}^E = \hat{\delta}_i + \hat{\Omega} \overline{\mathbf{X}}'_{i,t} \quad (3.2)$$

where $\overline{\mathbf{X}}'$ is a vector of the long-term values of the RER determinants, *i.e.* the trend components obtained using the Hodrick-Prescott filter, $\hat{\Omega}$ is a vector of estimated parameters from equation (3.1), and $\hat{\delta}_i = \overline{RER}_i - \hat{\beta}' \overline{\mathbf{X}}'_i$ is a country specific intercept that allows to normalize the equilibrium RER so that the long run RER misalignment is equal to zero in each country. \overline{RER} and $\overline{\mathbf{X}}'$ correspond to the mean values of the RER and its determinants, respectively.

Equation (3.2) can therefore be rewritten as:

$$RER_{i,t}^E = \overline{RER}_i + \hat{\Omega} \left(\overline{\mathbf{X}}'_{i,t} - \overline{\mathbf{X}}'_i \right) \quad (3.3)$$

As evidenced in equation (3.3), the equilibrium RER corresponds to the mean value of the RER and a term that depends on the weighted difference between the trend components of the RER fundamentals and their mean values. The RER misalignment can then be defined and computed as the difference between the observed RER and the equilibrium RER:

$$RER_{i,t}^{MIS} = RER_{i,t} - RER_{i,t}^E = (RER_{i,t} - \overline{RER}_i) - \hat{\Omega} \left(\overline{\mathbf{X}}'_{i,t} - \overline{\mathbf{X}}'_i \right) \quad (3.4)$$

As indicated in equation (3.4), the RER misalignment depends positively on the difference between the observed RER and its mean value, and depends negatively on the weighted difference between the trend components of the RER fundamentals and their mean values. Noting that $RER_{i,t} = \hat{\alpha}_i + \hat{\Omega} \mathbf{X}'_{i,t} + \hat{\varepsilon}_{i,t}$, that $\overline{RER}_i = \hat{\alpha}_i + \hat{\Omega} \overline{\mathbf{X}}'_i$, that the cyclical component of the RER determinants can be written as $\tilde{\mathbf{X}}'_{i,t} = \mathbf{X}'_{i,t} - \overline{\mathbf{X}}'_i$ and rearranging equation (3.4), the RER misalignment can be expressed as:

$$RER_{i,t}^{MIS} = \hat{\Omega} \tilde{\mathbf{X}}'_{i,t} + \hat{\varepsilon}_{i,t} \quad (3.5)$$

Equation (3.5) shows that the RER misalignment depends on the weighted cyclical components of the RER determinants and short-term shocks. The next section introduces the data and presents stylized facts on RER misalignment and natural disasters in low- and middle-income countries.

3 Data and Stylized Facts

The country-level data cover 109 low- and middle-income countries over the period 1960–2017, at an annual frequency. Sample selection is exclusively based on data availability and countries included in the sample are indicated in appendix Table 4.A.1. Appendix Table 5.A.1 lists all the data sources used in this paper.

3.1 Real Exchange Rate Misalignment

Real effective exchange rate data are retrieved from [Darvas \(2012\)](#) and correspond to the real effective exchange rates series that include 66 trading partners.

The determinants of the equilibrium RER computed in section 2 are retrieved from several sources. The commodity terms of trade come from [Gruss and Kebhaj \(2019\)](#) and data on net foreign assets (in % of GDP) and the productivity index, defined as the ratio of per capita nominal GDP to the OECD average per capita nominal GDP (in current USD), come from the WDI dataset ([World Bank - WDI, 2021](#)). The share of public consumption in GDP and trade openness, computed as the sum of the shares of merchandise imports and exports in GDP, come from the Penn World Tables version 9.1 ([Feenstra et al., 2015](#)).

3.2 Climate-related Natural Disasters

The most widely used data source for natural disasters is the EMDAT database ([CRED, 2020](#)). This database includes all the events that killed ten or more people, affected 100 or more people, led to a declaration of state of emergency or led to a call for international assistance at a global scale. For each event, the dataset contains information on casualties, the number of persons affected and physical damages (expressed in monetary terms).

This paper uses all the climate-related natural disasters contained in the dataset that occurred in one of the countries included in the sample during the period 1960–2017. Climate-related natural disasters include floods, droughts, extreme temperatures, landslides, storms and wildfires. The main variable of interest is the number of occurrences of climate-related natural disasters. The second variable of interest, disasters' intensity, is calculated as indicated in equation (3.6), based on the method in [Parker \(2018\)](#):

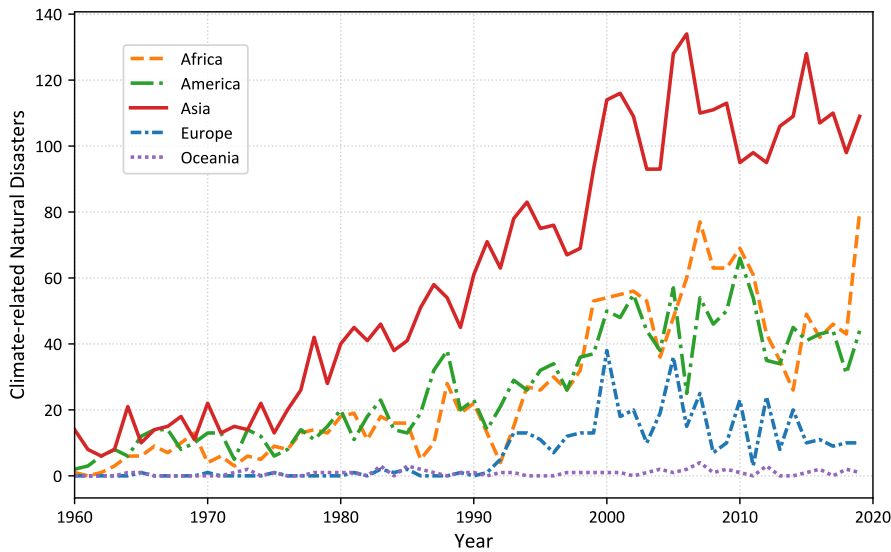
$$intensity_{i,t,k} = \begin{cases} \left[\frac{100 \times \frac{total\ death_{i,t,k} + 0.3 \times total\ affected_{i,t,k}}{population_{i,t}}}{occurrences_{i,t,k}} \right], & \text{if } intensity > 0.1 \\ 0 & \text{otherwise} \end{cases} \quad (3.6)$$

where i denotes the country, t the year and k the climate-related natural disaster's type¹. Then, the country-year observation is calculated as:

$$intensity_{i,t} = \sum_{k \in K} intensity_{i,t,k} \quad (3.7)$$

Disasters' intensity measure would ideally also capture monetary damages and would be the main variable of interest. However, the reported casualties, number of persons affected and monetary damages depend on socio-economic conditions and are likely to be underreported in developing countries since many inhabitants do not possess any identity document, and a large share of assets is informal and therefore non-insurable. For this reason, disaster's occurrence is the preferred variable in developing countries. Figure 3.1 shows the evolution of climate-related natural disaster occurrences reported in EM-DAT for developing countries.

Figure 3.1 – Climate-Related Natural Disaster Occurrences, by Continent



Note: The graph shows the total of climate-related natural disasters occurrences in low- and middle-income countries, by continent. Data are retrieved from EM-DAT. This graph is better seen if printed in colour.

Disasters' occurrence reported in EM-DAT also suffer from measurement error due to the criteria used to include events in the dataset. (Felbermayr and Gröschl, 2014)

¹The variable $total\ death_{i,t,k}$ corresponds to the sum of casualties of all disasters of type k in country i during year t .

show that the likelihood of a disaster of a given magnitude being reported depends on the country's GDP per capita. The authors assemble an alternative dataset, the ifo GAME dataset, that measures the physical intensity of natural disasters from primary meteorological and geophysical data and show that the negative effects on output are underestimated when using EMDAT. This paper therefore also uses data from the ifo GAME dataset to increase the robustness of the results.

The ifo GAME dataset contains limitations to address this paper's research question. First, it includes geophysical natural disasters (such as earthquakes) in addition to climate-related natural disasters, and the effects on GDP growth might differ across categories, as suggested by the results in [Felbermayr and Gröschl \(2014\)](#). As a consequence, the aggregate index cannot be used. Furthermore, data used to identify drought only consider precipitations, instead of an interaction between precipitations and temperatures, and the dataset covers a period that ends in 2010.

To overcome these limitations, I follow the approach in [Felbermayr and Gröschl \(2014\)](#) and construct alternative measures of climate-related natural disasters based on primary meteorological datasets. For total land precipitations and mean temperatures, I use monthly data from [Matsuura and Willmott \(2019b\)](#). 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. The observations are not weighted by local population density, as in [de Bandt et al. \(2021\)](#), since economic activity may not coincide with the distribution of population in developing country. I also use the SPEI developed by [Vicente-Serrano et al. \(2010\)](#) which captures drought conditions. An increase in the index denotes wetter conditions. This dataset also has a monthly frequency and is gridded with a 0.5° latitude \times 0.5° longitude resolution. Country-level aggregation is computed using the same approach as for temperatures and precipitations.

These alternative climate datasets allow to compute several alternative indicators for climate-related natural disasters. The SPEI dataset allow to build a drought index as indicated in equations (3.8) and (3.9):

$$drought_{i,m,t} = \begin{cases} 1 & \text{if } SPEI_{i,x,t} \leq \mu_{SPEI_{i,m,1901-2018}} - \sigma_{SPEI_{i,m,1901-2018}} \text{ for } x \text{ in } [m, m-2] \\ 0 & \text{otherwise} \end{cases} \quad (3.8)$$

$$drought_{i,t} = \begin{cases} 1 & \text{if } \sum_{m=1}^{12} drought_{i,m,t} \geq 1 \\ 0 & \text{otherwise} \end{cases} \quad (3.9)$$

where m denotes the month of the year, μ_X the average of variable X and σ_X the standard deviation of variable X . A month is therefore considered as dry if the SPEI index was below the mean SPEI index of the country over the entire period minus one standard deviation for at least three consecutive months. The yearly observation is a dummy variable that takes the value of one if at least one month during the year is considered as dry. Following [Generoso et al. \(2020b\)](#), I use the 6-month SPEI as a benchmark, given its ability to capture seasonal to medium-term trends in weather conditions, and I use the 3-month and 12-month SPEI for robustness.

The climate dataset built by [Matsuura and Willmott \(2019b\)](#) allow to construct indicators for heat and cold waves, as well as extreme precipitations events, as indicated in equations (3.10) to (3.13):

$$heat\ wave_{i,m,t} = \begin{cases} 1 & \text{if } dtemp_{i,m,t} \geq \mu_{dtemp_{i,m,1900-2017}} + 2\sigma_{dtemp_{i,m,1900-2017}} \\ 0 & \text{otherwise} \end{cases} \quad (3.10)$$

$$cold\ wave_{i,m,t} = \begin{cases} 1 & \text{if } dtemp_{i,m,t} \leq \mu_{dtemp_{i,m,1900-2017}} - 2\sigma_{dtemp_{i,m,1900-2017}} \\ 0 & \text{otherwise} \end{cases} \quad (3.11)$$

$$extreme\ precip_{i,m,t}^+ = \begin{cases} 1 & \text{if } dprecip_{i,m,t} \geq \mu_{dprecip_{i,m,1900-2017}} + \sigma_{dprecip_{i,m,1900-2017}} \\ 0 & \text{otherwise} \end{cases} \quad (3.12)$$

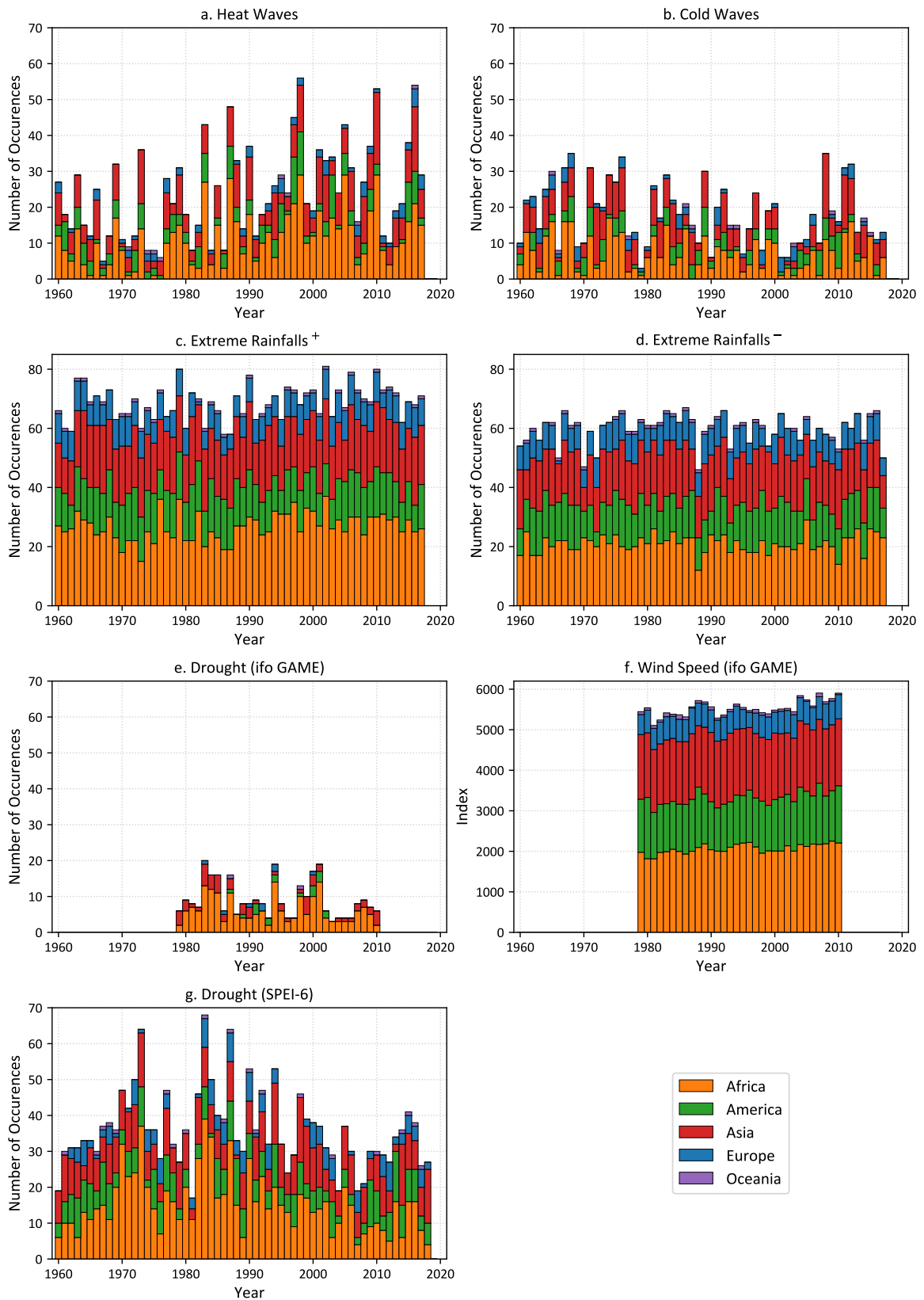
$$extreme\ precip_{i,m,t}^- = \begin{cases} 1 & \text{if } dprecip_{i,m,t} \leq \mu_{dprecip_{i,m,1900-2017}} - \sigma_{dprecip_{i,m,1900-2017}} \\ 0 & \text{otherwise} \end{cases} \quad (3.13)$$

where $dprecip_{i,m,t} = \frac{precip_{i,m,t} - precip_{i,m,norm}}{precip_{i,m,norm}}$, with $precip_{i,m,norm}$ the historical norm for month m defined as the 20-year moving average, following [Kahn et al. \(2021\)](#). Then, for each of the previous variables Var , the yearly indicator is a dummy variable equal to one if at least one month of the year has experienced extreme weather, as indicated in equation (3.14):

$$Var_{i,t} = \begin{cases} 1 & \text{if } \sum_{m=1}^{12} Var_{i,m,t} \geq 1 \\ 0 & \text{otherwise} \end{cases} \quad (3.14)$$

Figure 3.2 presents the time series of all variables built based on meteorological data and retrieved from the ifo GAME dataset, aggregated at the continental level.

Figure 3.2 – Climate-Related Natural Disaster Occurrences, by Continent



Note: The graph shows the occurrences of climate-related natural disasters in low- and middle-income countries, by continent. Data are retrieved from ifo GAME (subplots e. and f.) and primary meteorological datasets. This graph is better seen if printed in colour.

3.3 Other Socio-economic Variables

Other variables, used as control variables or to assess heterogeneity in the results, include population size, taken from the World Population Prospects database issued by the United Nations' Population Department, and land area, from the [World Bank - WDI \(2021\)](#).

Variables used to assess the transmission channels come from various sources. Annual food inflation is constructed as the average food consumer price index growth rate. Quarterly data for the food consumer price index is obtained from [Parker \(2018\)](#). Remittances data are obtained from the World Bank's Migration and Remittances Data dataset. Data for capital flows are obtained from the IMF's Balance of Payments and International Investment Position Statistics database. Following [Koepke and Paetzold \(2020\)](#), capital flows are defined as:

$$Net\ Capital\ Flows_{i,t} = Net\ Change\ in\ Assets_{i,t} - Net\ Change\ in\ Liabilities_{i,t} \quad (3.15)$$

where assets and liabilities comprise foreign direct investments, portfolio investments and other investments. Following this definition, an increase in net capital flows indicates either an increase in assets or a decrease in liabilities, and corresponds therefore to capital outflows from country i .

4 Empirical Framework

The effects of climate-related natural disasters on real exchange rate misalignment can be assessed following the framework introduced in section 2. Equation (3.5) expresses RER misalignment as a function of the cyclical components of the RER fundamental determinants as well as random shocks.

Equation (3.16) extends this framework by including climate-related natural disasters as an additional explanatory variable and writes:

$$RER_{i,t}^{MIS} = \alpha_0 + \beta_1 CRND_{i,t} + \Phi \tilde{\mathbf{X}}'_{i,t} + \delta_i + \gamma_t + \varepsilon_{i,t} \quad (3.16)$$

where i denotes the country and t the year. RER^{MIS} corresponds to the real exchange rate misalignment, $CRND$ denotes the occurrences of climate-related natural disasters in the main specification, Φ is a vector of parameters and \mathbf{X}' a vector containing the cyclical components of the fundamental RER determinants (commodity terms of trade, productivity differential with respect to OECD countries proxied by the ratio of real per

capita GDP over that of OECD countries, trade openness, government consumption, and net foreign assets). δ_i denotes country fixed effects and captures country-specific time-invariant factors, and γ_t denotes time fixed effects that capture common shocks, such as the international business cycle.

β_1 is the main coefficient of interest and corresponds to the estimated contemporary effect of one climate-related natural disaster occurrence on the RER misalignment index. Estimating the impulse response function of RER misalignment to climate-related natural disasters allows to assess whether the effects of these events are persistent.

I then use the Local Projections introduced in [Jordà \(2005\)](#) to obtain the impulse response function and separately estimate equation (4.2) for horizons $h = 0, 1, 2, 3$:

$$RER_{i,t+h}^{MIS} = \alpha_0^h + \beta_1^h CRND_{i,t} + \theta^h \sum_{p=1}^h CRND_{i,t+p} + \Phi \tilde{\mathbf{X}}'_{i,t} + \Psi \mathbf{C}_{i,t} + \delta_i^h + \gamma_t^h + \varepsilon_{i,t}^h \quad (3.17)$$

where all estimates are horizon-specific, denoted by subscript h and \mathbf{C} is a vector of control variables comprising one lag of both RER misalignment and $CRND$ as well as the forward values of both RER misalignment and $CRND$ between t and $t + h - 1$. All other variables are defined as above.

The estimate β_1^h indicates the effect of a one climate-related natural disaster occurrence on the RER misalignment index for each horizon $0 \leq h \leq 3$ and allows to track the dynamics of RER misalignment following such an event.

5 Results

5.1 Main Results

Table 4.1 presents the main estimates from equation (3.16). The results in column (1) indicate that climate-related natural disasters lead to currency overvaluation: one occurrence of such an event increases the RER misalignment in 0.015 units. Results in column (2) show that an increase in the climate-related natural disasters intensity index also leads to currency overvaluation, although the estimate appears to be lower at 0.008. Both coefficients are statistically significant at the 1% level of confidence.

Table 4.1 columns (3) and (4) report the estimates when control variables are excluded from the regression. Climate-related natural disasters can affect the RER misalignment through their negative effect on productivity if income falls (as found by [Felbermayr and Gröschl, 2014](#)), but also through net foreign assets, an increase in pub-

lic consumption or an alteration of trade openness. Removing the control variables show that the effects of climate-related natural disasters remain, both in terms of magnitude and significance.

Table 3.1 – Effects of Climate-Related Natural Disasters on RER Misalignment

Dependent Variable:	RER Misalignment					
	(1)	(2)	(3)	(4)	(5)	(6)
Climate-Related Natural Disaster Occurrence	0.015*** (0.004)		0.015*** (0.004)		0.015*** (0.004)	0.015*** (0.004)
Climate-Related Natural Disaster Intensity		0.004 (0.006)		0.002 (0.006)	0.000 (0.006)	-0.003 (0.006)
Commodity Terms of Trade ^a	0.010 (0.331)	0.005 (0.331)			0.010 (0.331)	
Productivity ^a	0.661*** (0.195)	0.651*** (0.196)			0.661*** (0.196)	
Net Foreign Assets ^a	0.194*** (0.039)	0.195*** (0.039)			0.194*** (0.039)	
Public Consumption ^a	1.944*** (0.367)	1.955*** (0.368)			1.944*** (0.367)	
Trade Openness ^a	-0.590*** (0.116)	-0.591*** (0.117)			-0.590*** (0.116)	
Constant	0.381*** (0.079)	0.375*** (0.079)	0.390*** (0.079)	0.384*** (0.080)	0.381*** (0.079)	0.149 (0.117)
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	4513	4513	4513	4513	4513	4513
Number of Countries	109	109	109	109	109	109

Note: ^a Cyclical component of the variable. Standard errors in parentheses. A positive RER misalignment corresponds to an overvalued RER. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

Climate-related natural disasters occurrences considered in Table 4.1 are retrieved from the EM-DAT dataset and their intensity is obtained following equation (3.7). Both variables suffer from measurement errors linked to the criteria for inclusion of the event in the dataset. Table 3.2 presents the estimates from equation (3.16) when climate-related natural disasters are measured based on primary meteorological datasets, solving therefore endogeneity issues inherent to disasters reported in EM-DAT.

Table 3.2 columns (1) and (2) include one variable from the ifo GAME database each, respectively wind speed and drought. Both types of disasters lead an increase in the RER misalignment, although the value of the estimate is small in the case of wind speed, at 0.001. The estimate of drought is more than seven times greater than the estimate for a disaster occurrence according to EMDAT (0.107 versus 0.015, Table 4.1 column 1). This result for RER misalignment is coherent with Felbermayr and Gröschl (2014), which find that the effect of disasters on output growth is underestimated when using EMDAT. Appendix Table 3.B.1 report the results for two measures of precipitations deviations (columns 1 and 2) and for temperatures deviations (column 3). None of these three estimates is significantly different from 0.

The ifo GAME database constructs droughts based only on precipitations data, despite the influence of temperatures on these phenomena. Table 3.2 column (3) includes the measure for droughts obtained from the SPEI database and constructed following equations (3.8) and (3.9). This measure takes into account evapotranspiration, in addition to precipitations. The estimate indicates a significant overvaluing effect of droughts since an occurrence increases the RER misalignment index in 0.027 unit. This result is obtained from the 6-month SPEI but is robust to using both the 3-month and the 12-month SPEI. These two robustness tests are reported in Appendix Table 3.B.1 columns (4) and (5), respectively.

Table 3.2 also reports the estimates for variables constructed using climate data from Matsuura and Willmott (2019b): heat waves (column 4), low rainfalls (column 5) and cold waves (column 6). Heat waves seem to have a negative effect on RER misalignment, although the estimate is only statistically significant at the 10 percent level. The effect of low precipitations is not different from zero, and cold waves increase real currency misalignment. The estimate for high precipitations is not statistically significant and is reported in Appendix Table 3.B.1 column (6).

The estimates for droughts, built using the SPEI, and cold and heat waves, built using data from Matsuura and Willmott (2019b) appear to be slightly greater than the estimates using EMDAT. This is coherent with the findings in Felbermayr and Gröschl (2014) which evidence an underestimation of the effects of natural disasters on output growth using variables in EMDAT.

5.2 Dynamic Approach

Figure 3.1 reports the dynamic response of RER misalignment to the occurrence of a climate-related natural disaster. The impulse response function is obtained from estimating equation (4.2) following the local projections approach.

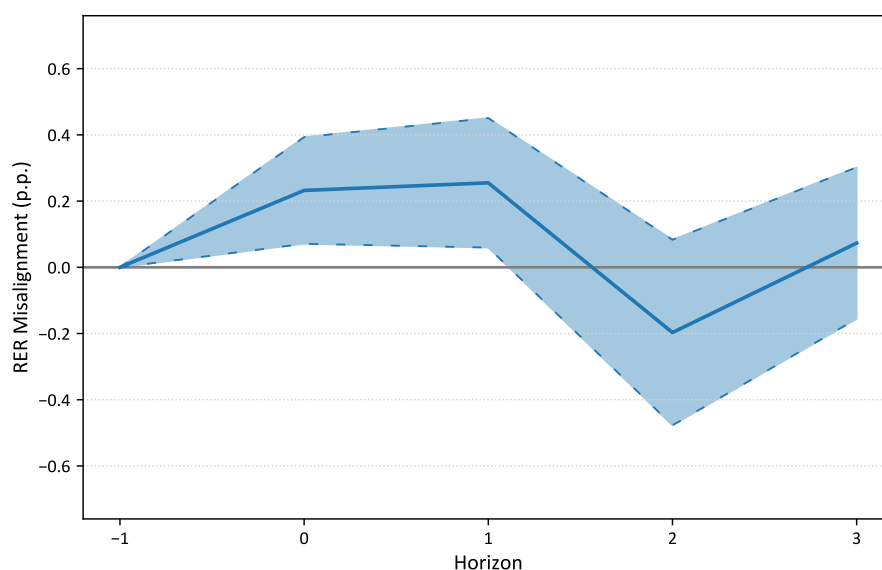
Table 3.2 – Effects of Climate-Related Natural Disasters based on Meteorological Observations

Disaster Variable Source Disaster Variable	RER Misalignment					
	ifoGAME		SPEI	University of Delaware		
	Wind Speed (1)	Drought (2)	Drought (3)	Heat Wave (4)	Rainfall ⁻ (5)	Cold Wave (6)
Climate-Related Natural Disaster	0.001** (0.001)	0.107*** (0.032)	0.027** (0.014)	-0.026* (0.016)	0.375 (0.413)	0.038** (0.018)
Commodity Terms of Trade ^a	0.678 (0.453)	0.324 (0.429)	-0.013 (0.324)	-0.006 (0.324)	0.003 (0.324)	-0.013 (0.324)
Productivity ^a	0.833*** (0.235)	0.668*** (0.217)	0.623*** (0.191)	0.604*** (0.191)	0.615*** (0.191)	0.611*** (0.191)
Net Foreign Assets ^a	0.201*** (0.039)	0.198*** (0.039)	0.196*** (0.039)	0.196*** (0.039)	0.194*** (0.039)	0.196*** (0.039)
Public Consumption ^a	2.451*** (0.452)	2.315*** (0.426)	2.025*** (0.376)	2.050*** (0.376)	2.037*** (0.376)	2.043*** (0.376)
Trade Openness ^a	-0.690*** (0.134)	-0.698*** (0.129)	-0.640*** (0.124)	-0.643*** (0.124)	-0.643*** (0.124)	-0.638*** (0.124)
Constant	0.206*** (0.060)	0.269*** (0.050)	0.359*** (0.079)	0.374*** (0.079)	0.008 (0.406)	0.362*** (0.079)
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	2794	2888	4386	4386	4386	4386
Number of Countries	107	106	105	105	105	105

Note: ^a Cyclical component of the variable. Standard errors in parentheses. A positive RER misalignment corresponds to an overvalued RER. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

The result shows that the effect is slightly persistent but temporary: the response of RER misalignment lasts for two years and disappears afterwards, without reverting however. Real overvaluation might provide short-term relief by facilitating the purchase of imports that can help face urgent needs following these disasters. However, this temporary effect deteriorates the competitiveness of the economy during the crucial post-disaster period and might add to the physical consequences of these events to affect further the recovery of the productive sector.

Figure 3.1 – RER Misalignment’s Response to a Climate-Related Natural Disaster



Note: The graph shows the response of RER misalignment to a climate-related natural disaster. Standard errors are clustered at the country level.

The impulse response function reported in Figure 3.1 is robust to alternative specifications. The baseline specification only includes one lag of both the dependent and the explanatory variables. Appendix Figure 3.B.1 reports the result when two lags of both the dependent and the explanatory variables are included in the vector of control variables. Appendix Figure 3.B.2 reports the baseline specification with Driscoll and Kraay (1998) standard errors, which are robust to cross-sectional dependence in addition to autocorrelation and heteroskedasticity. In both robustness tests, the results are very close to the baseline specification and the interpretation remains unchanged.

5.3 Heterogenous Effects

Table 3.3 introduces results that allow to assess the heterogenous effects of climate-related natural disasters on RER misalignment in developing countries. Columns (1) and (2) report the estimates from equation (3.16) in two subsamples: low-income

and middle-income countries. Within the sample of developing countries, low-income countries correspond to those for which the GDP per capita in a given year is inferior to the 33rd percentile of the distribution. The estimate is not different from zero in low-income countries, and positive and significant in middle-income countries, suggesting that currency overvaluation is more likely to appear in countries that have reached a certain level of economic activity.

Table 3.3 columns (3) and (4) divide the sample between countries where disasters are occasional and disaster-prone countries. Disaster-prone countries correspond to those that have experienced more climate-related natural disasters than the median between 1960 and 2019. The estimates show that these disasters lead to currency overvaluations in disaster-prone countries. The relation between climate change and climate-related natural disasters is highly complex, but it is increasingly recognized that climate change will affect the frequency and the intensity of these events. As countries become more disaster-prone, the results indicate that more countries might experience currency misalignments following these events.

Table 3.3 columns (5) to (7) assess whether territorial extension affects the relationship between climate-related natural disasters and RER misalignment. Large countries correspond to countries with land area above the median, smallest countries correspond to those with land area below the 25th percentile, and Small Island Developing States (SIDS) are listed in Appendix Table 3.A.3 and follow the list established by the United Nations.

Results in Table 3.3 column (5) show that the effects of climate-related natural disasters on RER misalignment in large countries do not differ than the effects in countries that are below the median. However, estimates in column (6) indicate that the effects are positive in countries larger than the 25th percentile but stronger in countries that are smaller than this threshold. Column (7) show that this effect is even greater in SIDS.

The results reported in Table 3.3 point towards large effects of climate-related natural disasters on RER misalignment in SIDS: these countries are often middle-income, disaster-prone and small economies. However, the effects are not restricted to these economies since they are also present in large and other disaster-prone countries

Table 3.3 – Heterogenous Effects of Climate-Related Natural Disasters on RER Misalignment

Dependent Variable:	RER Misalignment						
	Low-Income Countries (1)	Middle-Income Countries (2)	Occasional Disasters (3)	Disaster-Prone Countries (4)	Large Countries (5)	Smallest Countries (6)	Small Island Developing States (7)
Climate-Related Natural Disaster Occurrence	0.001 (0.005)	0.017*** (0.005)	-0.024 (0.017)	0.014*** (0.004)	0.023** (0.009)	0.013*** (0.004)	0.013*** (0.004)
Climate-Related Natural Disaster $\times \mathbb{1}_{\text{Large Country}}$					-0.010 (0.010)		
Climate-Related Natural Disaster $\times \mathbb{1}_{\text{Small Country}}$					0.041*** (0.016)		
Climate-Related Natural Disaster $\times \mathbb{1}_{\text{SIDS}}$							0.051*** (0.018)
Commodity Terms of Trade ^a	-0.258 (0.873)	0.004 (0.362)	-0.045 (0.419)	0.101 (0.537)	0.004 (0.322)	0.006 (0.322)	0.005 (0.322)
Productivity ^a	-0.257 (0.246)	0.947*** (0.244)	0.466* (0.245)	0.859*** (0.317)	0.625*** (0.189)	0.628*** (0.189)	0.628*** (0.189)
Net Foreign Assets ^a	0.449** (0.180)	0.186*** (0.042)	0.053 (0.220)	0.193*** (0.038)	0.194*** (0.039)	0.193*** (0.039)	0.193*** (0.039)
Public Consumption ^a	1.436*** (0.496)	2.288*** (0.460)	1.659*** (0.487)	2.317*** (0.583)	1.936*** (0.363)	1.942*** (0.363)	1.921*** (0.363)
Trade Openness ^a	-0.052 (0.217)	-0.691*** (0.134)	-0.546*** (0.139)	-0.763*** (0.247)	-0.592*** (0.115)	-0.592*** (0.115)	-0.594*** (0.115)
Constant	0.703*** (0.123)	0.326*** (0.095)	0.396 (0.246)	0.336*** (0.081)	0.380*** (0.079)	0.378*** (0.079)	0.381*** (0.079)
Country Fixed Effects	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y
Observations	1473	3063	1805	2731	4536	4536	4536
Number of Countries	50	85	52	58	110	110	110

Note: ^a Cyclical component of the variable. Standard errors in parentheses. A positive RER misalignment corresponds to an overvalued RER. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

6 Transmission Channels

The previous section identified temporary and significant effect of climate-related natural disasters on RER misalignment in developing countries. This sections empirically tests three potential transmission mechanisms that might explain the observed real currency overvaluation following disasters. The results presented in Table 3.1.

The first potential explanation for RER overvaluation following a disaster is inflation. By definition, the RER writes:

$$RER = NER \times \frac{P}{P^*} \quad (3.18)$$

where NER corresponds to the nominal exchange rate (in foreign currency per unit of local currency), P the domestic price level and P^* the foreign price level.

From equation (3.18), an increase in domestic inflation will increase the ratio $\frac{P}{P^*}$ and will therefore appreciate the RER. This mechanism is empirically evidenced in Klomp (2020), following earthquakes, and in Parker (2018) for developing countries.

Table 3.1 column (1) assesses the relation between climate-related natural disasters and food inflation. The estimate is insignificant, contrary to column (2), which indicates that an increase in climate-related natural disaster intensity increases food inflation in developing countries. These results correspond to the results in Parker (2018). If inflation acts as a transmission mechanism, it should lead to an increase in the RER misalignment. Results in Table 3.1 column (3) show however that an increase in inflation is associated with a decrease in the RER misalignment. This result corresponds to a typical case of reverse causality: high currency overvaluation often lead to nominal (and therefore real) devaluations that trigger high inflation episodes, creating therefore a negative relation between inflation and RER misalignment. Solving this reverse causality issue requires a specific empirical framework that is beyond the scope of this paper. However, the observed increase in food inflation following intense climate-related natural disasters leads to real currency appreciation, pointing to inflation as a likely transmission channel.

A second potential explanation is an increase in remittances towards a country affected by a natural disaster. This diaspora effect has been evidenced for trade flows in El Hadri et al. (2018), for example. Table 3.1 column (4) shows that remittances increase as a response to climate-related natural disasters in developing countries and column (5) confirms that remittances inflows (*i.e.* hard currency inflows) are associated with domestic currency real overvaluation. Results in Table 3.1 column (6) indicate that remittances act as a transmission mechanism but do not fully explain the effect observed:

Table 3.1 – Impact of Climate-Related Natural Disasters on RER Misalignment: What Are the Channels?

Dependent Variable:	RER Misalignment								
	Food Inflation (1)	Food Inflation (2)	RER Misalign. (3)	Remittances (4)	RER Misalign. (5)	RER Misalign. (6)	Net Capital Flows (7)	RER Misalign. (8)	RER Misalign. (9)
Climate-Related Natural Disaster Occurrence	0.166 (0.383)			0.627*** (0.043)		0.011** (0.004)	-0.699*** (0.096)		0.003 (0.005)
Food Inflation			-0.001*** (0.000)						
Remittances					0.010*** (0.002)	0.008*** (0.002)			
Net Capital Flows								-0.005*** (0.001)	-0.005*** (0.001)
Climate-Related Natural Disaster Intensity									
Constant	-86.825*** (6.046)	-99.228*** (9.945)	2.270*** (0.447)	-0.655 (0.568)	0.364*** (0.052)	0.355*** (0.052)	3.268 (8.095)	0.488 (0.348)	0.489 (0.348)
RER Misalign. determinants ^a	N	N	Y	N	Y	Y	N	Y	Y
Country Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	2141	1314	2036	3894	3421	3411	3505	3050	3050
Number of Countries	105	103	103	112	110	110	110	109	109

Note: ^a Cyclical component of the RER misalignment determinants. A positive RER misalignment corresponds to an overvalued RER. An increase in net capital flows corresponds to net acquisition of assets or a net decrease in liabilities (see [Koepke and Paetzold, 2020](#)). Net capital flows and remittances are expressed in millions of USD. Standard errors in parentheses. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

when adding remittances as a control variable to the baseline specification, a part of the effect of climate-related natural disasters on RER misalignment has gone through remittances but a direct effect remains since the estimate dropped from 0.015 to 0.011 but remains positive and statistically significant.

Capital inflows are a third potential explanation and the results reported in Table 3.1 columns (7) to (9) validate this hypothesis. Following [Koepke and Paetzold \(2020\)](#) and equation (3.15), an increase in Net Capital Flows corresponds to net capital outflows, and a decrease in Net Capital Flows corresponds to net capital inflows. The estimate reported in Table 3.1 column (7) evidences that climate-related natural disasters lead to net capital inflows in developing countries. In addition to the diaspora effect, this result might be explained by humanitarian aid, official development assistance of private capital inflows to benefit from business opportunities linked to reconstruction. The Estimates in column (8) show that net capital inflows are associated with an increase in RER misalignment, and the estimates reported in column (9) show that the direct effect of climate-related natural disasters on RER misalignment disappears when net capital flows are added as a control variable. Together, these results evidence that net capital inflows following a climate-related natural disaster are a transmission mechanism and lead to real currency overvaluation.

7 Conclusion

This paper assesses the effects of climate-related natural disasters on real exchange rate misalignment in developing countries. It adds to the empirical literature on the macroeconomic effects of natural disasters by focusing on the monetary and financial impact of these events, an overlooked dimension despite its importance for macroeconomic stability both in the short- and medium-term. This paper also contributes to the literature by identifying climate-related natural disasters, including droughts, based on primary climatic and meteorological datasets.

The findings indicate that climate-related natural disasters lead to real exchange rate overvaluations in developing countries: one occurrence leads to a 0.015 unit increase in the RER misalignment index. This effect is greater when droughts and cold waves are measured using primary climate and meteorological data. Dynamic results indicate that the effects of climate-related natural disasters on real exchange rate misalignment are immediate and slightly persistent since they remain significant one year after the disaster.

The results also indicate that the effects are heterogenous. These are stronger in

middle-income countries as well as disaster-prone countries. The effects are not different in large countries than in small ones, but they are stronger in the smallest countries (25% of the sample) and in small island developing states. This group of countries appears to be the most affected by the effect identified in this paper because they are predominantly middle-income, disaster-prone small countries.

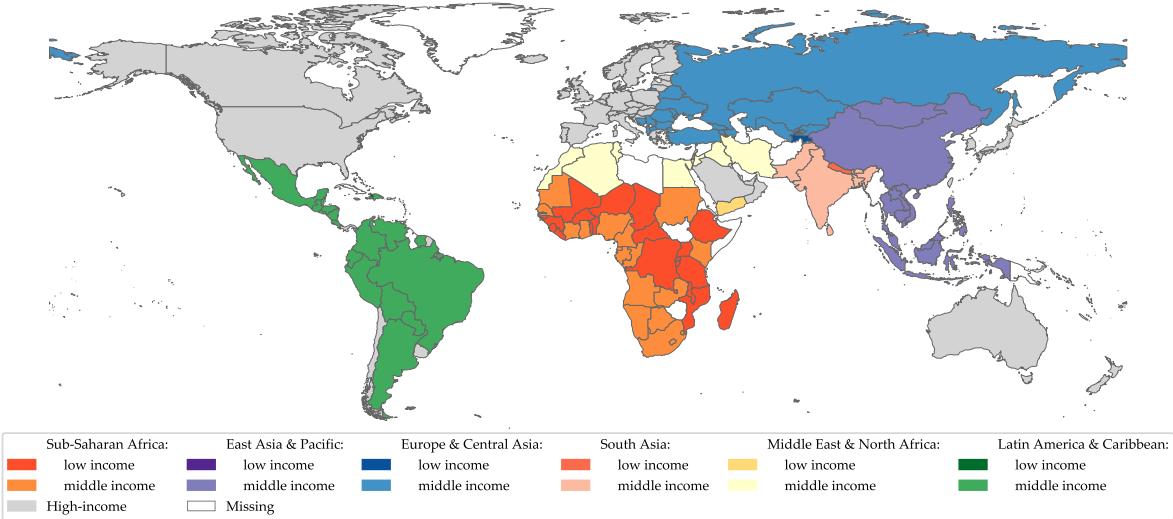
Inflation, including food inflation, is a channel through which climate-related natural disasters lead to real exchange rate overvaluation. The results indicate that remittances are one of these channels since they increase after a disaster and are associated with currency overvaluation. More generally, the results indicate that net capital inflows act as a transmission mechanism and can explain the effects of climate-related natural disasters on the currency misalignment.

These results can help inform policy-makers on the appropriate response to the effects of climate-related natural disasters. Capital inflows can help mitigate the social and human impacts of these events by facilitating the imports of food and medicines, among other vital goods. However, the overvaluation resulting from these capital inflows represents also a loss of competitiveness for the exporting sector and can therefore have negative effects on the recovery and in the medium run.

Appendix

3.A Sample and Data Sources

Figure 3.A.1 – Country Classification



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

Table 3.A.1 – List of Countries Included in the Main Regression Analysis

Low-Income Countries	Benin, Burkina Faso, Burundi, Central African Republic, Chad, Democratic Republic of the Congo, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Liberia, Madagascar, Malawi, Mali, Mozambique, Nepal, Niger, Rwanda, Sierra Leone, 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, Kyrgyzstan, Lao, Lesotho, Mauritania, Moldova, Mongolia, Morocco, Nicaragua, Nigeria, Pakistan, Philippines, Sao Tome and Principe, Senegal, Sudan, Tunisia, Ukraine, Uzbekistan, Viet Nam, Zambia
Upper-Middle Income Countries	Albania, Algeria, Argentina, Armenia, Azerbaijan, Belarus, Belize, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, China, Colombia, Costa Rica, Dominica, Dominican Republic, Ecuador, Fiji, Gabon, Georgia, Grenada, Guatemala, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Lebanon, Malaysia, Maldives, Mauritius, Mexico, Namibia, North Macedonia, Paraguay, Peru, Romania, Russia, Saint Lucia, Saint Vincent and the Grenadines, Serbia, South Africa, Sri Lanka, Suriname, Thailand, Turkey, Venezuela

Note: the sample selection of middle- and low-income countries is exclusively based on data availability. The classification corresponds to fiscal year 2020.

Table 3.A.2 – Data Sources

Variable:	Source:
<i>Real Exchange Rate Determinants:</i>	
REER	Darvas (2012)
Commodity terms of trade	Gruss and Kebhaj (2019)
Net foreign assets	World Bank - WDI (2021)
Productivity index	Constructed from World Bank - WDI (2021)
Public consumption	Penn World Tables version 9.1 (Feenstra et al., 2015)
Trade openness	Penn World Tables version 9.1 (Feenstra et al., 2015)
<i>Climate-Related Natural Disasters:</i>	
Climate-related natural disasters	EMDAT dataset (CRED, 2020)
Natural disasters	ifo GAME database (Felbermayr and Gröschl, 2014)
Temperatures & Precipitations	Matsuura and Willmott (2019b)
Standardized Precipitation-Evapotranspiration Index	Vicente-Serrano et al. (2010)
<i>Socio-Economic Variables:</i>	
Population	United Nations (DESA-PD): World Population Prospects
Real GDP per capita	World Bank - WDI (2021)
Land area	World Bank - WDI (2021)
Food Consumer Price Index	Parker (2018)
Remittances	World Bank - Migration and Remittances Data
Capital flows	IMF - Balance of Payments and International Investment Position Statistics

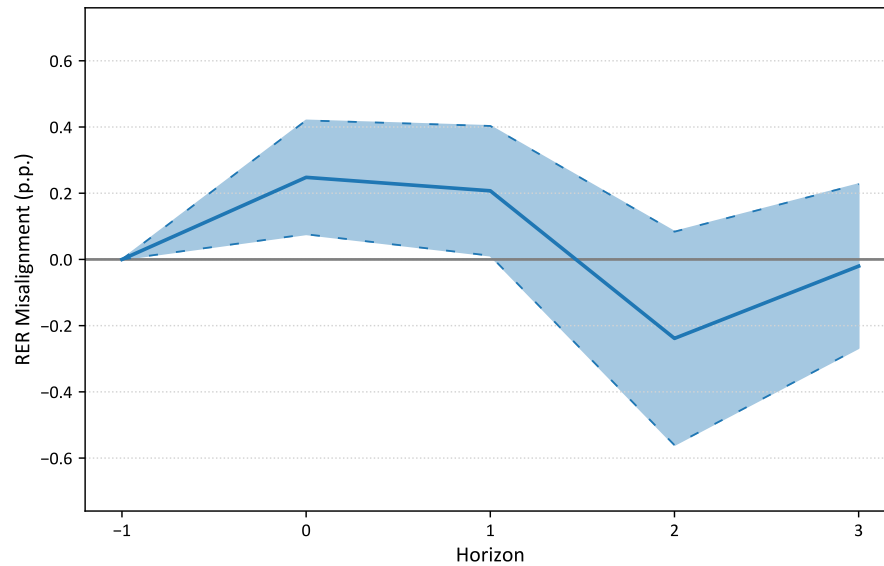
Table 3.A.3 – List of Small Island Developing States

Low-Income Countries	Guinea-Bissau, Haiti
Lower-Middle Income Countries	Cape Verde, Comoros, Sao Tome and Principe
Upper-Middle Income Countries	Belize, Dominica, Dominican Republic, Fiji, Grenada, Jamaica, Maldives, Mauritius, Saint Lucia, Saint Vincent and the Grenadines, Suriname

Note: the sample selection of Small Island Developing States is exclusively based on data availability.

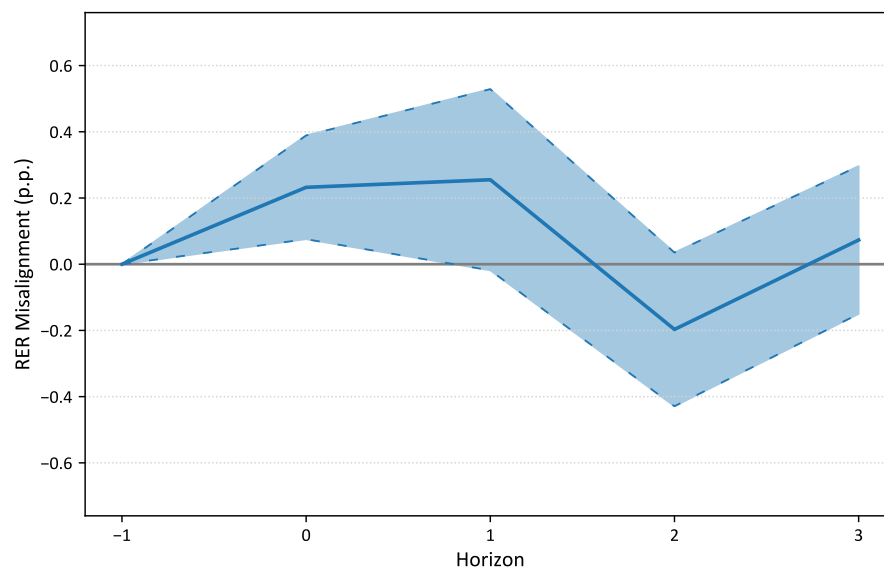
3.B Robustness Tests

Figure 3.B.1 – RER Misalignment's Response to a Climate-Related Natural Disaster - Additional Control Variables



Note: The graph shows the response of RER misalignment to a climate-related natural disaster. Standard errors are clustered at the country level.

Figure 3.B.2 – RER Misalignment's Response to a Climate-Related Natural Disaster - Driscoll-Kraay Standard Errors



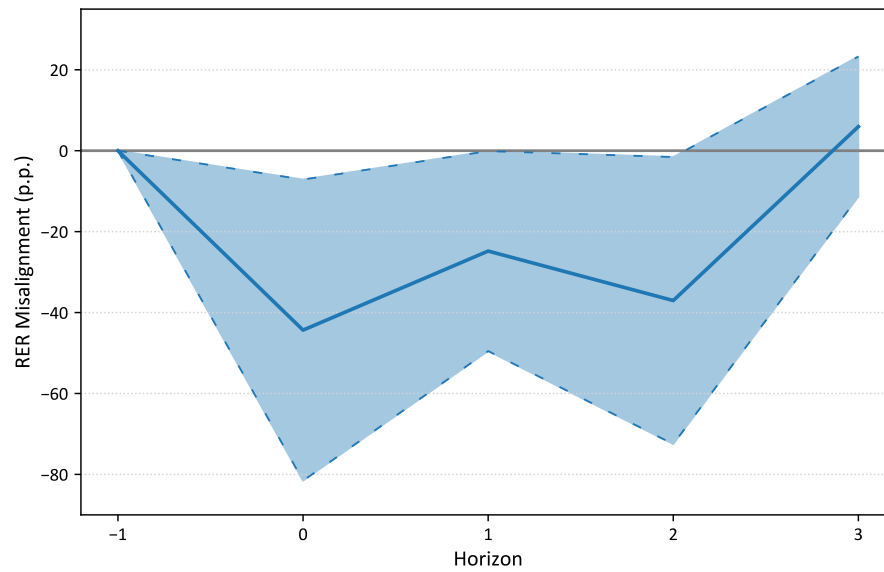
Note: The graph shows the response of RER misalignment to a climate-related natural disaster.

Table 3.B.1 – Effects of Climate-Related Natural Disasters based on Meteorological Observations: Additional Results

Dependent Variable:	RER Misalignment					
	ifoGAME		SPEI		U. Delaware	
Disaster Variable Source	Precipitation Deviations (1)	Precipitation Deviations (abs.) (2)	Temperature Deviations (3)	Drought (3 month) (4)	Drought (12 month) (5)	Rainfalls ⁺ (6)
Climate-Related Natural Disaster	0.002 (0.007)	-0.002 (0.002)	-0.003 (0.002)	0.033** (0.014)	0.032** (0.014)	-0.015 (0.014)
Commodity Terms of Trade ^a	0.389 (0.430)	0.686 (0.454)	0.691 (0.454)	0.005 (0.324)	-0.005 (0.324)	0.005 (0.324)
Productivity ^a	0.671*** (0.217)	0.866*** (0.236)	0.868*** (0.236)	0.620*** (0.191)	0.630*** (0.191)	0.609*** (0.191)
Net Foreign Assets ^a	0.197*** (0.039)	0.102* (0.054)	0.102* (0.053)	0.197*** (0.039)	0.193*** (0.039)	0.194*** (0.039)
Public Consumption ^a	2.329*** (0.427)	2.547*** (0.454)	2.538*** (0.454)	2.009*** (0.376)	2.015*** (0.376)	2.031*** (0.376)
Trade Openness ^a	-0.701*** (0.129)	-0.694*** (0.134)	-0.695*** (0.134)	-0.640*** (0.124)	-0.638*** (0.124)	-0.642*** (0.124)
Constant	0.269*** (0.051)	0.278*** (0.051)	0.278*** (0.051)	0.358*** (0.079)	0.358*** (0.079)	0.377*** (0.079)
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	2888	2774	2774	4386	4386	4386
Number of Countries	106	106	106	105	105	105

Note: ^a Cyclical component of the variable. Standard errors in parentheses. A positive RER misalignment corresponds to an overvalued RER. * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

Figure 3.B.3 – RER Misalignment's Response to a Climate-Related Natural Disaster - Driscoll-Kraay Standard Errors



Note: The graph shows the response of capital flows to a climate-related natural disaster. A decrease in capital flows refers to net capital inflows. The impulse response function is obtained by estimating: $CapFlows_{i,t+h} = \alpha_0^h + \beta_1^h CRND_{i,t} + \theta^h \sum_{p=1}^h CRND_{i,t+p} + \Psi C_{i,t} + \delta_i^h + \gamma_t^h + \varepsilon_{i,t}^h$, where $C_{i,t}$ is a vector of control variables comprising one lag of both capital flows and $CRND$ as well as the forward values of both capital flows and $CRND$ between t and $t+h-1$. Remaining variables are defined as in Equation (4.2).

Chapter 4

Climate-Related Natural Disasters and Financial Stability in Developing Countries¹

Abstract

Climate-related natural disasters have monetary and financial consequences in developing countries, but these have received relatively little attention. This paper uses macroeconomic data of the financial sector and data on natural disasters for 22 countries during the period 2005m3–2018m12 to assess the effects of climate-related natural disasters on financial stability in developing countries. The results show that such events lead to an increase in non-performing loans: one disaster occurrence leads to a 1.93 percentage point increase in the non-performing loans ratio. This effect materializes after four months and lasts for two periods. Provisions to non-performing loans also temporarily increase after ten months. These results evidence a higher fragility of the banking sector following climate-related natural disasters, in a context in which climate change will alter these natural disasters' frequency and intensity.

Keywords: Natural disasters, financial stability, developing countries.

JEL Classification: G21, O16, Q54.

¹Joint work with Vincent Fleuriet.

1 Introduction

Major weather shocks are particularly destructive in low- and middle-income countries, in terms of infrastructure, private wealth and human lives. Hurricanes Matthew in Haiti in 2016 and Irma in the Caribbean in 2017, landslides in Freetown in 2017, cyclones Idai in Mozambique in 2019 or hurricane Eta in Central America in 2020 all led to hundreds of deaths. Physical damages from these events are massive and can be expected to alter banking sector performances in these economies, among other effects.

This paper combines macroeconomic financial sector data with data on climate-related natural disasters to assess how these events affect financial sector stability. The effects of climate-related natural disasters on financial sector stability are ambiguous. Financing needs increase following physical destructions due to reconstruction needs. Such events can therefore increase business prospects for the financial sector. However, a majority of developing countries are characterized by a large informal sector which might contain the reconstruction-related business prospects for the financial sector. Furthermore, capital destruction increases the borrowers' risk profile, and their deposits might decrease. These potentially conflicting effects make an empirical approach appropriate.

This paper tests the hypothesis that the financial sector in developing countries is affected by climate-related natural disasters. To do so, it uses the monthly Financial Soundness Indicators (FSI) dataset from the IMF combined with data on climate-related natural disasters from EMDAT (CRED, 2020). The monthly panel dataset covers 22 low- and middle-income countries during the period 2005m3-2018m12 (*i.e.* a 166 months period). The empirical strategy relies on the local projections method introduced in Jordà (2005) which allows to evidence the dynamic effects of climate-related natural disasters on financial stability indicators.

A large strand of the empirical literature on the consequences of natural disasters for financial stability has focused on the U.S. banking sector. Barth et al. (2022a) finds that natural disasters lead to an increase in deposit rates, and Barth et al. (2022b) that loan rates increase more than deposit rates. This increase in loan demand, including in the real estate sector (Bos et al., 2022), offsets losses and actually boosts profits at larger banks (Blickle et al., 2021). Assessing the spacial consequences of natural disasters on the banking sector, Cortés and Strahan (2017) and Ivanov et al. (2022) find that those increases in credit demand following natural disasters are partially covered by capital reallocation, and the results in Duqi et al. (2021) suggest that economic activity recovers faster where the banking sector is less competitive. In other high-income countries, Hosono et al. (2016) finds that earthquakes constitute negative loan supply shock in

Japan, contrary to the effects observed in the U.S., while the results in [Koepke and Paetzold \(2020\)](#) point towards the existence of capital reallocation effects in Germany, confirming the results in [Cortés and Strahan \(2017\)](#) and [Ivanov et al. \(2022\)](#).

Contrary to other studies, [Noth and Schuwer \(2018\)](#) argue that the consequences of natural disasters weaken banks' stability in the U.S. by increasing the probability of defaults and the ratio of non-performing loans, among others, and the findings in [Klomp \(2014b\)](#) suggest that this result can be generalized to a broader range of countries.

The consequences of natural disasters on developing countries' banking sector might differ from those observed in the U.S. and other high-income countries, although empirical studies are scarcer. In the Caribbean, banks face deposit withdrawals and experience a negative funding shock after hurricanes, to which they respond by reducing the supply of lending and by drawing on liquid assets [Brei et al. \(2019\)](#). This negative effect on bank lending can be particularly detrimental to economic activity in a context of excess bank liquidity in several developing regions such as Central America ([Deléchat et al., 2014](#)) and Africa ([Beck and Cull, 2014](#)), including in the Economic Community of Central African States (ECCAS) ([Avom and Eyeffa Ekomo, 2007](#); [Begy, 2012](#)) and the West African Economic and Monetary Union (WAEMU) ([Doumbia, 2011](#)).

This paper contributes to the literature by studying the consequences of climate-related natural disasters on financial stability in developing countries, an essential dimension of macroeconomic stability and hence of development prospects. It does so by using high-frequency macroeconomic data.

The results show that climate-related natural disasters lead to an increase in non-performing loans in developing countries: One occurrence produces a 1.93 percentage point increase in non-performing loans four to five months after the event. Banks respond to climate-related natural disaster by increasing their provisions to non-performing loans as these materialize. The horizon is longer in this case, since the effect becomes positive and statistically significant ten to eleven months after the event.

The remainder of the article is organized as follows. Section 3 introduces the data, Section 4 details the empirical strategy and Section 5 presents the main results. Section 5 reports robustness tests, and Section 6 concludes.

2 Data and Stylized Facts

This paper uses country-level monthly data in order to assess the effects climate-related natural disasters on financial stability in developing countries. The sample includes a

total of 22 low- and middle-income countries between 2005m3 to 2018m12. The full list of countries included in the sample is indicated in Appendix Table 4.A.1, and Appendix Table 5.A.1 lists all the data sources used in this paper. The sample includes all countries for which Financial soundness indicators are available at a monthly frequency.

2.1 Climate-related Natural Disasters

This paper uses climate-related natural disasters from the EMDAT database (CRED, 2020). This database includes all events at the global scale that killed ten or more people, affected 100 or more people, led to a declaration of state of emergency or led to a call for international assistance. The dataset contains information on casualties, number of persons affected and physical damages in USD for each event.

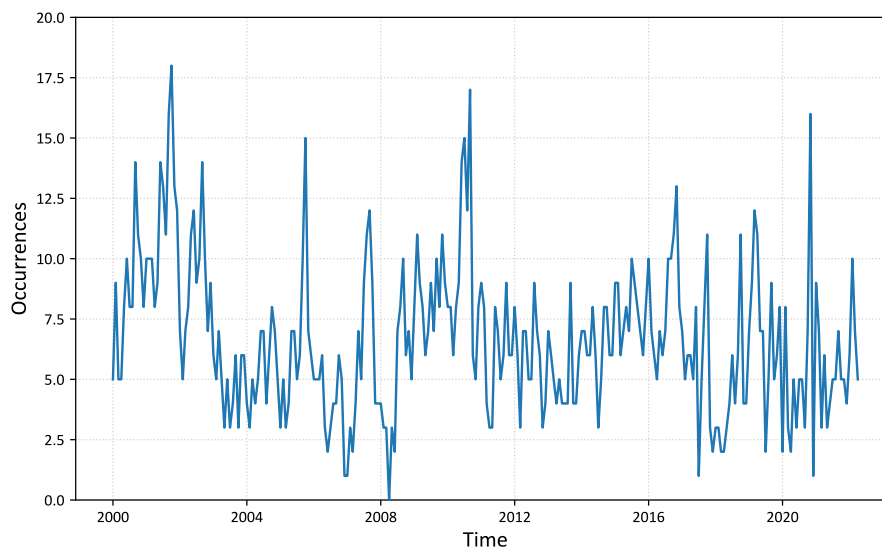
Climate-related natural disasters include floods, droughts, extreme temperatures, landslides, storms and wildfires. This paper uses all the climate-related natural disasters contained in the dataset that occurred in one of the countries included in the sample during the period 2005m3–2018m12. The main variable of interest is the number of occurrences of climate-related natural disasters, constructed as indicated in equation (4.1):

$$CRND_{i,t,m} = \sum_{k \in K} occurrence_{i,t,m,k} \quad (4.1)$$

where $K = \{\text{floods, droughts, extreme temperatures, landslides, storms, wildfires}\}$, i denotes the country, t the year and m the month.

Figure 4.1 shows the total number of climate-related natural disasters occurrences in the sample.

Figure 4.1 – Climate-Related Natural Disasters Occurrences



Note: The graph shows the number of occurrences of climate-related natural disasters in the sample.

2.2 Financial Stability Variables

The variables that capture financial stability in this paper are retrieved from the Financial Soundness Indicators (FSI) dataset from the IMF. The main variable of interest is the value of Non-performing Loans Net of Provisions to Capital, expressed in percent of loans and in national currency. This variable is available for 22 developing countries at a monthly frequency, restricting the sample to these countries. Provisions to non-performing loans, in percent, is an additional variable retrieved from the FSI dataset.

3 Empirical Framework

This paper uses adopts the local projections method introduced in [Jordà \(2005\)](#) to capture the effects of the occurrence of a climate-related natural disaster on non-performing loans over different horizons. Equation (4.2) is therefore separately estimated for horizons $h = 0, 1, \dots, 12$:

$$g_{i,t,m+h} = \alpha_0^h + \beta_1^h CRND_{i,t,m} + \Phi \mathbf{X}'_{i,t,m} + \gamma_i^h + \gamma_t^h + \gamma_m^h + \gamma_{i,m}^h + \varepsilon_{i,t,m}^h \quad (4.2)$$

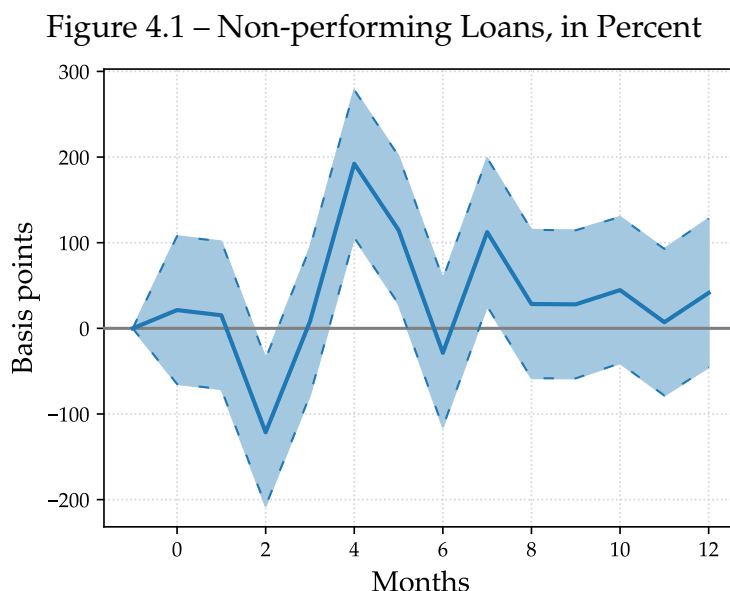
where i denotes the country, t the year and m the calendar month. $g_{i,t,m}$ denotes the month-over-month growth rate of non-performing loan, $CRND$ denotes the occurrences of climate-related natural disasters, Φ is a vector of parameters and \mathbf{X}' a vector of control variables containing two lags of the dependent and the explanatory vari-

ables, i.e. $\mathbf{X}'_{i,t,m} = [g_{i,t,m-1}, g_{i,t,m-2}, CRND_{i,t,m-1}, CRND_{i,t,m-2}]'$. γ_i^h denotes country fixed-effects which capture unobserved time-invariant country-specific characteristics, γ_t^h denotes year fixed-effects and γ_m^h calendar month fixed effects, which both capture common shocks but at different frequencies. Finally, $\gamma_{i,m}^h$ denotes country-calendar month fixed effects and captures country-specific seasonal patterns.

The specification of equation (4.2) remains parsimonious on purpose so that estimates are not affected by the issue of over-controlling, consistent with the common practice when using the local projections method. Several non-performing loans determinants are highly likely to respond to climate-related natural disasters, and adding them to equation (4.2) would raise the issue of bad controls and lead to bias in the estimates (Angrist and Pischke, 2009).

4 Results

The results presented in Figure 4.1 show that non-performing loans tend to increase following a climate-related natural disaster. The impulse-response function, obtained from estimating equation (4.2), indicates that following a slight decrease two month after the shock, the occurrence of a climate-related natural disaster leads to a 1.93 percentage point increase in non-performing loans net of provisions to capital four month after the shock. This effect diminishes afterwards but remain positive for two months.



Note: The graph shows the response of non-performing loans to a climate-related natural disaster. Non-performing loans are net of provisions to capital and measured in percent.

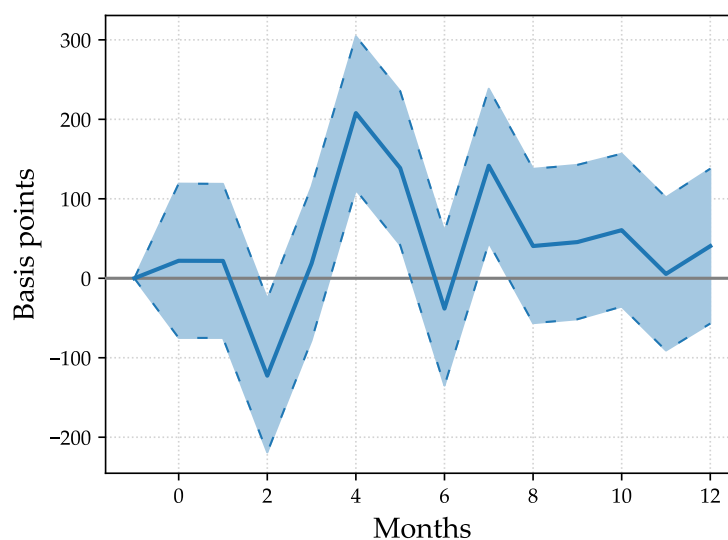
Figure 4.2 shows that the results are maintained when non-performing loans net of

provisions to capital are measured in local currency units.

Figure 4.3 reports the response of provisions to non-performing loans to the occurrence of a climate-related natural disaster and shows that banks tend to increase their provisions with an important delay. The response becomes positive and significant 10 months after the occurrence of the climate-related natural disaster, and remain positive for two periods only.

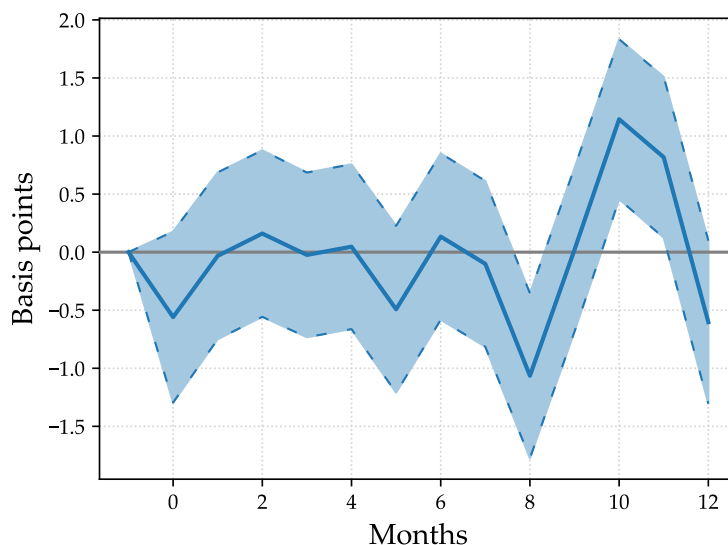
Table 4.1 reports the estimates from equation (4.2) for non-performing loans net of provisions to capital and for provisions to non-performing loans, corresponding to Figure 4.1 and Figure 4.3, respectively.

Figure 4.2 – Non-performing Loans, in Local Currency



Note: The graph shows the response of non-performing loans to a climate-related natural disaster. Non-performing loans are net of provisions to capital and measured in local currency.

Figure 4.3 – Provisions to Non-performing Loans



Note: The graph shows the response of provisions to non-performing loans to a climate-related natural disaster. Provisions to non-performing loans are in percent.

These results are coherent with the findings in [Noth and Schuwer \(2018\)](#) and [Klomp \(2014b\)](#). They might be explained by the fact that a drop in income and economic activity following a climate-related natural disaster, well established by empirical evidence (see [Felbermayr and Gröschl, 2014](#); [Noy, 2009](#); [Strobl, 2012](#), for example), could reduce households and enterprises' ability to pay back loans in the following months. Banks are expected to increase their provisions to non-performing loans as a response to such a situation, as indicated by the results.

The temporary nature of these effects might be explained by policy responses. In a context of highly informal economic activity, insurance companies are expected to play a limited role, while public transfers and physical capital rebuilding might help income recover. Private transfers such as remittances might also play a role. Investing further the mechanisms at play would deserve future research.

The results summarized in Figures 4.1 to 4.3 denote increased financial sector fragility following a climate-related natural disaster in developing countries. This increased fragility is particularly problematic in excessively liquid markets, where banks income rely relatively heavily on account management fees and loans are already scarce. This increased fragility might limit further banking sector loans to the private sector and reinforce existing development challenges where financial inclusion is hampered.

Table 4.1 – Effects of Climate-Related Natural Disasters on RER Misalignment

Dependent Variable:	Non-Performing Loans Net of Provisions to Capital												
	$h = 0$	$h = 1$	$h = 2$	$h = 3$	$h = 4$	$h = 5$	$h = 6$	$h = 7$	$h = 8$	$h = 9$	$h = 10$	$h = 11$	$h = 12$
Climate-Related Natural Disaster Occurrence	0.216 (0.521)	0.155 (0.521)	-1.199** (0.519)	0.084 (0.520)	1.925*** (0.520)	1.150** (0.522)	-0.278 (0.522)	1.133** (0.522)	0.293 (0.523)	0.290 (0.523)	0.407 (0.521)	0.039 (0.519)	0.403 (0.523)
Constant	0.558 (1.851)	-0.010 (1.850)	0.038 (1.843)	-0.107 (1.845)	-0.306 (1.845)	-0.181 (1.848)	0.125 (1.850)	-0.092 (1.851)	-0.069 (1.853)	-0.032 (1.853)	-0.251 (1.849)	2.921 (1.842)	0.721 (1.851)
Country Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Country×Month Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	2620	2618	2618	2618	2618	2618	2618	2617	2616	2615	2614	2613	2612
Number of Countries	22	22	22	22	22	22	22	22	22	22	22	22	22
Dependent Variable:	Provisions to Non-Performing Loans												
Climate-Related Natural Disaster Occurrence	-0.005 (0.004)	-0.000 (0.004)	0.002 (0.004)	0.001 (0.004)	0.001 (0.004)	-0.005 (0.004)	0.002 (0.004)	-0.001 (0.004)	-0.011*** (0.004)	-0.000 (0.004)	0.013*** (0.004)	0.008** (0.004)	-0.006 (0.004)
Constant	0.073** (0.029)	0.045 (0.029)	0.042 (0.028)	0.042 (0.028)	0.021 (0.028)	0.009 (0.028)	0.020 (0.028)	0.009 (0.028)	0.027 (0.028)	0.022 (0.028)	0.014 (0.027)	0.075*** (0.027)	-0.003 (0.027)
Country Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Country×Month Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1995	1991	1989	1987	1985	1983	1981	1978	1975	1972	1969	1966	1963
Number of Countries	18	18	18	18	18	18	18	18	18	18	18	18	18

Note: * Significant at the 10 percent level, ** significant at the 5 percent level, *** significant at the 1 percent level.

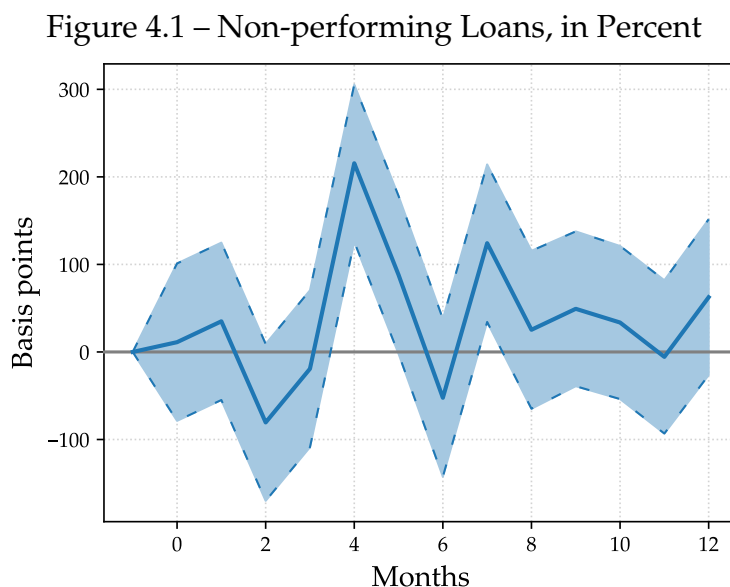
5 Robustness

To test the robustness of the main results reported in the previous section, equation (4.3) is similar to equation (4.2) except that it includes calendar month-year fixed effects:

$$g_{i,t,m+h} = \alpha_0^h + \beta_1^h CRND_{i,t,m} + \Phi \mathbf{X}'_{i,t,m} + \gamma_i^h + \gamma_t^h + \gamma_m^h + \gamma_{i,m}^h + \gamma_{t,m}^h + \varepsilon_{i,t,m}^h \quad (4.3)$$

where $\gamma_{i,m}^h$ denotes the calendar month-year fixed effects, all other variables remaining as in equation (4.2).

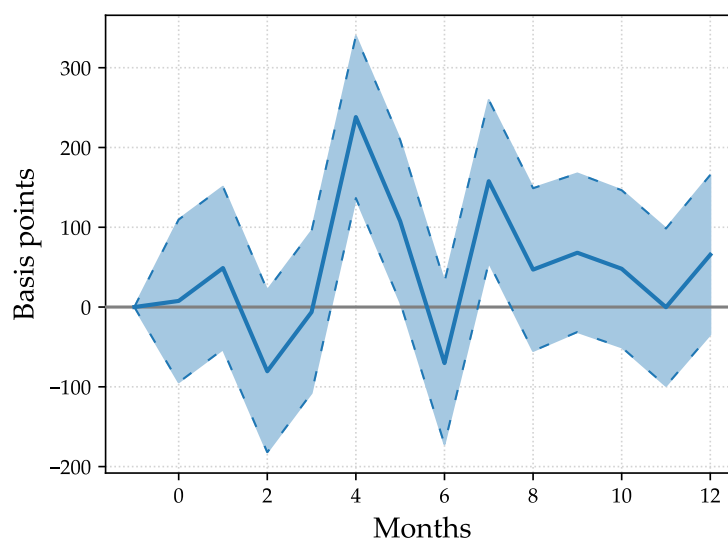
The inclusion of month-year fixed effects allows to capture common shocks more precisely since they can be month-specific, instead of simply year-specific.



Note: The graph shows the response of non-performing loans to a climate-related natural disaster. Non-performing loans are net of provisions to capital and measured in percent.

The results reported in Figure 4.1 and Figure 4.2 show that the positive relation between climate-related natural disasters and non-performing loans 4 to 5 months after the shock resists this test. The slight negative effect two months after the shock has disappeared in this richer specification, both when non-performing loans are measured in percent and in local currency units.

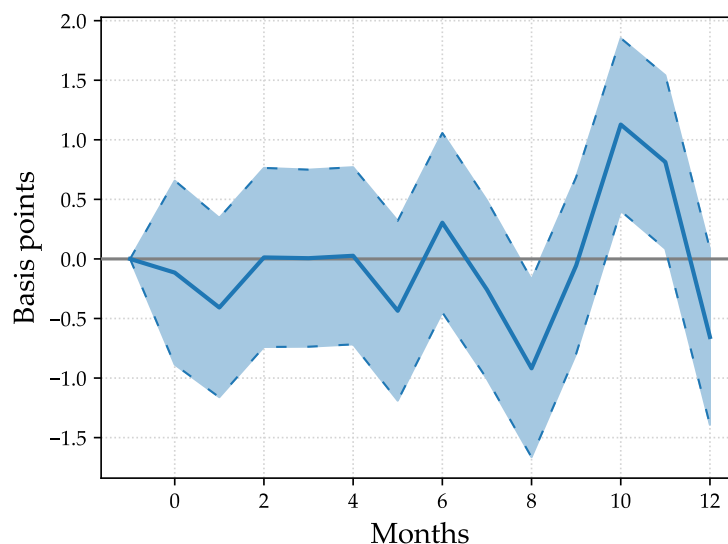
Figure 4.2 – Non-performing Loans, in Local Currency



Note: The graph shows the response of non-performing loans to a climate-related natural disaster. Non-performing loans are net of provisions to capital and measured in local currency.

The results reported in Figure 4.3 also confirm the increase in provisions to non-performing loans 10 to 11 months after the occurrence of a climate-related natural disasters.

Figure 4.3 – Provisions to Non-performing Loans



Note: The graph shows the response of provisions to non-performing loans to a climate-related natural disaster. Provisions to non-performing loans are in percent.

6 Conclusion

The consequences of climate-related natural disasters on the real sector and trade have been studied by a broad literature, but the financial consequences of these events in low- and middle-income countries has received relatively little attention. This paper assesses how climate-related natural disasters affect financial sector stability in low- and middle-income countries, where labour market informality is widespread and banking sector's structures differ from those that exist in high-income countries.

Using monthly data for a sample of 22 countries between 2005m3 and 2018m12 in an empirical framework relying on Local projections, this paper finds that climate-related natural disasters lead to an increase in non-performing loans in developing countries: One occurrence produces a 1.93 percentage point increase in non-performing loans four to five months after the event. As a response, banks increase their provisions to non-performing loans after these materialize, almost one year after the shock.

Future research could test whether these results are observed in a broader range of countries, at the cost of using data at a lower frequency. The mechanisms that explain these results would also deserve further research.

Appendix

4.A Sample and Data Sources

Table 4.A.1 – List of Countries Included in the Main Regression Analysis

Low-Income Countries		Central African Republic, Chad, Mozambique, Tajikistan
Lower-Middle Income Countries		Bolivia, Cameroon, Comoros, Congo, El Salvador, Honduras
Upper-Middle Income Countries		Albania, Armenia, Colombia, Costa Rica, Dominican Republic, Ecuador, Gabon, Georgia, Guatemala, Mexico, Paraguay, South Africa

Note: the sample selection of middle- and low-income countries is exclusively based on data availability. The classification corresponds to fiscal year 2020.

Table 4.A.2 – Data Sources

Variable:	Source:
Climate-related natural disasters	EM-DAT dataset (CRED, 2020)
Non-performing Loans Net of Provisions to Capital	Financial Soundness Indicators (FSI)
Provisions to Non-performing Loans Net	Financial Soundness Indicators (FSI)

Chapter 5

Climate Variability and International Migrations From Low-Income Countries: Does Financial Inclusion Matter?¹

Abstract

The relation between climate change or weather shocks and migration is complex and has been extensively studied by the literature. However, the effects of climate variability on migration have received much less attention. Using migration, climate and macroeconomic panel data for 114 low- and middle-income countries during the period 1986–2020, this paper finds that temperatures variability increases migration from low-income countries to neighbouring countries, while migration to OECD countries remains unaffected. In addition, the results indicate that access to domestic credit decreases the migration response to temperatures variability. This suggests that financial inclusion can constitute an adaptation policy in low-income countries.

Keywords: International migration, Climate change, Climate variability, Financial inclusion.

JEL Classification: F22, G20, O13, Q54.

¹Joint work with Maëlan Le Goff.

1 Introduction

Climate change is often associated with migration in public debate. Because of rising sea level, coastal erosion, temperatures hikes, desertification and the occurrence of climate-related natural disasters, migration is perceived as an adaptation strategy, at least at the personal level. However, this relation between the climate and migration is far from straightforward since both phenomena are highly complex. As noted by the Intergovernmental Panel on Climate Change (IPCC): “There is low confidence in quantitative projections of changes in mobility, due to its complex, multi-causal nature.”² In addition to gradual changes in temperatures and precipitation patterns and rapid-onset events, climate change also generates uncertainty by increasing temperatures and precipitations variability.

In this paper, we combine migration, climate and macroeconomic data to assess the effect of climate variability on international migration from low- and middle-income countries. To better consider uncertainty linked to climate change and understand to what extent migration may be a risk diversification strategy in this context, we focus on climate variability, instead of slow-onset or rapid-onset events as extensively examined in the literature. Temperature hikes and declining precipitations may affect migrations through their impact on agricultural yields and income, among other channels, but the uncertainty associated with climate variability might have large economic effects since adaptation might be even more difficult, in a context of constrained resources.

While the literature has evidenced the curbing role played by poverty in the climate-migration nexus, we test whether access to formal financial services may modify the impact of climate variability on international migration from low-income countries. The expected effect of this variable is ambiguous. On the one hand, having access to formal savings and credit may help individuals and households better cope *ex-ante* (investments to diversify income or better face weather shocks) or *ex-post* (income smoothing) with climate variability and limit their willingness to move. On the other hand, this better resilience to climate variability may prevent their income falling too much, letting them a sufficient financial leeway to move if they want to. In this case, financial inclusion removes the financial constraint on emigration.

This paper contributes to the literature two ways. First, it adds to a still scarce

²IPCC, 2014: Summary for policymakers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

literature assessing the macroeconomic effects of climate variability on international migrations. Second, it tries to identify a new mechanism through which financial inclusion could constitute an adaptation policy in developing countries.

To test the hypothesis that financial inclusion modifies the impact of climate variability on international migration, we use climate data from [Matsuura and Willmott \(2019a\)](#), bilateral migrants stock data from [UNDESA-PD \(2020\)](#) and macroeconomic data from [World Bank - WDI \(2021\)](#), complemented by several variables. Due to temporal depth constraints with the Global Findex dataset, we proxy financial inclusion with domestic credit to the private sector, measured in percent of GDP. The panel dataset covers seven five-year periods, from 1986 to 2020, and includes 114 low- and middle-income countries. Our empirical framework relies on fixed-effects estimators and we interact temperatures variability with domestic credit to assess the effect of financial inclusion on the relation between climate variability and international migration.

Our first results confirm findings of the literature ([Beine and Parsons, 2015, 2017](#); [Cattaneo and Peri, 2016](#), among others) and show that temperatures variability lead to an increase in international migration towards neighbouring countries and that this effect is driven by low-income countries. Migration to OECD countries remains unaffected. In a second step, the result indicates that financial inclusion reduces the effect of temperatures variability on emigration in low-income countries, suggesting that access to credit allows to reduce the income or wealth uncertainty associated with higher temperatures variability.

We test the robustness of this result by constructing an alternative measure of temperatures variability and controlling for temperatures deviations from their historical norms. The results are also robust to excluding the control variables from the regression. We finally test whether precipitations variability affect migration from low-income countries and whether financial inclusion also affects this relation: our results do not show any robust effect, as is common in the literature assessing the macroeconomic effects of climate change ([Dell et al., 2012](#); [Kahn et al., 2021](#); [de Bandt et al., 2021](#)). In these specifications, the effects of temperatures variability on migration and the mitigating effect of financial inclusion remains robust.

The remainder of the article is organized as follows. Section 2 reviews the literature, Section 3 presents the data and stylized facts and Section 4 introduces the empirical strategy. Section 5 presents and discusses the results and robustness checks and Section 6 concludes.

2 Review of the Literature

Climate change may affect emigration flows from developing countries through multiple channels highlighted in the literature. The most obvious one is the income channel. [de Bandt et al. \(2021\)](#) find that a 1°C rise in temperature results in a loss of growth in GDP per capita in developing countries between 0.74 and 1.52 percentage points. This negative effect on GDP is partly linked to the decline in productivity and agricultural yields caused by global warming and natural disasters ([Ortiz-Bobea et al., 2021](#); [Sultan et al., 2019](#)). Lower yields and productivity of agricultural and livestock activities are likely to reduce the income of households depending directly or indirectly from this production. They may also lead to an increase in the poverty rate and inequalities between those depending to agriculture or breeding, and the others.

At the same time, according to the neoclassical model of migration ([Todaro, 1969](#); [Harris and Todaro, 1970](#)), the decision to migrate is the result of a cost-benefit calculation of the individual, who seeks to maximize his utility, between staying and leaving. Hence, by reducing individuals' income, deteriorating their living conditions, and potentially increasing the income differential between home and host countries, climate change can make people in search of better living conditions to emigrate. [Falco et al. \(2019\)](#) empirically evidence that the impact of climate change on international migrations from low-income countries mainly pass through its detrimental effect on agricultural productivity.

By weighing on the availability of resources, climate change may also foster internal conflicts (see the review in [Burke et al., 2015b](#)), a significant push-factor for migrations. [McGuirk and Nunn \(2020\)](#) explain for example how global warming destabilizes the traditional cooperation between transhumant herders and farmers in Africa, leading to very violent internal conflicts (in Nigeria for example). [Abel et al. \(2019\)](#) highlight a significant effect of droughts on forced migration (measured by flows of asylum seekers) through the occurrence conflicts. Focusing on Sub-Saharan Africa, [Naudé \(2009\)](#) also establishes that natural disasters encourage international migrations directly and indirectly through the emergence of conflicts. Migratory flows caused by climate change being themselves a source of conflicts ([Abel et al., 2019](#)), a vicious circle can even appear.

Climate change may also have an impact on emigration if it deteriorates health. According to the IPCC ([IPCC, 2014](#)), there is little doubt that climate change is damaging to the health of populations, in particular in developing countries. This adverse effect on health could be explained in particular by deaths linked to an increasing frequency of heat waves and by the spread of vector transmissible diseases to areas

not infected so far. If by now the literature has been more interested in the effect of global warming on the spread of infectious diseases through population movements (McMichael, 2020), the deterioration of sanitary conditions may also play a role in the decision to emigrate.

Last but not least, global warming and the resulting higher frequency of natural disasters increase variability of crop yields and income, among others. In this context, migration, which may constitute a way to diversify risks as theorized by the New Economics of Migration (Stark and Levhari, 1982), may be a particularly attractive option, all the more so in countries where formal insurance systems are almost non-existent. Emigration appears then as a possible strategy for adapting to climate change (McLeman and Smit, 2006). Besides variability, climate change may also favor uncertainty and affect individuals' perspectives. Coniglio and Pesce (2015) evidence a direct effect of weather shocks on international migrations that they explain by a modification of people's outlook. While emigration can constitute a risk diversification strategy, the literature on the climate-migration nexus has paid little attention to the effect of climate variability. Most of the studies examine the effect of slow onset events and/or of punctual natural disasters, with ambiguous results on international migrations.

Kaczan and Orgill-Meyer (2020) list most of the articles examining the impact of climate change on migration, by distinguishing studies focusing on rapid-onset events (droughts, floods, etc.) from those examining slow onset events (sea level rise, desertification, land erosion, variation in mean annual temperatures, etc.). In the case of Burkina Faso, Henry et al. (2004) show that, while rainfall deficits slow down departures abroad due to their negative effect on income (the role played by the financial constraint is developed in the next paragraph), they tend to encourage internal migrations. Still in Burkina Faso, Nawrotzki and Bakhtsiyarava (2017) find that heat waves tend to curb international migrations. At the macroeconomic level, Cattaneo and Peri (2016) show a significant and positive average impact of the rise in temperatures on both internal and international migrations. To our knowledge, there are only a few papers that examine the effect of climate variability, sometimes called 'climate anomalies'. Using a gravity model, Beine and Parsons (2015) for example, find no significant effect of climate volatility (rainfall or temperatures) nor of natural disasters on international migrations. However, they evidence positive effects on rural exodus. Coniglio and Pesce (2015) use a similar measure of climate variability to examine the role played by the share of the agricultural sector in the climate-migration relationship. Using an instrumental variable methodology, Maurel and Tuccio (2016) show that climate volatility is detrimental to agricultural yields and thereby encourage international migrations.

Some conditional factors have been evidenced to help understand the ambiguous climate-migration relationship, in particular the financial constraint, but the role played by individual access to formal financial services has been totally ignored. As explained by [Findley \(1994\)](#), as well as [Henry et al. \(2004\)](#), economic difficulties caused by climate change can limit international migrations that are more expensive than internal migratory flows. That is why [Cattaneo and Peri \(2016\)](#) find that the positive effect of global warming on migration becomes negative in poor countries. The financial and material constraint may also explain why natural disasters seem to have less impact on international migrations than slow onset events. The deterioration of individuals' material situation in the aftermath of a major natural shock may prevent their departure, or cause temporary migrations inside their country or to proximate destinations with a rapid return ([Piguet et al., 2011](#)). [Bohra-Mishra et al. \(2014\)](#) find for example that weather shocks have less impact on international migrations from Indonesia than slow onset-events (rise in temperatures or rainfall evolution). Moreover, the climate-migration nexus may depend on how much people rely on the agricultural sector. According to [Coniglio and Pesce \(2015\)](#), the effect of the rainfall variability on migratory flows to OECD countries depends on the share of the agricultural sector in the home economies. Also, the effect seems to be more important when climate anomalies take place during the agricultural season. [Cai et al. \(2016\)](#) even show a positive effect of a rise in temperatures on migration only in countries highly dependent on the agricultural sector. [Benonnier et al. \(2022\)](#) evidence that the effect of climate change on international migration from low-income countries is stronger when considering the share of non-irrigated agricultural land.

In this paper, we argue that the literature has neglected the role of the higher uncertainty channel in the climate-migration relationship. To better consider uncertainty linked to climate change and understand to what extent migration may be a strategy of risk diversification in this context, we focus on climate variability, instead of slow-onset or rapid-onset events as extensively examined in the literature. Moreover, while the literature has evidenced the curbing role played by poverty in the climate-migration nexus, we test whether access to formal financial services may modify the impact of climate variability on international migration from poor countries. The expected effect of this variable is ambiguous. On the one hand, having access to formal savings and credit may help individuals/households better cope ex-ante (investments to diversify income or better face weather shocks) or ex-post (income smoothing) with climate variability and limit their willingness to move. On the other hand, this better resilience to climate variability may prevent their income falling too much, letting them a sufficient financial leeway to move if they want to. In this case, financial inclusion removes the

financial constraint on emigration.

3 Data and Stylized Facts

To assess the effect of changing climate on migration in low- and middle-income countries, we construct a country-level dataset covering 114 countries over the period 1986–2020. Sample selection is exclusively based on data availability. Appendix Table 5.A.1 lists all the data sources for this paper.

3.1 Migration Data

The migration data used to construct the dependent variables comes from the United Nations Department of Economic and Social Affairs - Population Division ([UNDESA-PD, 2020](#)). This dataset includes the total number of migrants (migrant stock) by country of origin and destination every five years between 1990 and 2020. Total population data is obtained from the WDI dataset ([World Bank - WDI, 2021](#)).

We compute migration rates for each country of origin as indicated in equation 5.1, following [Cattaneo and Peri \(2016\)](#), among others:

$$\text{Emigration Rate}_{i,p}^D = \frac{\sum_{j=1}^J \text{Migrants}_{i,j,t=p} - \sum_{j=1}^J \text{Migrants}_{i,j,t-5}}{\text{Population}_{i,t-5}} \times 100 \quad (5.1)$$

where i is the country of origin, $D = \{\text{World, OECD countries, Neighbouring countries}\}$ denotes the destination zone of migrants from origin country i and j denotes each country of destination within destination zone D . t denotes the year and p the five-years period. In our model we consider various destination areas to take into account the fact that economic difficulties caused by climate change in low-income countries can limit international migrations that are more expensive than internal migratory flows (see the discussion in Section 2). Because migrants can die or return, a few migration flows are negative. Following the migration literature, we transformed this negative flows into zeros.³

³A proper approach could have been to take into account return migrations and demographic changes, as in [Abel et al. \(2019\)](#). However, the use of their dataset would make us loose one five-year period and loose liberty degrees. Moreover, as shown in Appendix Table 5.A.2, the variables calculated by [Abel et al. \(2019\)](#) that are available for our sample of countries are highly correlated with our own measure of migration flows.

3.2 Climate Data

We use monthly land mean temperature and total precipitation from the University of Delaware (Matsuura and Willmott, 2019a). The global data set is gridded with a 0.5° latitude \times 0.5° longitude resolution (which corresponds to approximately 55km near the equator) and covers the period 1900–2017. We aggregate the data at the country-level by computing the unweighted average of all the observations within the land boundaries of each countries. Contrary to a common practice, we do not weight the climate observations by local population density since economic activity may not coincide with the distribution of population in developing countries. As argued in de Bandt et al. (2021), climate conditions might affect the economy through capital destruction during extreme weather events with distant impacts, economic production and population density might not be correlated in several developing countries, and agricultural production, a major component of GDP in many developing countries, may be determined by upstream as much as local climate conditions and is usually located where population density is low.

Inspired by Beine and Parsons (2015), Marchiori et al. (2012) and Maurel and Tuccio (2016), the main explanatory variable, temperatures variability, denoted $\sigma_{T,i,p}$, is calculated as indicated in equation (5.2):

$$\sigma_{T,i,p} = \frac{|\widetilde{T}_{i,p}|}{\sigma_{T,i,1900-1950}} = \frac{|T_{i,p} - \overline{T}_{i,1900-1950}|}{\sigma_{T,i,1900-1950}} \quad (5.2)$$

where i denotes the country and p the five-years period. $\widetilde{T}_{i,p}$ denotes temperatures deviation from their historical norms in country i during period p , in Celsius degrees ($^\circ\text{C}$), $T_{i,p}$ is the average mean annual temperature in country i during period p , and $\overline{T}_{i,1900-1950}$ is the average mean annual temperature in country i over the period 1900–1950, which we consider as the historical norm⁴. $\sigma_{T,i,1900-1950}$ is the mean annual temperature standard deviation in country i over the period 1900–1950.

Similarly, precipitations variability, denoted $\sigma_{P,i,p}$, is calculated as indicated in equation (5.3):

$$\sigma_{P,i,p} = \frac{|\widetilde{P}_{i,p}|}{\sigma_{P,i,1900-1950}} = \frac{|P_{i,p} - \overline{P}_{i,1900-1950}|}{\sigma_{P,i,1900-1950}} \quad (5.3)$$

⁴The Intergovernmental Panel on Climate Change (IPCC) considers the pre-industrial period (1850–1900) as the historical norm. Because the data does not cover this period, we consider 1900–1950 as the period of reference. As shown in de Bandt et al. (2021), climate change had not yet materialized in higher temperatures in any continent over that period.

where $P_{i,p}$ is the average total annual precipitations in country i during period p , in millimetres.

3.3 Financial Inclusion Data

We proxy financial inclusion by using domestic credit to the private sector, expressed as a percentage of GDP. The data comes from the [World Bank - WDI \(2021\)](#). This variable has the advantage to have a broad coverage, both across countries and across periods in our sample. A broader access to credit is expected to be reflected in a relatively high level of domestic credit, although this high level could also reflect credit concentration.

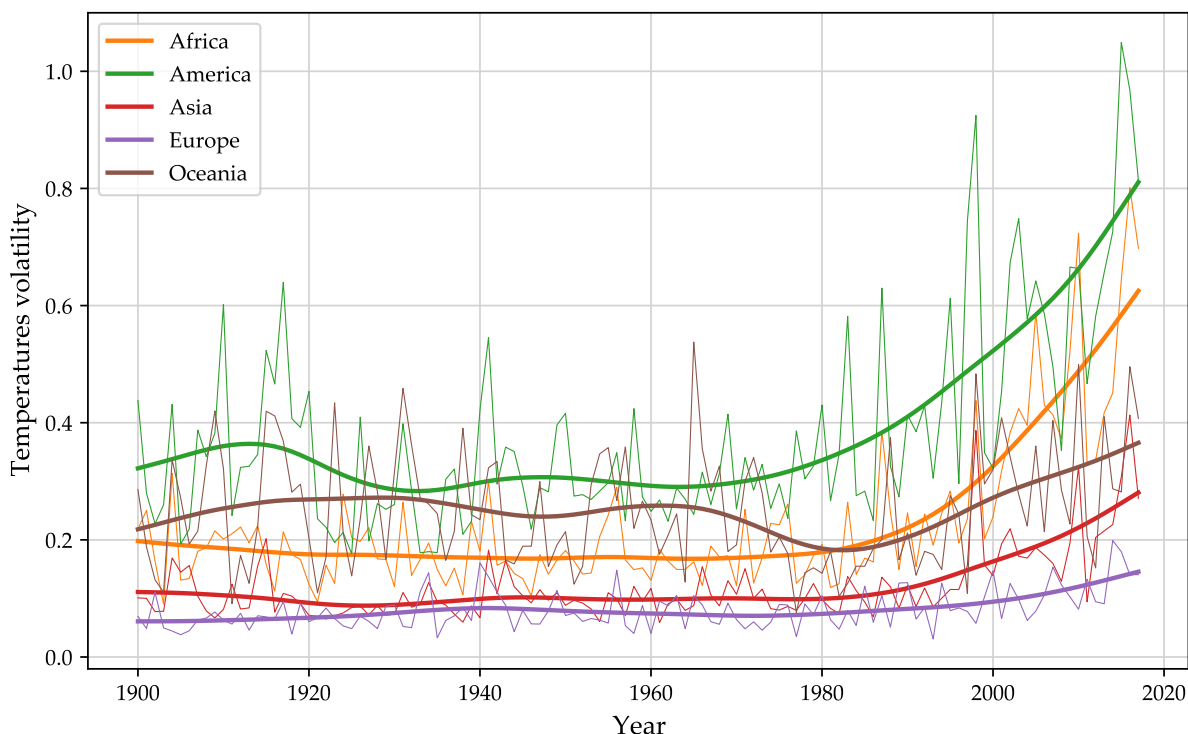
Alternative sources are available, such as the Global Findex dataset which captures more precisely financial inclusion. Ideally, we could use variables such as the percentage of the population that holds a bank account, but the data are available in years 2011, 2014 and 2017, which correspond to two five-year periods only. For this reason, we cannot use this data source and rely on domestic credit to the private sector, which allows us to have close to 400 observations. The correlation between domestic credit to the private sector and bank account holders, for the three years available, amounts to 69%. This comforts us in using domestic credit to the private sector as a proxy for financial inclusion.

3.4 Socio-Economic Data

The main control variables come from several sources. We use data on real GDP per capita and life expectancy from the World Development Indicators (WDI). We also use the Polity2 index issued by the Center for Systemic Peace to capture the political conditions in the country of origin. This index takes a value ranging between -10 (strongly autocratic) and 10 (strongly democratic). Furthermore, we capture the intensity of civil conflicts using data from the Major Episodes of Political Violence dataset, also issued by the Center for Systemic Peace. The magnitude of each conflict is coded on a 0 to 10 scale. A score of 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". Magnitude scores are considered consistent and comparable across cases and can vary across year during a single conflict episode, allowing therefore to obtain a country-year indicator for civil conflict.

3.5 Stylized Facts

Figure 5.1 – Temperatures Variability, by Continent



Note: This graph is better seen in colour. Thin lines denote temperatures variability ($\sigma_{T,i,p}$), thick lines denote the trend component of temperatures variability obtained using the Hodrick-Prescott filter ($\lambda = 1600$). Continental temperatures are computed as the unweighted average of country mean annual temperatures.

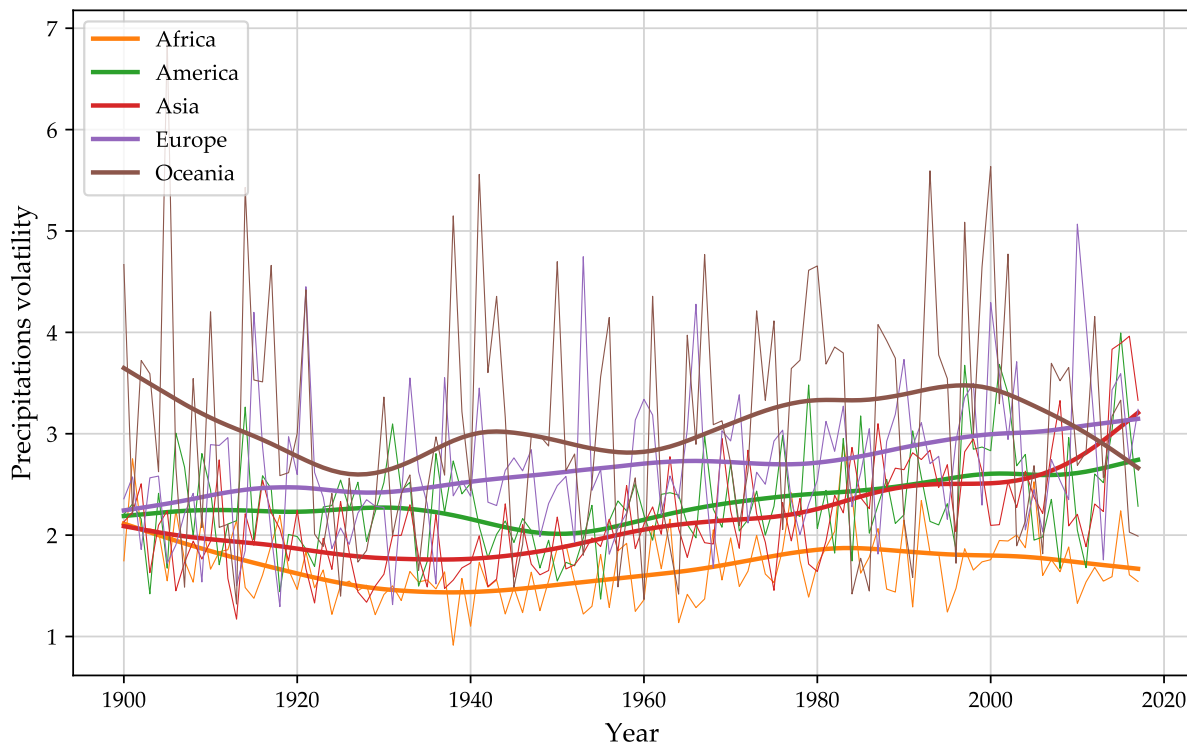
Figure 5.1 shows the evolution of temperatures variability in each continent. Thin lines indicate the time series of temperatures volatility, and thick lines indicate their trend (obtained using the Hodrick-Prescott filter with a smoothing parameter $\lambda = 1600$ ⁵).

Despite heterogeneity in the level of temperatures variability, Figure 5.1 evidences an increase in temperatures variability since the 1980s in all continents. This phenomenon seems particularly strong in America and Africa, and remains weaker in Europe.

Similarly, Figure 5.2 shows the evolution of precipitations variability in each continent. Heterogeneity is lower than with temperatures variability and the series do not show any particular strong pattern over the last decades.

⁵This smoothing parameter value is usually used for quarterly data. We chose it here for data visualization purposes only, since the trend component is smoother than when using a smoothing parameter of 6.25 usually used for annual data.

Figure 5.2 – Precipitations Variability, by Continent



Note: This graph is better seen in colour. Thin lines denote precipitations volatility ($\sigma_{P,i,p}$), thick lines denote the trend component of precipitations volatility obtained using the Hodrick-Prescott filter ($\lambda = 1600$). Continental precipitations are computed as the unweighted average of country total annual precipitations.

4 Empirical Framework

We assess the effect of changing climate on migration in low- and middle-income countries by estimating the empirical specification indicated in equation (5.4):

$$\begin{aligned} Migr_{i,p}^D = & \delta_1 \sigma_{T,i,p} + \alpha_1 \sigma_{P,i,p} + \varphi_1 RGDPpc_{i,p} + \varphi_2 LifeExp_{i,p} + \varphi_3 Democ_{i,p} \\ & + \varphi_4 CivCon_{i,p} + \gamma_i + \gamma_p + \varepsilon_{i,p} \end{aligned} \quad (5.4)$$

where i denotes the country and p the five-years period. $Migr_{i,p}^D$ denotes the migration rate from origin country i to destination zone D , with $D = \{\text{World, OECD, Neighbours}\}$, $\sigma_{T,i,p}$ denotes temperatures variability and $\sigma_{P,i,p}$ precipitations variability. We include a set of control variables that might affect the migration rates of country i to destinations D . $RGDPpc_{i,p}$ is the real GDP per capita, $LifeExp_{i,p}$ life expectancy, $Democ_{i,p}$ democracy, and $CivCon_{i,p}$ civil conflict intensity. γ_i denotes country of origin fixed effects and captures country-specific time-invariant

factors, such as geography and history, that may affect migration rate, and γ_p denotes time fixed effects that capture common shocks, such as the international business cycle.

The coefficient δ_1 captures the effect of an increase in temperatures variability on migration. Because changes in temperatures affect the macroeconomy through labour productivity (Kahn et al., 2021) and land productivity (Ortiz-Bobea et al., 2021) in developing country, we expect δ_1 to be positive and statistically significant.

As evidenced in the literature, the effect of climate variability on migration may be different in low-income countries because of more binding financial constraints. To examine whether financial development may modify the climate-migration nexus in low-income countries, either by overcoming the financial constraint or by helping people better cope with climate variability, we estimate equation (5.5):

$$\begin{aligned}
 Migr_{i,p}^D = & \delta_1 \sigma_{T,i,p} + \alpha_1 \sigma_{P,i,p} + \delta_2 \sigma_{T,i,p} \times LowInc_{i,p} + \delta_3 \sigma_{T,i,p} \times Credit_{i,p} \\
 & + \delta_4 \sigma_{T,i,p} \times LowInc_{i,p} \times Credit_{i,p} + \alpha_2 \sigma_{P,i,p} \times LowInc_{i,p} \\
 & + \alpha_3 \sigma_{P,i,p} \times Credit_{i,p} + \alpha_4 \sigma_{P,i,p} \times LowInc_{i,p} \times Credit_{i,p} \quad (5.5) \\
 & + \varphi_1 RGDPpc_{i,p} + \varphi_2 LifeExp_{i,p} + \varphi_3 Democ_{i,p} \\
 & + \varphi_4 CivCon_{i,p} + \gamma_i + \gamma_p + \varepsilon_{i,p}
 \end{aligned}$$

where $LowInc_{i,p}$ is a dummy equal to 1 if country i 's income per capita is below the 33rd percentile of the distribution at the beginning of period p and $Credit_{i,p}$ denotes domestic credit to the private sector measured in percent of GDP. we proxy financial inclusion with this variable due to temporal depth constraints with the Global Findex dataset. All other variables are the same as in equation (5.4), and equation (5.5) also includes country and year fixed effects.

5 Results

Table 5.1 – Climate Variability and International Migrations

	Emigration rate to:								
	World	OECD	Neighb.	World	OECD	Neighb.	World	OECD	Neighb.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Temperatures variability	1.913** (0.789)	-0.124 (0.317)	2.124*** (0.665)	2.581** (1.032)	0.087 (0.370)	2.559*** (0.891)	1.338* (0.770)	-0.231 (0.304)	1.695*** (0.645)
Precipitations variability	-0.015 (0.108)	0.061 (0.043)	-0.080 (0.091)	-0.125 (0.155)	0.032 (0.056)	-0.141 (0.134)	-0.022 (0.108)	0.055 (0.043)	-0.090 (0.091)
Real GDP per capita	-0.000** (0.000)	-0.000 (0.000)	-0.000* (0.000)	-0.000* (0.000)	-0.000 (0.000)	-0.000* (0.000)	-	-	-
Life expectancy	-0.097* (0.050)	0.014 (0.020)	-0.071* (0.043)	-0.094 (0.065)	0.022 (0.023)	-0.075 (0.056)	-	-	-
Democracy	-0.168*** (0.050)	-0.000 (0.020)	-0.106** (0.042)	-0.201*** (0.066)	0.014 (0.024)	-0.125** (0.057)	-	-	-
Civil conflict intensity	-0.231* (0.118)	-0.046 (0.047)	-0.212** (0.099)	-0.204 (0.179)	0.020 (0.064)	-0.271* (0.154)	-	-	-
Credit	-	-	-	-0.037* (0.019)	-0.012* (0.007)	-0.014 (0.016)	-	-	-
Low income	-	-	-	0.709 (0.930)	-0.171 (0.333)	-0.176 (0.803)	-	-	-
Constant	7.690** (3.142)	-0.108 (1.263)	5.206** (2.648)	8.165** (4.088)	-0.377 (1.464)	6.031* (3.530)	0.834** (0.359)	0.530*** (0.142)	0.145 (0.301)
Country Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Period Fixed Effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	522	522	522	391	391	391	522	522	522

Standard errors in parentheses. * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

Table 5.1 reports the estimates obtained from equation (5.4). Column 1 suggests that a 0.1 unit increase in temperatures variability leads to a 0.2 percent increase in the emigration rate to the rest of the world. Table 5.1 columns 2 and 3 show that this increase in emigration is driven by migration flows between neighbouring countries while migration outflows to OECD countries remain unaffected. This first result confirms the fact that climate change in low-income countries tends to promote short-distance migrations, rather than migrations to more distant destinations.

Life expectancy and democracy also affect the emigration rate with the expected sign since an increase in these variables tends to be associated with a decrease in the

emigration rate. The coefficient associated with real GDP per capita is negative, suggesting that a decrease in income increases emigration. The relation between civil conflict intensity and emigration is more ambiguous: while the literature finds that civil conflicts are associated with an increase in emigration, our estimates indicate the opposite. This result deserves further investigation but might be due to the fact that we take into account civil conflicts' intensity, as opposed to a more common strategy consisting in adding a dummy equal to 1 if a country experiences a civil conflict: The more violent a civil conflict, the greater the physical damages and material losses for individuals, which limits the possibility to emigrate.

Table 5.1 columns (7) to (9) report the estimates without including the control variables to test the robustness of the estimates presented in columns (1) to (3). The control variables are likely to be affected by temperatures and precipitations variability and could constitute bad controls. Dell et al. (2012) and Kahn et al. (2021) show that temperatures hikes affect output, Burke et al. (2015b) show that they increase conflict intensity and Kim et al. (2019) and Sun et al. (2019) that they affect health outcomes, among others. The estimates in columns (7) and (9) are positive and statistically significant, confirming the previous results indicating that the increase in emigration due to temperatures variability is driven by migration flows between neighbouring countries while migration outflows to OECD countries remain unaffected.

Next, we test whether financial inclusion affects the relation between climate variability and emigration in developing countries, and whether this is the case for all levels of income. In a first step, we add two additional control variable to equation (5.4): domestic credit to the private sector and a dummy equal to 1 if the country belongs to the bottom 33rd percentile of income per capita at the beginning of period p . Table 5.1 columns 4 to 6 show that the effect of temperatures variability on emigration rate remains unaltered and an increase in domestic credit seems to be associated with lower emigration rates, but the coefficient is only significant at the 10 percent level. The dummy for low-income countries is not significant.

In a second step, we include an interaction term between domestic credit and temperatures variability. Because precipitations variability has no statistically significant effect on emigration rate from developing countries, we first focus our analysis on temperature variability. Columns 1 to 3 in Table 5.2 show that the association between temperatures variability and migration rate remains unaltered and the coefficients associated with temperatures variability seem even slightly higher. We find no effect of domestic credit on this relation, nor any direct effect on emigration rate.

Table 5.2 – Financial Inclusion, Temperatures Variability and Migrations

	Emigration rate to:					
	World	OECD	Neighbours	World	OECD	Neighbours
	(1)	(2)	(3)	(4)	(5)	(6)
Temperatures variability	3.290*** (1.261)	-0.022 (0.452)	3.471*** (1.085)	1.394 (1.774)	0.172 (0.642)	0.587 (1.513)
Credit	-0.028 (0.022)	-0.013* (0.008)	0.002 (0.019)	-0.027 (0.024)	-0.013 (0.009)	-0.007 (0.020)
Low income	- -	- -	- -	0.151 (1.345)	-0.104 (0.487)	-1.553 (1.147)
Temperatures variability × Credit	-0.033 (0.036)	0.005 (0.013)	-0.045 (0.031)	-0.009 (0.038)	0.003 (0.014)	-0.006 (0.033)
Temperatures variability × Low income	- -	- -	- -	5.687** (2.687)	-0.406 (0.973)	7.656*** (2.292)
Temperatures variability × Credit × Low income	- -	- -	- -	-0.283* (0.151)	0.009 (0.055)	-0.329** (0.129)
Precipitations variability	-0.137 (0.155)	0.035 (0.055)	-0.140 (0.133)	-0.135 (0.155)	0.033 (0.056)	-0.149 (0.132)
Real GDP per capita	-0.000** (0.000)	-0.000 (0.000)	-0.000* (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Life expectancy	-0.100 (0.065)	0.023 (0.023)	-0.077 (0.056)	-0.079 (0.067)	0.022 (0.024)	-0.067 (0.057)
Democracy	-0.207*** (0.066)	0.015 (0.024)	-0.130** (0.057)	-0.209*** (0.066)	0.016 (0.024)	-0.140** (0.057)
Civil conflict intensity	-0.194 (0.179)	0.018 (0.064)	-0.264* (0.154)	-0.194 (0.180)	0.016 (0.065)	-0.244 (0.153)
Constant	8.787** (3.972)	-0.538 (1.424)	5.697* (3.419)	7.204* (4.201)	-0.368 (1.521)	5.622 (3.582)
Country Fixed Effects	Y	Y	Y	Y	Y	Y
Period Fixed Effects	Y	Y	Y	Y	Y	Y
Observations	391	391	391	391	391	391

Standard errors in parentheses. * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

Assuming that financial development can make more difference in low-income countries, we now test whether this result holds for all levels of income. Columns 4 to 6 in Table 5.2 report the estimates obtained from equation (5.5): Neither domestic credit nor the dummy for low-income countries are significant. The interaction term between credit and temperature variability remains insignificant and the coefficients capturing the effect of temperatures variability on migration rates have lost significance. The coefficient of the interaction term between temperature volatility and the dummy for low-income countries is significant when destinations are neighbouring countries and the rest of the world, but not OECD countries. This evidences that the results reported in Table 5.1 are entirely driven by low-income countries: temperatures variability leads to migration outflows that are directed to neighbouring countries, *i.e.* for which international migration costs are minimized, instead of OECD countries, where potential income differential is the highest.

Furthermore, the coefficient associated to the interaction between temperatures variability and domestic credit in low-income countries is negative and statistically significant. This result suggests that access to credit reduces the effect of temperatures variability on emigration in low-income countries. This can be due to the fact that access to credit and formal saving tools allows to reduce the uncertainty associated with higher temperatures variability. Whether this is the uncertainty regarding agricultural output, wages or other incomes remains an open question. Our results are in line with the findings in Marchiori et al. (2017). Although the authors find that income variability plays a relatively little role compared to income level in the decision to migrate, the role of income variability is greater when income levels are close to subsistence.

We test the robustness of this result by constructing a different indicator of temperatures variability, inspired by Marchiori et al. (2012) and indicated in equation (5.6). The indicator for precipitations variability is modified in the same way and all variables are as indicated in Section 3.

$$\sigma_{T,i,p} = \frac{T_{i,p} - \overline{T_{i,1900-1950}}}{\sigma_{T,i,1900-1950}} \quad (5.6)$$

Results are reported in Table 5.B.1 in Appendix 5.B and show that the results presented in Table 5.2 columns 4 to 6 are robust to the use of this alternative indicator for temperature variability: access to credit in low-income countries lowers the effect of temperatures variability on emigration to neighbouring countries.

Table 5.3 – Relation Between Precipitations Variability and Migrations

	Emigration Rate to Neighbours				
	(1)	(2)	(3)	(4)	(5)
Temperatures variability	2.759*** (0.890)	0.479 (1.485)	0.112 (0.835)	0.040 (0.833)	0.897* (0.500)
Precipitations variability	-0.174 (0.287)	-0.118 (0.278)	-0.028 (0.201)	-0.076 (0.065)	-0.078 (0.203)
Credit	-0.014 (0.020)	-0.002 (0.024)	0.002 (0.016)	0.001 (0.013)	-0.007 (0.014)
Low income	0.766 (1.181)	-0.601 (1.258)	-0.838 (0.938)	-1.177 (0.841)	0.511 (0.847)
Precipitations variability × Credit	-0.000 (0.008)	-0.002 (0.008)	-0.000 (0.005)	- -	0.000 (0.005)
Precipitations variability × Low income	-0.961** (0.448)	-1.610*** (0.454)	-0.469* (0.253)	- -	-0.340 (0.253)
Precipitations variability × Credit × Low income	0.065** (0.026)	0.102*** (0.026)	0.031** (0.013)	- -	0.024** (0.012)
Temperatures variability × Credit	- -	-0.007 (0.032)	-0.003 (0.015)	-0.002 (0.015)	- -
Temperatures variability × Low income	- -	10.196*** (2.331)	5.351*** (1.450)	4.864*** (1.446)	- -
Temperatures variability × Credit × Low income	- -	-0.492*** (0.133)	-0.198*** (0.063)	-0.165*** (0.062)	- -
Constant	6.151* (3.650)	5.558 (3.567)	0.498 (0.715)	0.627 (0.601)	0.516 (0.661)
Control Variables	Y	Y	N	N	N
Country Fixed Effects	Y	Y	Y	Y	Y
Period Fixed Effects	Y	Y	Y	Y	Y
Observations	391	391	527	527	527

Standard errors in parentheses. * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

Table 5.3 reports additional results. Estimates for precipitations variability reported

in tables 5.1 and 5.2 are not significant. However, column 1 in Table 5.3 tests whether this absence of relation between precipitations variability and emigration holds for all levels of income and is affected by domestic credit. The results obtained are the inverse of those for temperatures deviations: precipitations volatility is associated with lower emigration in low-income countries, and domestic credit tends to mitigate this negative effect. Furthermore, column 2 shows that when including interaction terms for credit and the dummy indicating low-income countries to both temperatures and precipitations variability, both effects are reinforced since the estimates are greater in absolute value and highly significant.

Columns 3 to 5 in Table 5.3 shows that the results for precipitations variability reported in columns 1 and 2 are not robust while those for temperatures variability stand. Excluding the set of control variables ($RGDPpc_{i,p}$, $LifeExp_{i,p}$, $Democ_{i,p}$ and $CivCon_{i,p}$) decreases the estimates' values and erases the statistical significance of the estimates for precipitations variability in low-income countries (significance drops to 10% only). Furthermore, when the interaction terms are included separately for temperatures variability (column 4) and precipitations variability (column 5), the previous results hold for temperatures variability but are not significant for precipitations variability.

Table 5.B.2 in Appendix 5.B reports the results for an additional robustness check. Temperatures and precipitations deviations from their historical norms are included in equation (5.5) as additional control variables. The main result of this paper regarding temperatures variability remains unchanged: an increase in temperatures variability leads to an increase in the emigration rate from low-income countries to neighbouring countries. However, access to formal savings and credit tools in these countries lowers the effect of temperatures variability on emigration.

6 Conclusion

While there is a vast and growing literature on the climate-migration nexus in developing countries, it has tended to neglect the role of uncertainty. Most of the micro- and macroeconomic analyses deal either with slow onset-events or rapid onset-events, while only a few examine the impact of climate variability. This instability may affect migrations through traditional channels evidenced in the literature (decrease in crop yields, in income, increase in conflicts, etc.), but also more directly by increasing uncertainty and making individuals' perspectives more hazardous.

In this paper we examine the impact of climate variability on international migra-

tions in developing countries and how individuals' access to formal savings and credit tools may modify this relationship. By carrying out fixed-effects estimations on a panel of 114 developing countries over the period 1986–2020, our results first confirm that climate change tends to encourage outward migration to neighboring countries rather than remote destinations. Moreover, we find that in the poorest countries, access to formal savings and credit tools attenuates the effect of temperatures variability on emigration to neighbors. This interesting finding highlights that the effect of climate variability on intra-regional migrations in poor areas may be limited by the development of alternative risk diversification strategies, the adoption and implementation of which can be facilitated by financial inclusion.

The last Grounswell report published by the World Bank mentioned that "[...] countries can also anticipate and prepare for the drivers of migration, for instance by supporting communities to adapt in place by diversifying livelihoods or by facilitating mobility when needed⁶." Our results highlight that the development of financial inclusion may be a relevant policy to limit climate migrations within developing regions and reduce the risk of destabilization that they pose, especially where most of the countries are very vulnerable to climate change.

⁶Clement, Viviane; Rigaud, Kanta Kumari; de Sherbinin, Alex; Jones, Bryan; Adamo, Susana; Schewe, Jacob; Sadiq, Nian; Shabahat, Elham. 2021. Groundswell Part 2: Acting on Internal Climate Migration. World Bank, Washington, DC. © World Bank. <https://openknowledge.worldbank.org/handle/10986/36248> License: CC BY 3.0 IGO

Appendix

5.A Data Sources

Table 5.A.1 – List of Variables and Sources

Variable:	Source:
Number of migrants	UNDESA-PD (2020)
Population	World Bank - WDI (2021)
Temperatures & Precipitations	Matsuura and Willmott (2019a)
Domestic credit to private sector	World Bank - WDI (2021)
GDP per capita	World Bank - WDI (2021)
Life expectancy	World Bank - WDI (2021)
Democracy	Polity2 index (Polity5 dataset - Center for Systemic Peace)
Civil conflict	Major Episodes of Political Violence (Center for Systemic Peace)

Table 5.A.2 – Correlation between our migration rate and variables in Abel et al. (2019)

Country	Variable			Country	Variable		
	DA	SD Drop ⁻	SD Rev ⁻		DA	SD Drop ⁻	SD Rev ⁻
Afghanistan	0.912**	0.718	0.745	Sri Lanka	0.999***	0.992***	0.994***
Angola	0.906**	0.861*	0.861*	Lesotho	0.963***	0.937**	0.937**
Albania	0.987***	0.994***	0.997***	Morocco	0.999***	0.970***	0.970***
Argentina	0.905**	0.991***	0.833*	Moldova	0.928**	0.996***	0.822*
Armenia	0.356	0.566	0.305	Madagascar	1.000***	1.000***	1.000***
Azerbaijan	0.840*	0.929**	-0.028	Mexico	0.998***	0.992***	0.992***
Burundi	0.847*	0.815*	0.767	North Macedonia	0.988***	0.809*	0.814*
Benin	0.997***	1.000***	1.000***	Mali	0.975***	0.885**	0.831*
Burkina Faso	0.880**	0.995***	0.748	Myanmar	0.999***	0.973***	0.967***
Bangladesh	0.981***	0.821*	0.741	Montenegro	-	-	-
Bulgaria	0.999***	0.996***	0.996***	Mongolia	1.000***	0.997***	0.993***
Bosnia & Herzegovina	0.637	0.921**	0.835*	Mozambique	0.909**	0.864*	0.864*
Belarus	0.990***	-0.006	-0.038	Mauritania	-0.626	0.819*	-0.758
Belize	0.987***	0.967***	0.954**	Mauritius	0.736	0.846*	0.666
Bolivia	0.999***	0.963***	0.964***	Malawi	0.919**	0.994***	0.839*
Brazil	0.974***	0.994***	0.939**	Malaysia	0.936**	1.000***	0.917**
Bhutan	0.799*	-0.832*	-0.833*	Namibia	0.837*	0.860*	0.784
Botswana	0.839*	0.994***	0.742	Niger	0.926**	0.999***	0.877*
Central African Rep.	0.998***	1.000***	0.996***	Nigeria	0.999***	0.998***	0.998***
China	0.996***	0.996***	0.996***	Nicaragua	0.979***	0.923**	0.923**
Côte d'Ivoire	0.997***	0.996***	0.994***	Nepal	0.964***	0.997***	0.999***
Cameroon	0.788	0.933**	0.559	Pakistan	0.601	0.980***	0.357
Congo	0.737	0.873*	0.681	Peru	0.991***	0.994***	0.994***
Colombia	0.996***	0.997***	0.997***	Philippines	0.991***	0.977***	0.964***
Comoros	0.996***	0.998***	0.998***	Papua New Guinea	0.518	0.935**	0.472
Cape Verde	0.824*	0.941**	0.929**	North Korea	0.999***	0.987***	0.991***
Costa Rica	0.865*	0.996***	0.837*	Paraguay	0.999***	0.996***	0.993***
Cuba	0.994***	1.000***	1.000***	Palestine	0.840*	0.996***	0.996***
Djibouti	0.685	0.921**	0.629	Russia	0.978***	0.164	-0.353
Dominica	-	-	-	Rwanda	0.437	0.432	0.447
Dominican Rep.	0.988***	0.989***	0.992***	Sudan	1	1	1
Algeria	0.997***	0.999***	0.997***	Senegal	0.355	0.970***	0.056
Ecuador	0.999***	0.993***	0.987***	Solomon Islands	0.173	0.688	0.011
Egypt	0.996***	0.933**	0.934**	Sierra Leone	0.539	0.231	0.184
Eritrea	0.921*	0.939*	0.941*	El Salvador	0.998***	0.159	0.099
Ethiopia	-0.478	0.811*	-0.861*	Somalia	0.999***	0.990***	0.990***
Fiji	0.003	0.909**	0.886**	Serbia	1.000***	1.000***	1.000***
Gabon	0.998***	0.956**	0.956**	South Sudan	-	-	-
Georgia	0.693	0.384	0.277	Sao Tome & Principe	0.992***	0.948**	0.908**
Ghana	0.576	0.998***	0.52	Suriname	0.883**	0.938**	0.938**
Guinea	-0.728	0.909**	-0.715	Eswatini	0.943**	0.859*	0.757
Gambia	0.892**	0.989***	0.876*	Syria	0.990***	0.995***	0.988***
Guinea-Bissau	0.908**	0.453	0.797*	Chad	0.709	0.840*	0.535
Equatorial Guinea	0.990***	0.994***	0.994***	Togo	0.986***	0.867*	0.867*
Grenada	0.981***	0.797*	0.794*	Thailand	0.936**	0.894**	0.664
Guatemala	-0.573	0.746	-0.601	Tajikistan	0.463	0.648	0.235
Guyana	0.963***	0.863*	0.869*	Turkmenistan	-0.771	0.027	-0.943**
Honduras	0.186	0.996***	0.15	Timor-Leste	0.879**	0.817*	0.826*
Haiti	0.743	0.746	0.747	Tunisia	1.000***	0.997***	0.996***
Indonesia	0.890**	0.945**	0.718	Turkey	0.984***	0.731	0.761
India	0.977***	0.996***	0.947**	Tanzania	-0.771	0.427	-0.804*
Iran	-0.096	0.946**	-0.194	Uganda	0.971***	0.872*	0.982***
Iraq	0.922**	0.827*	0.830*	Ukraine	0.749	0.829*	-0.606
Jamaica	0.991***	0.988***	0.988***	Uzbekistan	0.840*	0.951**	0.763
Jordan	-0.003	0.995***	0.195	St. Vincent & Grenadines	0.971***	0.766	0.766
Kazakhstan	0.759	0.951**	0.761	Venezuela	1.000***	1.000***	1.000***
Kenya	0.691	0.980***	0.467	Viet Nam	0.993***	0.952**	0.917**
Kyrgyzstan	0.77	0.996***	0.634	Vanuatu	0.920**	0.953**	0.924**
Cambodia	0.995***	0.981***	0.981***	Samoa	0.990***	0.984***	0.980***
Lao	0.997***	0.990***	0.989***	Yemen	0.999***	0.999***	1.000***
Lebanon	0.444	0.957**	0.577	South Africa	-0.604	0.994***	-0.641
Liberia	0.401	0.504	0.289	Zambia	0.378	0.984***	0.327
Libya	-0.817*	0.981***	-0.862*	Zimbabwe	0.999***	0.997***	0.962***
Saint Lucia	0.554	0.551	0.545	Aggregate	0.742***	0.801***	0.733***

Note: The table indicates the correlation between our migration rate and three migrations rates from Abel et al. (2019). DA refers to demographic accounting, minimization open, $SD\ Drop^-$ to stock differentiation, drop negative and $SD\ Rev^-$ to stock differentiation, reverse negative. * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

5.B Additional Results

Table 5.B.1 – Financial Inclusion, Temperatures Variability and Migrations

	Emigration rate to:		
	World	OECD	Neighbours
	(1)	(2)	(3)
Temperatures variability	1.447 (1.745)	0.132 (0.630)	0.692 (1.490)
Credit	-0.023 (0.024)	-0.014 (0.009)	-0.002 (0.020)
Low income	0.491 (1.324)	-0.131 (0.478)	-1.190 (1.131)
Temperatures variability × Credit	-0.009 (0.038)	0.004 (0.014)	-0.007 (0.033)
Temperatures variability × Low income	5.184** (2.611)	-0.340 (0.943)	7.180*** (2.229)
Temperatures variability × Credit × Low income	-0.337** (0.145)	0.008 (0.052)	-0.388*** (0.124)
Precipitations variability	0.041 (0.118)	-0.016 (0.043)	0.032 (0.101)
Real GDP per capita	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Life expectancy	-0.063 (0.066)	0.022 (0.024)	-0.048 (0.057)
Democracy	-0.204*** (0.067)	0.017 (0.024)	-0.134** (0.057)
Civil conflict intensity	-0.243 (0.178)	0.023 (0.064)	-0.297* (0.152)
Constant	6.047 (4.163)	-0.286 (1.503)	4.206 (3.555)
Country Fixed Effects	Y	Y	Y
Period Fixed Effects	Y	Y	Y
Observations	391	391	391

Temperatures and precipitations variability are measured as $\sigma_{C,i,p} = \frac{C_{i,p} - \overline{C_{i,1900-1950}}}{\sigma_{C,i,1900-1950}}$, where the climate variable $C = \{T, P\}$. Standard errors in parentheses. * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

Table 5.B.2 – Financial Inclusion, Temperatures Variability and Migrations

	Emigration rate to:		
	World	OECD	Neighbours
	(1)	(2)	(3)
Temperatures variability	2.147 (1.930)	0.030 (0.702)	1.098 (1.646)
Credit	-0.027 (0.024)	-0.014 (0.009)	-0.007 (0.020)
Low income	-0.054 (1.350)	-0.069 (0.491)	-1.709 (1.152)
Temperatures variability × Credit	-0.009 (0.038)	0.004 (0.014)	-0.006 (0.033)
Temperatures variability × Low income	6.292** (2.707)	-0.502 (0.984)	8.149*** (2.309)
Temperatures variability × Credit × Low income	-0.296* (0.151)	0.011 (0.055)	-0.340*** (0.129)
Precipitations variability	-0.064 (0.163)	0.023 (0.059)	-0.085 (0.139)
Temperatures deviation	-1.018 (1.093)	0.194 (0.397)	-0.679 (0.932)
Precipitations deviation	0.003 (0.002)	-0.000 (0.001)	0.002 (0.002)
Real GDP per capita	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Life expectancy	-0.081 (0.067)	0.022 (0.024)	-0.070 (0.057)
Democracy	-0.205*** (0.067)	0.015 (0.024)	-0.137** (0.057)
Civil conflict intensity	-0.193 (0.180)	0.016 (0.065)	-0.244 (0.153)
Constant	7.683* (4.209)	-0.433 (1.531)	6.063* (3.590)
Country Fixed Effects	Y	Y	Y
Period Fixed Effects	Y	Y	Y
Observations	391	391	391

Temperatures and Precipitations deviations from their historical norms are measured as $\widetilde{C}_{i,p} = C_{i,p} - \overline{C}_{i,1900-1950}$, where the climate variable $C = \{T, P\}$. Standard errors in parentheses. * Significant at the 10 percent level, ** Significant at the 5 percent level, *** Significant at the 1 percent level.

Chapter 6

Résumé de la thèse

1 Changement climatique et macroéconomie

Il est désormais scientifiquement incontesté que le climat est en train de changer. Les causes du changement climatique, ou l'attribution du changement climatique, ont été plus débattues jusqu'à récemment, mais il est désormais établi comme un fait que l'activité humaine est une force à l'origine de ces changements. Selon le sixième rapport d'évaluation (AR6) du Groupe de travail I du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) (Masson-Delmotte et al., 2021) : "Il est sans équivoque que l'influence humaine a réchauffé l'atmosphère, l'océan et les terres. Des changements rapides et généralisés se sont produits dans l'atmosphère, l'océan, la cryosphère et la biosphère". Le rapport ajoute : "L'influence humaine a réchauffé le climat à un rythme sans précédent depuis au moins les 2000 dernières années"¹.

Ce fait a des conséquences majeures pour l'économie, et en particulier pour l'économie des pays en développement (c'est-à-dire ceux classés comme étant à faible revenu et à revenu intermédiaire par la Banque mondiale)²). D'une part, les changements des conditions climatiques affectent l'économie. Ceci est capturé par les fonctions de dommages, qui sont des fonctions centrales dans les modèles d'évaluation intégrée (IAM), dont Nordhaus (1977) a été le pionnier. D'autre part, l'activité économique a une incidence sur le climat en raison des émissions de gaz à effet de serre résultant de l'utilisation d'énergie au cours du processus de production, entre autres causes (telles que les changements dans l'utilisation des terres).

Les conséquences du changement climatique sont encore plus importantes pour les pays en développement. La notion de "responsabilités communes mais différenciées" est au centre des négociations internationales sur le changement climatique depuis la

¹Le Résumé à l'intention des décideurs est disponible en suivant le lien : https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WG1_SPM_French.pdf.

²La classification actuelle et l'historique sont disponibles en suivant le lien : <https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups>

Convention-cadre des Nations unies sur les changements climatiques du Sommet de la Terre de Rio de Janeiro, en 1992. Ce principe a permis aux pays en développement, lors de la signature de l'Accord de Paris (2015)³, de fixer dans leur Contribution déterminée au niveau national des horizons plus longs pour atteindre des émissions nettes nulles. Cependant, à mesure que les conditions climatiques continuent d'évoluer, les pays en développement croissant à un rythme élevé sont susceptibles de faire face à des pressions grandissantes, tant de la part de la communauté internationale que de leurs sociétés, pour s'orienter vers des programmes de développement plus écologiques. Avec les technologies existantes, l'objectif de limiter les émissions de gaz à effets de serre pourrait entrer en conflit avec d'autres Objectifs de développement durable.

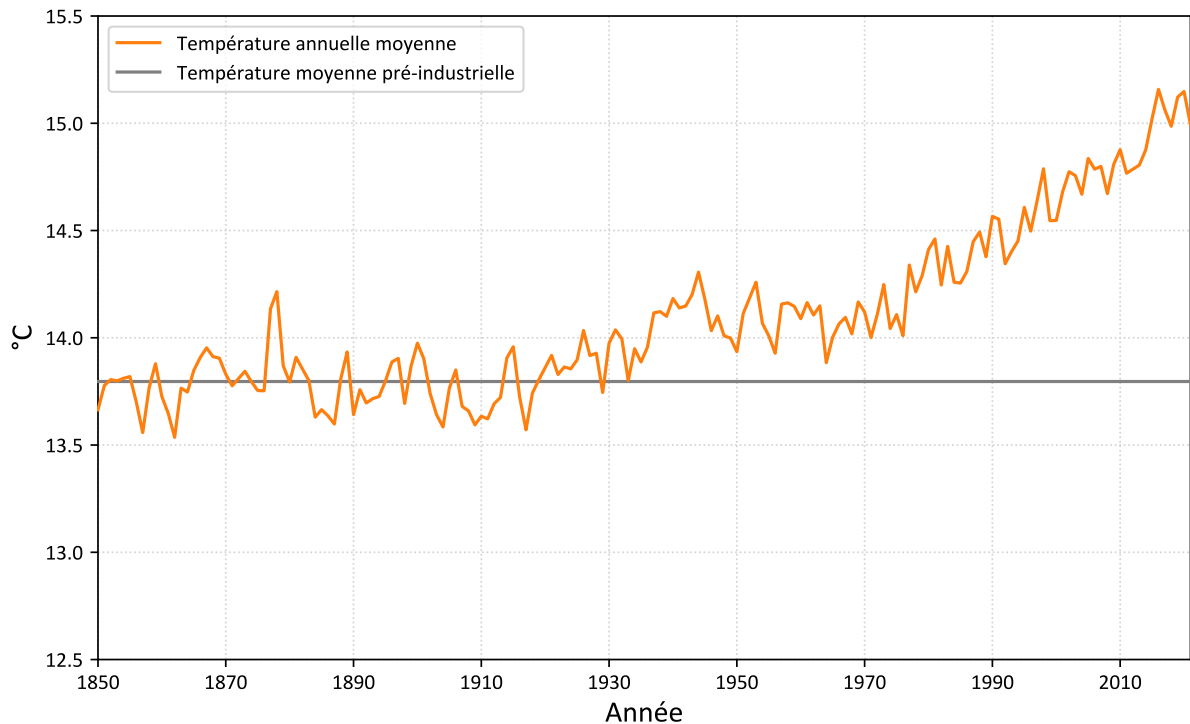
Les liens entre le climat et l'économie suscitent depuis longtemps l'intérêt des chercheurs. [Ibn Khaldun \(1377\)](#) et [Montesquieu \(1748\)](#) en sont deux exemples, mais les réflexions sur ces liens ont commencé bien plus tôt. Récemment, le réchauffement climatique a suscité un regain d'intérêt et des contributions majeures ont été apportées à la littérature, tant théorique ([Nordhaus, 1977](#), entre autres) qu'empirique ([Dell et al., 2012](#), entre autres). Le chapitre 1 contient une discussion plus détaillée de ces contributions.

2 Faits stylisés sur le changement climatique

Avant d'aborder la manière dont le changement climatique affecte l'économie, cette section présente quelques faits stylisés sur ce phénomène.

³L'Accord de Paris est disponible au lien suivant : <https://unfccc.int/fr/a-propos-des-ndcs/l-accord-de-paris>

Figure 6.1 – Température moyenne annuelle mondiale

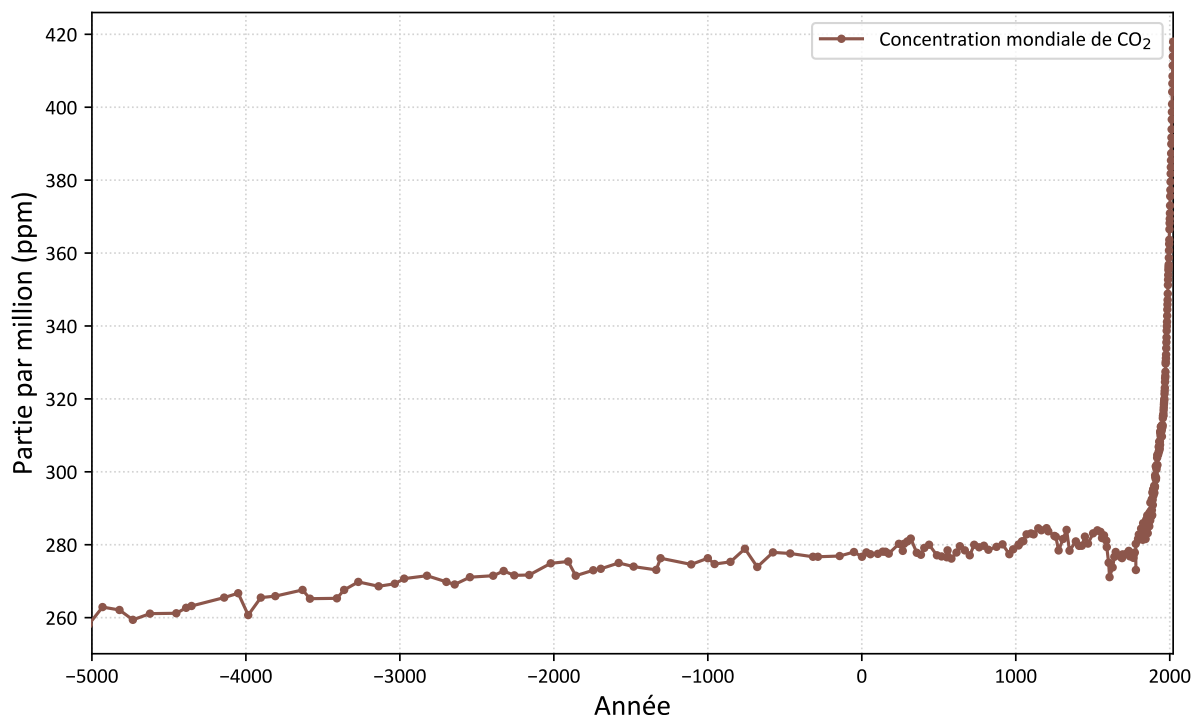


Note : Rohde and Hausfather (2020), calculs de l'auteur. La température moyenne pré-industrielle correspond à la période 1850–1900.

Le réchauffement de la planète est sans doute la matérialisation la plus connue du changement climatique. Le Graphique 6.1 montre l'évolution de la température annuelle moyenne mondiale entre 1850 et 2021. Les températures restent globalement constantes jusqu'aux années 1930 et commencent à augmenter de façon marquée au début des années 1970. Selon Berkeley Earth, la température annuelle moyenne mondiale était en 2021 supérieure de 1,2°C à la moyenne de la période 1950-1980⁴.

Cette augmentation de la température annuelle moyenne mondiale résulte d'une concentration atmosphérique plus élevée de CO₂ et d'autres gaz à effets de serre, qui résulte elle-même d'émissions élevées et toujours en hausse de CO₂ et d'autres gaz à effets de serre. Hsiang and Kopp (2018) présentent une introduction solide à la physique qui sous-tend le changement climatique. Le Graphique 6.2 montre que la concentration mondiale actuelle de CO₂ dans l'atmosphère est supérieure d'environ 55 % à la moyenne enregistrée entre 5000 av. J.-C. et 1000 apr. Elle prouve également qu'un changement majeur s'est produit au début de l'ère industrielle, vers le début du XIXe siècle.

⁴Ce nombre correspond à la température de la surface terrestre. L'ensemble de la série chronologique couvrant la période 1750–2021 est disponible en libre accès au lien suivant : https://berkeley-earth-temperature.s3.us-west-1.amazonaws.com/Global/Complete_TAVG_summary.txt

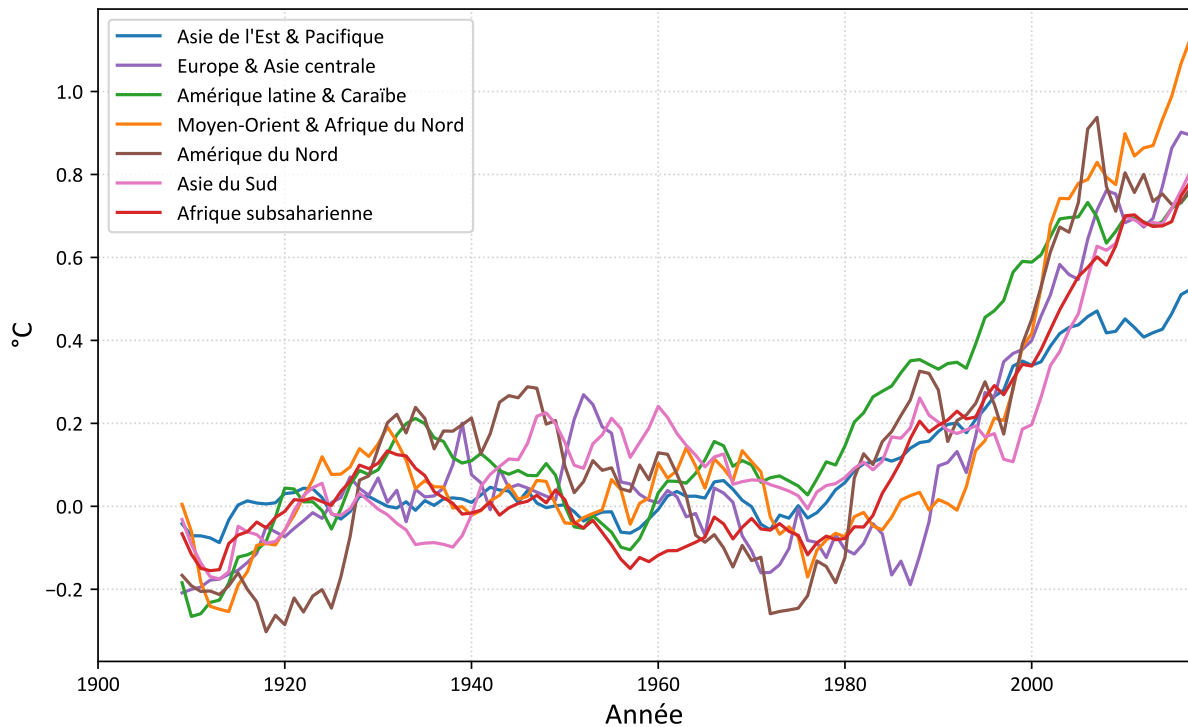
Figure 6.2 – Concentration atmosphérique mondiale de CO₂

Source : Our World in Data, élaboration de l'auteur.

Les émissions nationales de gaz à effets de serre qui expliquent la forte augmentation de la concentration mondiale sont loin d'être réparties uniformément. Jusqu'en 2017, les principaux contributeurs aux émissions mondiales cumulées de CO₂ étaient les États-Unis (25 %), l'UE et le Royaume-Uni (22 %) et la Chine (12,7 %). L'ensemble du continent africain et l'Amérique du Sud ont chacun contribué à environ 3 % des émissions historiques totales de CO₂⁵. Le chapitre 1 présente des faits stylisés plus détaillés, au niveau des pays, à l'aide des données de [Boden et al. \(2017\)](#). Cette répartition inégale des émissions historiques de gaz à effets de serre est la principale explication de l'émergence de la notion de Responsabilités communes mais différenciées. L'hétérogénéité est à prendre en compte pour l'attribution du changement climatique.

⁵Les données sous-jacentes sont disponibles auprès de Our World in Data au lien suivant : <https://ourworldindata.org/co2-emissions>

Figure 6.3 – Écarts de température, par région

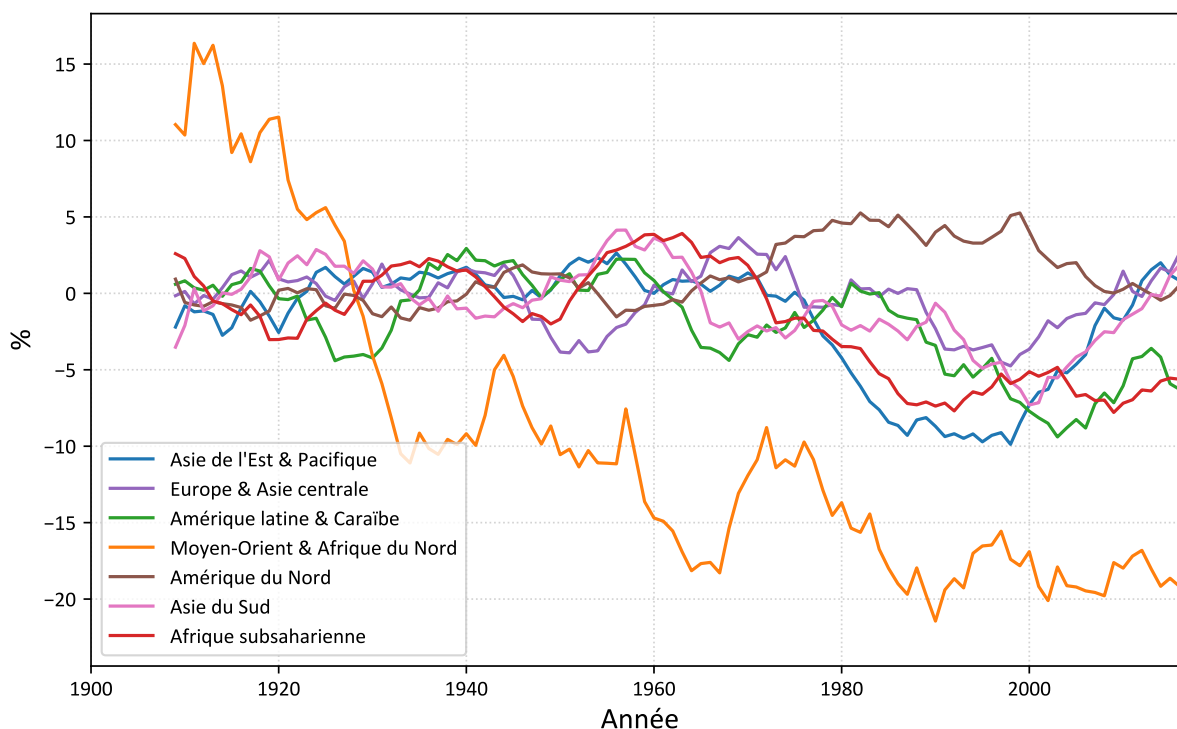


Note : [Matsuura and Willmott \(2019a\)](#), calculs et élaboration de l'auteur. Les séries montrent pour chaque région l'écart de température (moyenne mobile sur 10 ans) par rapport à la température moyenne pendant la période 1900–1950. Températures régionales calculées par l'auteur en utilisant la moyenne non pondérée des températures annuelles moyennes des pays.

L'hétérogénéité caractérise également la matérialisation du changement climatique. Comme le montre le Graphique 6.3, les températures annuelles moyennes des différentes régions suivent une tendance similaire, mais avec une intensité variable. À la fin des années 2010, les températures annuelles moyennes étaient supérieures de plus de 1°C à leur norme historique au Moyen-Orient et en Afrique du Nord, tandis que l'augmentation était de l'ordre de +0,5°C en Asie de l'Est et Pacifique. La norme historique est définie comme la moyenne de la période 1900-1950, ici et dans le reste de cette thèse, sauf indication contraire. L'hétérogénéité de la matérialisation du changement climatique est plus marquée lorsqu'on considère les précipitations annuelles. Le Graphique 6.4 montre les écarts des précipitations annuelles totales par rapport à leurs normes historiques, exprimés en pourcentage. Aucune tendance commune n'apparaît et des schémas divergents sont visibles au cours de la période 1980-2000. La région MENA a connu un déclin marqué des précipitations annuelles depuis le début du XXe siècle, à partir d'un niveau déjà bas, qui s'est combiné avec les plus fortes hausses de température observées, à partir de niveaux déjà élevés, pour modifier les conditions de sécheresse dans la région. Le chapitre 2 se concentre sur les conséquences macroé-

conomiques de cette dynamique.

Figure 6.4 – Écarts de précipitations, par région

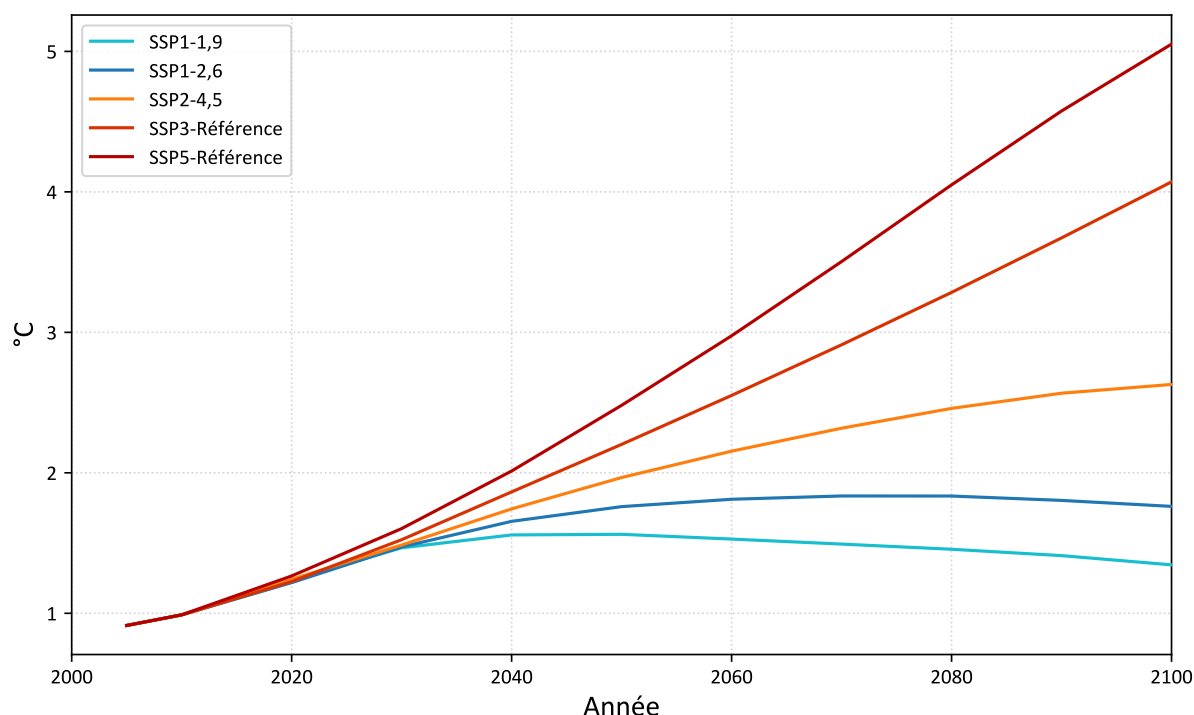


Note : [Matsuura and Willmott \(2019a\)](#), calculs et élaboration de l’auteur. Les séries montrent pour chaque région l’écart en pourcentage des précipitations (moyenne mobile sur 10 ans) par rapport aux précipitations moyennes pendant la période 1900–1950. Précipitations régionales calculées par l’auteur en utilisant la moyenne non pondérée des précipitations annuelles totales des pays.

Les graphiques précédents contiennent des données historiques qui montrent que le changement climatique est déjà une réalité et que ses effets sont susceptibles d’être déjà ressentis. Les projections futures sont au cœur des travaux du GIEC. Leurs rapports présentent des scénarios climatiques qui décrivent les trajectoires probables des températures en fonction d’un ensemble d’hypothèses. Le Graphique 6.5 présente certains des scénarios, ou Shared Socioeconomic Pathways (SSP), largement discutés dans le rapport AR6 du GIEC ([Masson-Delmotte et al., 2021](#)). Les scénarios reposant sur les niveaux futurs les plus bas d’émissions de gaz à effets de serre prévoient que la température annuelle moyenne mondiale culminera à +1,5 à +2,0°C au-dessus des niveaux préindustriels vers 2050 à 2070 ⁶. Ils correspondent aux scénarios SSP1-1.9 et SSP1-2.6. Au contraire, les scénarios de référence SPP3 et SPP5, dans lesquels l’utilisation de l’énergie reste fortement émettrice, prévoient une augmentation continue de la

⁶Les niveaux préindustriels correspondent à l’année 1750 dans le Graphique 5. Les données sont disponibles publiquement dans la base de données SSP version 2.0, au lien suivant : <https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10>.

Figure 6.5 – Augmentation de la température moyenne mondiale par rapport à l'ère préindustrielle



Source : [Riahi et al. \(2017\)](#), élaboration de l'auteur. SSP correspond à Shared Socioeconomic Pathways, les scénarios utilisés par le GIEC. L'ère préindustrielle correspond à l'année 1750.

température annuelle moyenne mondiale jusqu'en 2100, avec des températures à ce moment-là supérieures de 4 à 5°C à celles de l'ère préindustrielle.

Ces projections soulignent la portée et l'importance des politiques d'atténuation, c'est-à-dire des politiques visant à réduire les émissions de gaz à effets de serre. Dans tous les scénarios, mais en particulier dans les scénarios SSP3 et SSP5, les politiques d'adaptation seront fondamentales pour la prospérité future des économies, et encore plus dans les pays en développement. Ces politiques doivent s'appuyer sur des analyses économiques solides des effets du changement climatique, qui doivent surmonter plusieurs difficultés.

3 Quantifier les effets du changement climatique : défis empiriques

L'abondance de données d'observation et de modélisation de haute qualité issues de la science du climat a permis le développement récent d'une littérature empirique sur les conséquences économiques du changement climatique. Les données géolocalisées

à haute fréquence, principalement concernant les températures et les précipitations, sont des atouts solides pour construire des stratégies empiriques robustes car elles peuvent être considérées comme des chocs aléatoires exogènes. Cependant, ces données désignent des conditions météorologiques, par opposition aux conditions climatiques qui sont elles définies comme des changements de conditions météorologiques sur le long terme (généralement 30 ans ou plus). Une des contributions de cette thèse est d'introduire une nouvelle stratégie d'identification qui s'appuie sur des changements durables des conditions météorologiques dans les chapitres 1 et 2.

Un autre défi associé à la notion de changement climatique est la diversité de sa matérialisation, qui ne peut être capturée par une seule variable. Cette thèse vise ainsi à explorer les effets macroéconomiques de plusieurs aspects du changement climatique. Le changement climatique comprend une augmentation de la température annuelle moyenne mondiale (et locale), également connue sous le nom de réchauffement climatique, et des variations des régimes de précipitations. Ces régimes de précipitations sont très localisés et leur agrégation au niveau national est problématique ([Damania et al., 2020](#)). Le chapitre 1 explore cette dimension du changement climatique. Les modifications combinées des températures et des régimes de précipitations affectent les régimes de sécheresse, qui ont reçu peu d'attention dans la littérature macroéconomique. Le chapitre 2 se concentre sur cet aspect du changement climatique dans la région MENA.

Le changement climatique affecte non seulement les niveaux de températures et de précipitations, mais aussi leur volatilité. Cette volatilité accrue devrait augmenter l'incertitude économique et pourrait rendre les politiques d'adaptation plus difficiles à mettre en œuvre. Le chapitre 5 explore les effets de la volatilité des températures et des précipitations sur les migrations internationales en provenance des pays en développement. La modification de la fréquence et de l'intensité des événements extrêmes liés au climat, souvent appelés catastrophes naturelles (liées au climat), est une autre conséquence du changement climatique. Les chapitres 3 et 4 explorent les conséquences de ces événements sur les taux de change et la stabilité financière.

L'agrégation de résultats microéconomiques, également connue sous le nom d'approche énumérative, constitue un autre défi à relever pour identifier les effets du changement climatique. L'approche énumérative présente deux limites principales. Premièrement, l'agrégation de résultats microéconomiques, c'est-à-dire sectoriels, implique que les effets sur certains secteurs ne seront pas couverts et que l'évaluation ne sera pas exhaustive. Deuxièmement, l'agrégation des résultats microéconomiques ne tiendra pas compte de potentiels effets d'équilibre général. Ces limites justifient une approche macroéconomique. La revue de littérature du chapitre 1 discute ce sujet plus

en détail.

Enfin, cette thèse s'abstient de couvrir deux dimensions du changement climatique, ou étroitement liées à celui-ci. Tout d'abord, le changement climatique étant un processus hautement complexe et non linéaire, avec des points de basculement imprévus, les travaux empiriques qui s'appuient sur des données historiques ont une capacité relativement faible à fournir des informations sur les effets du changement climatique futur, en particulier pour les scénarios à plus fortes émissions. Par conséquent, cette thèse ne contient ni ne travaille à partir de projections. Deuxièmement, le changement climatique n'est qu'un aspect de problèmes environnementaux plus larges qui incluent, entre autres, la pollution et la perte de biodiversité. Ces questions, liées au changement climatique, n'entrent pas dans le cadre de cette thèse malgré leur importance indiscutable.

4 Contribution de cette thèse

Cette section présente la contribution de chaque chapitre, sur la base des éléments exposés précédemment.

4.1 Chapitre 1

Le changement climatique, c'est-à-dire l'évolution des températures et des précipitations, est de plus en plus reconnu comme l'un des défis majeurs de notre époque. Ses impacts environnementaux et socio-économiques croissants et mondiaux pèsent lourdement sur l'agenda international actuel et sur l'élaboration des politiques nationales. Son impact peut toutefois varier considérablement en fonction du niveau de développement économique, les pays à revenu faible ou intermédiaire supportant un coût disproportionné, même si leurs faibles émissions de carbone n'ont contribué que marginalement à l'augmentation des températures et, dans certains cas, ont contribué à les atténuer. Cette combinaison d'un impact élevé et d'une faible contribution historique au changement climatique peut impliquer des priorités différentes entre politiques d'atténuation et d'adaptation dans les pays en développement, notamment en utilisant des outils politiques axés sur l'obtention d'une croissance économique rapide pour assurer la convergence économique avec les pays développés et atteindre les objectifs de développement durable. Ces dilemmes politiques pour les pays en développement, entre l'augmentation du niveau de vie et la limitation des émissions de gaz à effet de serre, ainsi que le risque d'échecs de l'action collective découlant des différences de niveaux de développement, ont été reconnus par l'Accord de Paris sur

le climat de 2015 qui comprend des engagements de transfert annuel des économies avancées vers les pays en développement à hauteur de 100 milliards de dollars US.

Ce chapitre examine les conséquences macroéconomiques du changement climatique dans les pays en développement. La littérature récente et en plein essor qui relie les températures et les précipitations à la croissance de la production indique déjà un effet négatif sur la croissance économique dans la grande majorité des pays développés et en développement (Dell et al., 2012, 2014), avec de possibles effets non linéaires accélérés et cumulatifs (Burke et al., 2015c). En utilisant la méthode des projections locales avec une spécification quadratique, Acevedo et al. (2020) trouve également que les hausses de température réduisent la croissance de la production. Kahn et al. (2021) utilisent un modèle ARDL, sans terme quadratique, mais évaluent l'effet macroéconomique des écarts de température par rapport à leurs normes historiques, au lieu des niveaux des températures. En raison des caractéristiques distinctes des pays à revenu faible et intermédiaire (croissance démographique plus élevée, niveaux de développement et de résilience plus faibles, qualité institutionnelle moindre), l'impact du climat sur la croissance économique (ou le développement, approximé par le PIB par habitant) peut toutefois différer sensiblement de celui des pays à revenu élevé, tant en termes de portée que de mécanismes de transmission.

Pour aborder ces questions, nous avons choisi de nous concentrer sur l'évaluation de l'effet du réchauffement climatique, défini comme l'écart positif durable des températures par rapport à leurs normes historiques, sur la croissance réelle du PIB et du PIB par habitant, en combinant les données économiques et climatiques pour obtenir un panel de 126 pays à revenu faible et intermédiaire sur la période 1960-2017. Nous contrôlons par les écarts durables des précipitations par rapport à leurs normes historiques afin d'évaluer si les effets du changement climatique sur la production proviennent principalement du réchauffement de la planète ou des précipitations.

Pour compléter notre analyse, nous mettons en lumière les canaux de transmission en décomposant le PIB par ses composantes de demande et sectorielles. Enfin, nous testons l'impact de variables politiques présentant un intérêt particulier pour les pays en développement afin d'évaluer dans quelle mesure elles pourraient être efficaces pour atténuer l'effet macroéconomique du réchauffement climatique sur la production.

Cet article contribue à la littérature existante en introduisant des innovations méthodologiques significatives. Premièrement, nous nous écartons des études antérieures dont les estimations centrales sont obtenues à partir d'échantillons comprenant des pays de tous niveaux de revenu. Celles-ci peuvent sous-estimer l'impact sur les pays en développement, très exposés aux risques du changement climatique. Afin d'aborder les questions cruciales de politique financière et d'aide internationale

pour atteindre les objectifs de développement durable, nous nous concentrons exclusivement sur les pays à revenu faible et intermédiaire.

Deuxièmement, nous abandonnons l'hypothèse selon laquelle la productivité du travail est le principal canal de transmission et nous envisageons la possibilité d'une transmission par la productivité des terres. Par conséquent, nous construisons les observations climatiques annuelles par pays en adoptant une approche agnostique et nous les calculons comme la moyenne non pondérée des observations climatiques maillées à l'intérieur des frontières terrestres.

Troisièmement, nous nous écartons de l'utilisation des chocs météorologiques et adoptons une variante de la méthode des projections locales (Jordà, 2005) introduite dans Ramey and Zubairy (2018) pour capturer les effets d'écarts durables des températures et des précipitations par rapport à leurs normes historiques sur la croissance de la production par habitant, pour différents horizons. Outre le fait que cette stratégie est plus proche de la question de politique générale qui nous intéresse, à savoir l'évaluation des effets du changement climatique plutôt que des chocs météorologiques, elle est à même de réduire le biais introduit par l'utilisation du choc contemporain tout en contrôlant pour les valeurs futures de la variable indépendante au sein de l'horizon (Ramey and Zubairy, 2018).

Quatrièmement, nous complétons cette analyse en inspectant les mécanismes de transmission sous-jacents, tant du côté de la demande que de l'offre, avant de discuter du rôle des variables politiques. Nos résultats fournissent des indications supplémentaires sur la façon dont le changement climatique affecte la croissance économique dans les pays en développement.

Dans un premier exercice, nous constatons que le réchauffement climatique a un impact négatif substantiel et durable sur la croissance du PIB (et du PIB par habitant) dans les pays en développement. Dans le pays médian, une augmentation durable de la température de 1°C fait baisser le taux de croissance annuel du PIB réel par habitant de 1,25 point de pourcentage (0,82–1,69 p.p., intervalle de confiance de 90%), tandis que l'effet des écarts de précipitations n'est pas économiquement significatif, conformément aux études récentes. Nous confirmons ensuite la robustesse de ce résultat en présentant une série de tests qui consistent à exclure la Chine, la Russie et l'Inde, trois pays en développement qui ont eu une contribution non négligeable au changement climatique et qui pourraient introduire un problème de causalité inverse, en utilisant le PIB réel au lieu du PIB réel par habitant comme variable dépendante, en contrôlant l'occurrence de catastrophes naturelles, les niveaux de températures et de précipitations et les effets des mouvements des termes de l'échange, en utilisant les erreurs standard de Driscoll and Kraay (1998), et en ajoutant des tendances temporelles linéaires

et quadratiques spécifiques au pays pour contrôler les changements graduels des taux de croissance des pays qui peuvent être dus à des facteurs variant dans le temps spécifiques au pays.

Dans le deuxième exercice sur les mécanismes de transmission utilisant à la fois la demande et les composantes sectorielles, nous constatons que le réchauffement climatique augmente la part relative de la consommation privée et diminue celle de l'investissement, reflétant peut-être des exigences de subsistance plus contraignantes dans un contexte de baisse de la production et des revenus. Nous constatons également que le réchauffement climatique entraîne une augmentation de la part de la valeur ajoutée agricole dans le PIB au détriment de la valeur ajoutée industrielle, malgré une baisse de la croissance de la production agricole, ce qui conduit à un renforcement potentiel du "problème alimentaire" : en raison des besoins de subsistance, les pays en développement ont tendance à consacrer une part plus importante de leurs ressources relativement rares à la production et à la consommation alimentaires. La décomposition sectorielle et de la demande du PIB indique une évolution vers des gains à court terme au détriment de l'investissement, de la diversification économique et de la prospérité future.

Dans un troisième exercice, nous examinons le rôle de plusieurs politiques d'adaptation ou de maladaptation potentielles, telles que l'électrification, la déforestation, la consommation de charbon, le régime de change ou la qualité des institutions, pour atténuer l'effet négatif du réchauffement climatique sur la croissance de la production dans les pays en développement. Nous n'examinons pas les effets de ces politiques sur le changement climatique lui-même par le biais de l'augmentation des émissions de gaz à effet de serre, c'est-à-dire leur compatibilité ou non avec les efforts d'atténuation. Certaines de ces politiques pourraient donc être considérées comme des politiques de maladaptation. L'inférence causale de cet exercice est plus difficile, mais les résultats semblent indiquer qu'un niveau de développement plus élevé est associé à un effet moindre du réchauffement climatique sur la croissance de la production par habitant.

En résumé, puisque nos résultats indiquent également que le développement devient plus difficile à poursuivre à mesure que les températures augmentent, nous constatons que le réchauffement climatique renforce les pièges du développement, menace les gains de niveau de vie, en particulier depuis le début du 21^e siècle, et entravera la poursuite de l'adaptation au changement climatique dans les pays en développement.

4.2 Chapitre 2

La pénurie d'eau a toujours été un élément déterminant du développement économique des membres de la Ligue arabe, de l'Iran et de la Turquie. La région connaît les niveaux de stress hydrique les plus aigus au monde, et le stress hydrique atteint des niveaux critiques dans une majorité de ses pays. L'évolution des dynamiques de sécheresse résulte de l'évolution de la combinaison des températures et des précipitations et continuera d'évoluer à mesure que le climat mondial changera. L'environnement difficile de la région la rend particulièrement vulnérable au changement climatique, et les efforts et politiques d'adaptation sont une nécessité absolue pour favoriser l'émergence d'économies résilientes et renforcer les bases d'une croissance inclusive et d'un développement durable. Cela se traduit par le fait que l'Égypte accueille la COP27 en 2022 et les Émirats arabes unis la COP28 en 2023. Une compréhension plus approfondie des effets des sécheresses sur l'économie permettrait de mieux élaborer et calibrer les politiques d'adaptation dans la région.

Ce chapitre combine des données macroéconomiques et climatiques afin d'évaluer empiriquement les effets de sécheresses s'écartant durables de leurs normes historiques sur la croissance du PIB réel dans les pays membres de la Ligue arabe, en Iran et en Turquie. Les conditions climatiques sèches affectent la production agricole, la mortalité du bétail et les coûts de construction et d'entretien des infrastructures, en plus d'un large éventail d'autres impacts. Ce chapitre teste l'hypothèse selon laquelle les sécheresses affectent négativement la croissance du PIB dans la région. Il teste également l'hypothèse selon laquelle la croissance du PIB des pays exportateurs de pétrole est moins affectée par les sécheresses. Plusieurs pays de la région sont fortement dépendants du secteur pétrolier et des exportations de pétrole. Comme l'offre est largement indépendante des conditions climatiques dans les pays producteurs et que la demande est exogène, une plus grande dépendance à l'égard de ce secteur pourrait être associée à un effet moindre des sécheresses sur les fluctuations macroéconomiques.

Une littérature empirique récente et croissante a cherché à faire la lumière sur les effets macroéconomiques du changement climatique en utilisant des données de panel. Ces études se sont principalement concentrées sur la relation entre les températures et la production (Dell et al., 2012; Burke et al., 2015c; Acevedo et al., 2020) et ont trouvé une relation négative entre ces deux variables. Kotz et al. (2021) étudie cette relation en utilisant des données sur les températures quotidiennes et Colacito et al. (2019) montre qu'aux États-Unis, les températures affectent la production agrégée à travers un large éventail de secteurs. Kahn et al. (2021) s'écartent de l'utilisation des températures annuelles moyennes et considèrent plutôt l'écart des températures par rapport à leurs

normes historiques afin de se concentrer sur les *changements* de température plutôt que sur les *niveaux* de température. [de Bandt et al. \(2021\)](#) suivent cette approche et adoptent une stratégie empirique qui permet d'évaluer les effets des écarts de température durables par rapport à leurs normes historiques sur la croissance de la production. Ces articles contrôlent généralement pour les précipitations, mais les résultats de cette littérature indiquent principalement une absence de relation avec le niveau de production ou la croissance de la production. Cela peut s'expliquer par plusieurs problèmes qui se posent lors de l'agrégation des données de précipitations au niveau des pays ([Damania et al., 2020](#)). Peu d'attention a été accordée aux effets macroéconomiques des changements combinés des températures et des précipitations.

Ce chapitre contribue à la littérature à plusieurs égards. Premièrement, il évalue les effets macroéconomiques d'une évolution durable des conditions de sécheresse, une conséquence du changement climatique qui a été relativement négligée par les macroéconomistes. Deuxièmement, il se concentre sur une région qui sera fortement touchée par le changement climatique bien qu'elle ait peu contribué aux émissions historiques de CO₂ [4,4 % des émissions historiques mondiales de CO₂ selon les données de Bod17, évitant ainsi les problèmes de causalité inverse dans la stratégie empirique. Troisièmement, il met en lumière les mécanismes de transmission potentiels et les effets hétérogènes en tenant compte de la diversité des pays de la région.

Pour évaluer la relation entre les écarts durables de la sécheresse par rapport à leurs normes historiques et la croissance de la production, ce document utilise les données macroéconomiques des bases de données [World Bank - WDI \(2021\)](#) et [IMF - IFS \(2020\)](#) et l'SPEI de [Vicente-Serrano et al. \(2010\)](#) qui mesure les sécheresses. L'indice de sécheresse est obtenu comme l'opposé du SPEI de sorte qu'une augmentation de l'indice correspond à des conditions climatiques plus sèches. Des variables de contrôle supplémentaires sont obtenues à partir de plusieurs autres sources. L'ensemble de données de panel a une fréquence annuelle, couvre la période 1960–2018 et inclut 21 pays membres de la Ligue arabe, l'Iran et la Turquie. Bahreïn est exclu de l'échantillon en raison de l'absence de variables climatiques. La stratégie empirique utilise la méthode des projections locales introduite dans [Jordà \(2005\)](#) et s'appuie sur [de Bandt et al. \(2021\)](#) pour évaluer les effets des déviations durables de l'indice de sécheresse par rapport à ses normes historiques sur la croissance réelle du PIB dans la région. Cette stratégie permet de faire un pas en avant dans l'évaluation des effets du changement climatique plutôt que des chocs météorologiques.

Les résultats montrent que les sécheresses entraînent une baisse du taux de croissance contemporain de la production dans les pays importateurs de pétrole et n'ont aucun effet statistiquement significatif sur le taux de croissance de la production dans les

pays exportateurs de pétrole, puisque les résultats pour ce groupe ne sont que faiblement significatifs dans la spécification principale et ne résistent pas à plusieurs vérifications de robustesse. Les résultats montrent également que les effets ne se renforcent pas à mesure que l'horizon augmente et disparaissent après un an. Comme ces effets ne réapparaissent pas par la suite, les sécheresses n'ont pas d'effets permanents sur la croissance de la production, mais entraînent des pertes durables du niveau de production dans les pays importateurs de pétrole. La violence civile semble être l'un des canaux de transmission des effets des sécheresses sur la croissance. Le secteur agricole est un autre canal par lequel les sécheresses diminuent la croissance du PIB réel, et l'irrigation ne s'est pas avérée être une stratégie d'adaptation efficace au niveau macroéconomique. Ces résultats mettent en lumière l'importance de la diversification économique, et les risques qui y sont associés.

4.3 Chapitre 3

Les catastrophes naturelles liées au climat ont récemment eu des effets dramatiques et croissants sur le secteur réel et les populations des pays en développement. Ces effets sont bien documentés et identifiés par une abondante littérature, mais les conséquences monétaires et financières de ces événements ont reçu beaucoup moins d'attention, malgré leur importance pour la stabilité macroéconomique, la reconstruction post-catastrophe et le développement durable. Cela se produit dans un contexte où le changement climatique modifiera la fréquence et l'intensité de ces catastrophes naturelles tout en réduisant les revenus et la capacité d'adaptation des pays en développement.

Cet article combine des données macroéconomiques avec des données météorologiques primaires pour construire un indice de mésalignement du taux de change réel et évaluer comment le mésalignement du taux de change réel est affecté par les catastrophes naturelles liées au climat. Un mésalignement du taux de change réel important pourrait créer ou renforcer des déséquilibres macroéconomiques et pourrait menacer la reprise économique après une catastrophe. D'un point de vue théorique, les effets des catastrophes naturelles liées au climat sur le mésalignement du taux de change réel sont ambigus. Plusieurs conséquences potentielles de tels événements peuvent entraîner des dépréciations du taux de change réel en raison de pénuries de devises étrangères : augmentation des importations pour compenser les perturbations de l'offre domestique et obtenir des intrants pour la reconstruction, baisse des entrées d'investissements directs étrangers et diminution de la production agricole et des exportations, entre autres effets potentiels. Au contraire, plusieurs

effets des catastrophes naturelles liées au climat peuvent conduire à une appréciation du taux de change réel : augmentation des exportations en raison de la hausse de la demande étrangère et de l'augmentation des envois de fonds des migrants (effet diaspora), aide publique au développement et entrées de capitaux pour la reconstruction, ainsi qu'inflation due aux pénuries. Ces effets potentiellement contradictoires rendent une approche empirique appropriée.

La littérature empirique sur les effets économiques des catastrophes naturelles s'est principalement concentrée sur le secteur réel et a trouvé des effets négatifs sur la croissance de la production (Felbermayr and Gröschl, 2014; Noy, 2009; Strobl, 2012), le stock de capital (Acevedo, 2016), les flux commerciaux (El Hadri et al., 2018, 2019) et les finances publiques (Acevedo, 2014; Klomp, 2017), entre autres. Klomp (2020) et Parker (2018) ont évalué les effets monétaires en se concentrant sur l'inflation, mais les effets des catastrophes naturelles sur le taux de change ont reçu peu d'attention. Un autre volet de la littérature s'est concentré sur l'estimation des indices de mésalignement du taux de change réel. L'approche comportementale a été établie dans Edwards (1989) et développée dans ElBadawi (1994) et Clark and MacDonald (1998), entre autres. Des approches alternatives sont discutées dans Noureldin (2018), y compris leurs inconvénients dans le cas des pays en développement. Ces indices de mésalignement du taux de change réel ont été utilisés pour évaluer l'impact du mésalignement monétaire sur une série de variables, dont la croissance de la production (ElBadawi et al., 2012), la diversification des exportations (Sekkat, 2016) et les conflits civils (Ambaw and Sim, 2019), entre autres.

Ce chapitre contribue à la littérature à plusieurs égards. Premièrement, il étudie les conséquences monétaires et financières des catastrophes naturelles liées au climat dans les pays en développement, une dimension essentielle de la stabilité macroéconomique qui a été relativement négligée dans la littérature empirique sur les catastrophes naturelles. Deuxièmement, il fournit des estimations par pays du mésalignement du taux de change réel sur une longue période (1960–2019) en se basant sur l'approche comportementale. Troisièmement, alors que les effets macroéconomiques du mésalignement du taux de change réel ont été largement étudiés, ce chapitre ajoute à une littérature encore rare sur les déterminants du mésalignement du taux de change réel.

Ce chapitre teste l'hypothèse selon laquelle le mésalignement du taux de change réel est affecté par les catastrophes naturelles liées au climat dans les pays en développement. Pour ce faire, il utilise les données du taux de change effectif réel de Darvas (2012) et les données macroéconomiques des bases de données des Indicateurs du développement dans le monde et des Statistiques financières internationales, complétées par plusieurs autres sources. Les données sur les catastrophes naturelles

liées au climat proviennent d'EMDAT (CRED, 2020) et d'ifo GAME, et ce chapitre construit des mesures supplémentaires des catastrophes naturelles à partir d'ensembles de données météorologiques primaires. L'ensemble de données de panel couvre 109 pays à revenu faible et intermédiaire à une fréquence annuelle au cours de la période 1960–2019. La stratégie empirique repose sur un modèle de panel à effets fixes, complété par la méthode des projections locales (Jordà, 2005) qui permet de mettre en évidence les effets dynamiques des catastrophes naturelles liées au climat sur le mésalignement du taux de change réel.

Les résultats montrent que les catastrophes naturelles liées au climat entraînent une surévaluation temporaire de la monnaie réelle dans les pays en développement : Une occurrence produit une augmentation de 0,015 unité de l'indice de mésalignement du taux de change réel. Cet effet tend à augmenter lorsque l'on utilise des mesures des catastrophes naturelles basées sur des données climatiques primaires et s'explique principalement par les pays à revenu intermédiaire, les petits pays et les pays exposés aux catastrophes, ainsi que les petits États insulaires en développement. Une évaluation des canaux de transmission indique une augmentation de l'inflation, bien que les preuves soient incomplètes, ainsi qu'une augmentation des transferts de fonds et des entrées nettes de capitaux. Ces résultats soulignent l'importance de réponses politiques bien calibrées afin de ne pas affecter davantage la stabilité macroéconomique après avoir été frappé par des catastrophes naturelles liées au climat.

4.4 Chapitre 4

Les chocs météorologiques majeurs sont particulièrement destructeurs dans les pays à revenu faible ou intermédiaire, en termes d'infrastructures, de richesse privée et de vies humaines. Les ouragans Matthew en Haïti en 2016 et Irma dans les Caraïbes en 2017, les glissements de terrain à Freetown en 2017, les cyclones Idai au Mozambique en 2019 ou l'ouragan Eta en Amérique centrale en 2020 ont tous fait des centaines de morts. Les dommages physiques causés par ces événements sont massifs et on peut s'attendre à ce qu'ils altèrent les performances du secteur bancaire dans ces économies, entre autres effets.

Ce chapitre combine des données macroéconomiques sur le secteur financier avec des données sur les catastrophes naturelles liées au climat pour évaluer comment ces événements affectent la stabilité du secteur financier. Les effets des catastrophes naturelles liées au climat sur la stabilité du secteur financier sont ambigus. Les besoins de financement augmentent après les destructions physiques en raison des besoins de reconstruction. De tels événements peuvent donc augmenter les perspectives d'affaires

pour le secteur financier. Cependant, la majorité des pays en développement sont caractérisés par un secteur informel important qui pourrait entraver les perspectives d'affaires liées à la reconstruction pour le secteur financier. En outre, la destruction de capital augmente le profil de risque des emprunteurs, et leurs dépôts pourraient diminuer. Ces effets potentiellement contradictoires rendent une approche empirique appropriée.

Cet article teste l'hypothèse selon laquelle le secteur financier des pays en développement est affecté par les catastrophes naturelles liées au climat. Pour ce faire, il utilise l'ensemble de données mensuelles de la base FSI du FMI combiné aux données sur les catastrophes naturelles liées au climat d'EMDAT (CRED, 2020). L'ensemble de données mensuelles en panel couvre 22 pays à revenu faible et intermédiaire au cours de la période 2005m3-2018m12 (soit une période de 166 mois). La stratégie empirique s'appuie sur la méthode des projections locales (Jordà, 2005) qui permet de mettre en évidence les effets dynamiques des catastrophes naturelles liées au climat sur les indicateurs de stabilité financière.

Un large pan de la littérature empirique sur les conséquences des catastrophes naturelles sur la stabilité financière s'est concentré sur le secteur bancaire américain. Barth et al. (2022a) constate que les catastrophes naturelles entraînent une augmentation des taux de dépôt, et Barth et al. (2022b) que les taux de prêt augmentent davantage que les taux de dépôt. Cette augmentation de la demande de prêts, y compris dans le secteur immobilier (Bos et al., 2022), compense les pertes et augmente *in fine* les bénéfices des grandes banques (Blickle et al., 2021). En évaluant les conséquences spatiales des catastrophes naturelles sur le secteur bancaire, Cortés and Strahan (2017) et Ivanov et al. (2022) constatent que les hausses de la demande de crédit consécutives aux catastrophes naturelles sont partiellement couvertes par la réallocation du capital, et les résultats de Duqi et al. (2021) suggèrent que l'activité économique se redresse plus rapidement là où le secteur bancaire est moins compétitif. Dans d'autres pays à revenu élevé, Hosono et al. (2016) constate que les tremblements de terre constituent un choc négatif d'offre de prêts au Japon, contrairement aux effets observés aux États-Unis, tandis que les résultats de Koepke and Paetzold (2020) indiquent l'existence d'effets de réallocation du capital en Allemagne, confirmant les résultats de Cortés and Strahan (2017) et Ivanov et al. (2022).

Contrairement à d'autres études, Noth and Schuwer (2018) affirment que les conséquences des catastrophes naturelles affaiblissent la stabilité des banques aux États-Unis en augmentant la probabilité de défaillance et le ratio de prêts non performants, entre autres, et les résultats dans Klomp (2014b) suggèrent que ce résultat peut être généralisé à un plus grand nombre de pays.

Les conséquences des catastrophes naturelles sur le secteur bancaire des pays en développement pourraient être différentes de celles observées aux États-Unis et dans d'autres pays à revenu élevé, bien que les études empiriques soient plus rares. Dans les Caraïbes, les banques sont confrontées à des retraits de dépôts et subissent un choc de financement négatif après les ouragans, auxquels elles répondent en réduisant l'offre de prêts et en puisant dans les actifs liquides [Brei et al. \(2019\)](#). Cet effet négatif sur le crédit bancaire peut être particulièrement préjudiciable à l'activité économique dans un contexte de surliquidité bancaire dans plusieurs régions en développement telles que l'Amérique centrale ([Deléchat et al., 2014](#)) et l'Afrique ([Beck and Cull, 2014](#)), y compris dans la CEMAC ([Avom and Eyeffa Ekomo, 2007](#); [Beguy, 2012](#)) et l'UEMOA ([Doumbia, 2011](#)).

Ce chapitre contribue à la littérature en étudiant les conséquences des catastrophes naturelles liées au climat sur la stabilité financière des pays en développement, une dimension essentielle de la stabilité macroéconomique et donc des perspectives de développement. Pour ce faire, il utilise des données macroéconomiques à haute fréquence.

Les résultats montrent que les catastrophes naturelles liées au climat entraînent une augmentation des prêts non performants dans les pays en développement : une occurrence produit une augmentation de 1,93 point de pourcentage des prêts non performants quatre à cinq mois après l'événement. Les banques réagissent aux catastrophes naturelles liées au climat en augmentant leurs provisions pour prêts non performants au fur et à mesure que celles-ci se matérialisent. L'horizon est plus long dans ce cas, puisque l'effet devient positif et statistiquement significatif dix à onze mois après l'événement.

4.5 Chapitre 5

Le changement climatique est souvent associé aux flux migratoires dans le débat public. En raison de l'élévation du niveau de la mer, de l'érosion côtière, de la hausse des températures, de la désertification et de l'apparition de catastrophes naturelles liées au climat, la migration est perçue comme une stratégie d'adaptation, du moins au niveau personnel. Toutefois, la relation entre le climat et la migration est loin d'être évidente, car les deux phénomènes sont très complexes. Comme le note le Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) : "La confiance dans les projections quantitatives de l'évolution des migrations est faible, en raison de sa nature complexe

et multi-causale" ⁷. Outre les changements progressifs des températures et des régimes de précipitations et les événements à déclenchement rapide, le changement climatique génère également des incertitudes en augmentant la variabilité des températures et des précipitations.

Dans ce chapitre, nous combinons des données sur la migration, le climat et la macroéconomie afin d'évaluer l'effet de la variabilité climatique sur la migration internationale des pays à revenu faible et intermédiaire. Pour mieux prendre en compte l'incertitude liée au changement climatique et comprendre dans quelle mesure la migration peut constituer une stratégie de diversification des risques dans ce contexte, nous nous concentrons sur la variabilité climatique, plutôt que sur les événements à déclenchement lent ou rapide, comme cela a été largement étudié dans la littérature. Les hausses de température et la baisse des précipitations peuvent affecter les migrations par leur impact sur les rendements et les revenus agricoles, entre autres canaux, mais l'incertitude associée à la variabilité climatique pourrait avoir des effets économiques importants puisque l'adaptation pourrait être encore plus difficile, dans un contexte de ressources limitées.

Alors que la littérature a mis en évidence le rôle de frein joué par la pauvreté dans le lien entre climat et migration, nous testons si l'accès aux services financiers formels peut modifier l'impact de la variabilité climatique sur la migration internationale des pays à faible revenu. L'effet attendu de cette variable est ambigu. D'une part, l'accès à l'épargne et au crédit formels peut aider les individus et les ménages à mieux faire face *ex-ante* (investissements pour diversifier les revenus ou mieux faire face aux chocs climatiques) ou *ex-post* (lissage des revenus) à la variabilité climatique et limiter leur volonté de se déplacer. D'un autre côté, cette meilleure résistance à la variabilité climatique peut empêcher que leur revenu ne chute trop, leur laissant une marge de manœuvre financière suffisante pour se déplacer s'ils le souhaitent. Dans ce cas, l'inclusion financière supprime la contrainte financière à l'émigration.

Ce chapitre contribue à la littérature de deux manières. Premièrement, il s'ajoute à une littérature encore rare qui évalue les effets macroéconomiques de la variabilité climatique sur les migrations internationales. Deuxièmement, il tente d'identifier un nouveau mécanisme par lequel l'inclusion financière pourrait constituer une politique d'adaptation dans les pays en développement.

⁷IPCC, 2014 : Résumé à l'intention des décideurs. In : *Climate Change 2014 : Impacts, adaptation et vulnérabilité. Partie A : Aspects mondiaux et sectoriels. Contribution du groupe de travail II au cinquième rapport d'évaluation du Groupe d'experts intergouvernemental sur l'évolution du climat* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, et L.L. White (eds.)]. Cambridge University Press, Cambridge, Royaume-Uni et New York, NY, USA, pp. 1-32.

Pour tester l'hypothèse selon laquelle l'inclusion financière modifie l'impact de la variabilité climatique sur les migrations internationales, nous utilisons les données climatiques de [Matsuura and Willmott \(2019a\)](#), les données sur les stocks de migrants bilatéraux de [UNDESA-PD \(2020\)](#) et les données macroéconomiques de [World Bank - WDI \(2021\)](#), complétées par plusieurs variables. En raison des contraintes de profondeur temporelle de la base de données Global Findex, nous substituons à l'inclusion financière le crédit domestique au secteur privé, mesuré en pourcentage du PIB. L'ensemble de données de panel couvre sept périodes de cinq ans, de 1986 à 2020, et comprend 114 pays à revenu faible ou intermédiaire. Notre cadre empirique repose sur des estimateurs à effets fixes et nous interagissons entre la variabilité des températures et le crédit domestique pour évaluer l'effet de l'inclusion financière sur la relation entre la variabilité du climat et la migration internationale.

Nos premiers résultats confirment les conclusions de la littérature [([Beine and Parsons, 2015, 2017](#); [Cattaneo and Peri, 2016](#), amon d'autres) et montrent que la variabilité des températures conduit à une augmentation de la migration internationale vers les pays voisins et que cet effet est porté par les pays à faible revenu. La migration vers les pays OECD n'est pas affectée. Dans un deuxième temps, les résultats indiquent que l'inclusion financière réduit l'effet de la variabilité des températures sur l'émigration dans les pays à faible revenu, ce qui suggère que l'accès au crédit permet de réduire l'incertitude du revenu ou de la richesse associée à une plus grande variabilité des températures.

Nous testons la robustesse de ce résultat en construisant une mesure alternative de la variabilité des températures et en contrôlant pour les écarts des températures par rapport à leurs normes historiques. Les résultats sont également robustes si l'on exclut les variables de contrôle de la régression. Enfin, nous testons si la variabilité des précipitations affecte la migration des pays à faible revenu et si l'inclusion financière affecte également cette relation : nos résultats ne montrent pas d'effet robuste, comme cela est courant dans la littérature évaluant les effets macroéconomiques du changement climatique ([Dell et al., 2012](#); [Kahn et al., 2021](#); [de Bandt et al., 2021](#)). Dans ces spécifications, les effets de la variabilité des températures sur la migration et l'effet atténuant de l'inclusion financière restent robustes.

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