



**Essays on Climate Change, Institutional Quality, Economic Growth, and Poverty
Vulnerability: Macro–Micro Perspectives from Sub-Saharan Africa**

**Submitted by: Desalegn Dawit Chamma
Economics Department, Addis Ababa University**

**Main Supervisor:
Professor Paul Nystedt
Professor of Economics at Jönköping University**

**Co-Supervisors:
Dr. Tekie Alemu: Associate Professor of Economics at Addis Ababa University
Dr. Johannes Hagen: Associate Professor of Economics at Jönköping University**

**A Dissertation Submitted to the Department of Economics, School of Graduate
Studies, Addis Ababa University, in Partial Fulfillment of the Requirements for
the Degree of Doctor of Philosophy in Economics.**


**Addis Ababa University
Addis Ababa, Ethiopia
June 22, 2025**


Addis Ababa University
School of Graduate Studies

This is to certify that the dissertation prepared by Desalegn Dawit, entitled '*Essays on Climate Change, Institutional Quality, Economic Growth, and Poverty Vulnerability: Macro–Micro Perspectives from Sub-Saharan Africa*,' submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Economics, complies with the university's regulations and meets the accepted standards of originality and academic quality.

Signed by the Examining Committee:

Examinaer Dr. Alemayehu Seyoum: Signature  Date 02/07/2025
(External)

Examinaer Dr. Zerayehu Sime: Signature  Date 27/06/25
(Internal)

Principal Supervisor: Professor Paul Nystedt: Signature  Date 25/6 2025

Co-Supervisor: Dr. Tekie Alemu: Signature  Date 2/7/25

Co-Supervisor: Dr. Johannes Hagen: Signature  Date: June 27, 2025

Chair of Department or Graduate Programm Coordinator

Statement of the Author

I, Desalegn Dawit, hereby declare that this dissertation titled “*Essays on Climate Change, Institutional Quality, Economic Growth, and Poverty Vulnerability: Macro–Micro Perspectives from Sub-Saharan Africa*” is my original work and has not been presented for a degree in any other university or institution.

All sources of materials used in the dissertation have been duly acknowledged, and proper citations have been provided in accordance with academic standards. This work has been conducted in compliance with the ethical guidelines and regulations of Addis Ababa University.

Furthermore, I grant Addis Ababa University the right to archive and distribute this dissertation in print and electronic formats, in accordance with institutional policies.

Desalegn Dawit Chamma

Addis Ababa University

June 22, 2025

I. Table of Contents

CHAPTER 1: GENERAL INTRODUCTION.....	1
1.1 BACKGROUND	1
1.2 OBJECTIVES OF THE STUDY	4
1.2.1 <i>General Objective:</i>	4
1.2.2 <i>Specific Objectives</i>	4
1.3 SIGNIFICANCE OF THE STUDY.....	4
1.4 SCOPE OF THE STUDY.....	5
1.5 LIMITATIONS OF THE STUDY.....	5
1.6 STRUCTURE OF THE STUDY	6
CHAPTER 2: CLIMATE CHANGE AND ECONOMIC GROWTH IN SUB-SAHARAN AFRICA: AN EMPIRICAL ANALYSIS OF AGGREGATE AND SECTOR LEVEL GROWTH	7
2.1 INTRODUCTION	8
2.2 LITERATURE REVIEW:.....	11
2.2.1 <i>Effects of Climate Change on Aggregate and Sector-level Growth</i>	11
2.3 THEORETICAL AND EMPIRICAL BACKGROUND	14
2.3.1 <i>Theoretical Framework</i>	14
2.3.2 <i>Empirical Framework</i>	17
2.4 DATA SOURCES AND VARIABLE MEASUREMENT.....	22
2.5 RESULTS.....	25
2.5.1 <i>Descriptive Statistics</i>	25
2.5.2 <i>Empirical Results</i>	28
2.5.3 <i>Discussion</i>	33
2.6 CONCLUSION AND RECOMMENDATION	36
REFERENCE:	45
CHAPTER 3: CORRUPTION, POLITICAL INSTABILITY, CLIMATE CHANGE, AND ECONOMIC GROWTH IN SUB-SAHARAN AFRICAN COUNTRIES	54
3.1 INTRODUCTION	55
3.2 LITERATURE.....	57
3.2.1 <i>Climate change, Institutional quality, and Economic Growth</i>	57
3.3 THEORETICAL FRAMEWORK	58
3.3.1 <i>Conceptual Model Illustration</i>	60
3.4 DATA SOURCES AND VARIABLES	61
3.5 METHODS.....	62
3.5.1 <i>Empirical Framework</i>	62
3.5.2 <i>Model Specification</i>	63

3.5.3 <i>Long-Run Multiplier</i>	64
3.6 RESULTS AND DISCUSSION.....	65
3.6.1 <i>Descriptive Results</i>	65
3.6.2 <i>Empirical Results</i>	66
3.6.3 <i>Discussion</i>	73
3.6.4 <i>Robustness Check and Diagnostic Tests</i>	74
3.7 CONCLUSION AND POLICY IMPLICATIONS.....	75
3.7.1 <i>Conclusion</i>	75
3.7.2 <i>Policy Implications</i>	75
REFERENCE:	77
CHAPTER 4: CLIMATE VARIABILITY AND POVERTY VULNERABILITY AMONG ETHIOPIAN SMALLHOLDERS: A SHORT-PANEL ANALYSIS	87
4.1 INTRODUCTION	88
4.2 LITERATURE REVIEW.....	89
4.2.1 <i>Climate Variability, Poverty Vulnerability, and the Role of Shocks</i>	89
4.3 THEORETICAL BACKGROUND: HOUSEHOLD VULNERABILITY TO POVERTY	90
AND ECONOMIC SHOCKS	90
4.4 EMPIRICAL FRAMEWORK	92
4.5 DATA AND VARIABLES	93
4.6 METHOD	94
4.6.1 <i>Measuring Poverty Vulnerability</i>	95
4.7 RESULT AND DISCUSSION	96
4.7.1 <i>Descriptive statistics</i>	96
4.7.2 <i>Household and Regional Determinants of Per Adult-Equivalent Consumption</i>	101
4.7.3 <i>Random-Effects and Total Impact Analysis</i>	101
4.7.4 <i>Poverty Vulnerability Estimates</i>	102
4.7.5 <i>Robustness Check</i>	105
4.7.6 <i>Discussion</i>	106
4.8 CONCLUSION AND POLICY IMPLICATIONS.....	107
4.8.1 <i>Conclusion</i>	107
4.8.1 <i>Policy Implications</i>	107
REFERENCE:	108
CHAPTER 5: GENERAL DISCUSSION, CONCLUSION, AND POLICY IMPLICATION	113
5.1 GENERAL DISCUSSION	113
5.2 GENERAL CONCLUSION	115
5.3 GENERAL POLICY IMPLICATION.....	116

REFERENCE:	117
------------------	-----

II. List of Tables

Table 2.1: Descriptive statistics and an explanation of the variables.....	27
Table 2.2: Estimation results of the fixed effects model.....	29
Table 2.3: Estimation results of Seemingly Unrelated Regression Model	32
Table 2.4: Estimation results of the fixed effects model With and Without Lag	41
Table 2.5 Threshold-Based Analysis of Climate Extremes on GDP Per Capita	42
Table 2.6 Effects of Temperature Thresholds on GDP Per Capita.....	43
Table 2.7 Summary Table of Diagnostic Tests for SUR	44
Table 3.1: Table Descriptive Statistics Two-year averaged	65
Table 3.2: Dynamic panel-data estimation results of GDPPC model.....	67
Table 3.3: Dynamic Panel Estimation: Institutional Quality (Corruption as Dependent Variable)	68
Table 3.4: Dynamic panel-data estimation of Political Instability model.....	70
Table 3.5: Dynamic panel-data estimation CO2 Emission model	71
Table 3.6: Long-run relationship between GDPPC, CO2, Corruption, and Political instability	72
Table 3.7: Pairwise Correlations Report	76
Table 3.8: Bootstrap results of Granger-causality regression estimation.....	76
Table 4.1: Household Level Poverty decomposition (poverty line 3781ETB = 1.24USD).....	97
Table 4.2: Poverty Status of Households/category	97
Table 4.3: Summary statistics of the variables: mean and standard deviation by year: 2011/12 – 2015/16	98
Table 4.4: Estimation Results of Multilevel (two-level) Random Coefficient Model.....	99
Table 4.5: Decomposition of Estimated Vulnerability: A Summary	102
Table 4.6 Regional mean household vulnerability by year	103
Table 4.7: Estimation Results on Climate Variability’s Impact on Poverty Vulnerability	105
Table 4.8: 2SLS-IV in a Two-Level Model Estimation	106

III. List of Figures

Figure 2.1: The direct and indirect effects of climate change on the economic growth of SSA countries at both the sector and aggregate levels. 17

Figure 2.2: Average values of the coefficient of variations for precipitation, temperature, and GDP per capita per country (1970-2019).....26

Figure 2.3: Effects of temperature and the squared coefficient of variations in precipitation on per capita GDP.30

Figure 3.1. Integrated Conceptual Model: Climate, Institutions, and Growth Dynamics61

Figure 4.1: Poverty and Risk-induced Vulnerability103

Figure 4.2: Vulnerability distribution by year (on the left) and by region (on the right)..... 104

IV. List of Appendices

Appendix 2.1: Supplementary Logarithmic Transformations and Differentiation in the Model38

Appendix 2.2: Additional information on climate change data indicators39

Appendix 2.3: List of Countries in the Study40

Appendix 2.4: Estimation results of the fixed effects model With and Without Lag41

Appendix 3.1: Pairwise and Bootstrap Results.....76

V. Abbreviations

AR(1) and AR(2)	Autoregressive Models of Order 1 and Order 2
CO ₂	Carbon dioxide Emission
CRS	Constant Returns to Scale
CRU	Climate Research Unit
CSA	Central Statistical Agency
EKC	Environmental Kuznets Curve
ESS	Ethiopian Socioeconomic Survey
FDI	Foreign Direct Investment
FE	Fixed-Effect Model
GHG	Greenhouse Gas
HRC	High-Risk Countries
IMF	International Monetary Fund
IPCC	Intergovernmental Panel for Climate Change
IV	Instrumental Variables Regression
JEL	Journal of Economic Literature
LCDs	Least Developing Countries
LRC	Low-Risk Countries
LSMS-ISA	Living Standards Measurement Study - Integrated Surveys on Agriculture
NMAE	National Meteorological Agency of Ethiopia
PWT	Penn World Table
SEM	Simultaneous Equation Model
SSA	Sub-Saharan African Countries
SUR	Seemingly Unrelated Regression Model
System GMM	System Generalized Method of Moments
TI-CPI	Transparency International Corruption Perceptions Index
TLU	Tropical Livestock Unit
WB	World Bank
WDI	World Development Indicator

Acknowledgment

To God be the glory, for granting me the strength, perseverance, and clarity to complete this work. I would like to express my deepest and heartfelt gratitude to my Principal Supervisor, Professor Paul Nystedt, for his invaluable guidance, encouragement, and unwavering support throughout my PhD journey. His insightful advice and constructive feedback have been instrumental in shaping this research. I am also profoundly grateful to my Co-Supervisors, Dr. Johannes Haggen (Associate Professor) and Dr. Tekie Alemu (Associate Professor), for their expertise, thoughtful suggestions, and continuous support. Their guidance has significantly contributed to the depth and quality of this dissertation.

I sincerely thank the Swedish International Development Cooperation Agency (SIDA) for its generous financial support, which made this research possible by covering key expenses, including stipend and travel. This support allowed me to participate in development and environmental economics seminars at Gothenburg University and conduct my research at Jönköping University under the guidance of Professor Paul Nystedt and Dr. Johannes Haggen. I am deeply grateful for their invaluable support throughout my academic journey.

I am also thankful to the Department of Economics, Addis Ababa University for providing an excellent academic environment and the necessary resources that facilitated my research. I deeply appreciate the faculty and administrative staff for their assistance and support.

On a personal level, I owe an immeasurable debt of gratitude to my beloved wife, Zemenay Zefine, for her unwavering love, patience, and support throughout this journey. Her encouragement and sacrifices have been a source of strength during challenging times. To my wonderful daughter, Ahava Desalegn, and my two sons, Zerubbabel and Betsidk Desalegn, I dedicate this work to you. Your love, understanding, and patience have been my greatest motivation. I hope this achievement serves as an inspiration for your own aspirations.

Finally, I extend my heartfelt gratitude to my brothers, Desalegn Kuche, Assdesach and Wesagn Dawit, for their unwavering support and encouragement. I also sincerely appreciate my colleagues, friends, and all well-wishers who have stood by me throughout this journey. Your kindness, motivation, and belief in me have been truly invaluable.

*Essays on Climate Change, Institutional Quality, Economic Growth, and Poverty
Vulnerability: Macro–Micro Perspectives from Sub-Saharan Africa*

Abstract

This dissertation comprises empirical analyses of climate change's effects on aggregate and sectoral economic growth in Sub-Saharan Africa, including an examination of how institutional quality may influence these effects. It also investigates how climate variability affects poverty vulnerability in Ethiopia. As part of this dissertation, the first paper uses panel data from 43 Sub-Saharan African countries (1970–2019) and employs fixed effects and seemingly unrelated regression models to examine climate change's effects on aggregate and sectoral economic growth, finding that rising temperatures and reduced precipitation disproportionately affect agriculture, with vulnerable countries facing the greatest economic losses, while industry, manufacturing, and services exhibit resilience. Expanding upon this, the second paper employs System GMM and a long-run multiplier approach with panel data from 43 Sub-Saharan African countries (1996–2019) to explore how institutional quality conditions climate change's effects on economic growth, revealing that stronger institutions enhance resilience but struggle to offset rising temperatures' long-term impacts, while corruption and political instability worsen environmental degradation and economic challenges, emphasizing the need for integrated institutional reforms and climate adaptation strategies. Extending this analysis, the third paper examines climate variability's impacts on poverty vulnerability in Ethiopia, using three-round micro-panel data from the Ethiopian Socioeconomic Survey (3,313 households) and climate data from the Ethiopian Meteorological Agency (2010–2016) with a two-level random coefficient model and fixed effects, finding that climate variability has a greater impact on poverty vulnerability than socioeconomic factors, particularly among rural households with larger families and higher dependency ratios. Thus, this dissertation recommends a multi-pronged policy framework for SSA: (1) boost agricultural resilience through climate-smart practices (e.g., drought-resistant crops, irrigation systems) to mitigate sectoral losses; (2) strengthen institutional quality via anti-corruption measures and governance reforms to curb environmental degradation and enhance long-term economic stability; and (3) implement targeted interventions in Ethiopia and similar SSA contexts, including climate-resilient agriculture, sustainable farming techniques (e.g., agroforestry), livelihood diversification (e.g., off-farm income), and expanded social protection (e.g., cash transfers, insurance schemes) to reduce poverty vulnerability and build household resilience.

Key Words: *Climate Change, Economic Growth, Institutional Quality, Poverty Vulnerability*

JEL: Q54, Q56, D72, D73, I32

Chapter 1: GENERAL INTRODUCTION

1.1 Background

Sub-Saharan Africa (SSA) is experiencing significant economic changes characterized by increasing urbanization, a growing middle class, and the gradual growth of non-agricultural sectors such as manufacturing, industry, and services ([Abreha et al., 2021](#); [ADB, 2021](#); [Bughin et al., 2016](#); [Njoh, 2003](#)). These changes are transforming the region's economic landscape, creating opportunities for diversification and reducing overreliance on traditional agricultural activities ([Jayne et al., 2018](#); [Kessides, 2006](#); [Sparks, 2021](#)). Despite this progress, agriculture remains crucial for supporting livelihoods, ensuring food security, and contributing significantly to GDP and rural development, particularly for the majority of the population in rural areas ([Diao et al., 2007](#); [Li et al., 2024](#)). Over 60% of the population depends on agriculture for their livelihoods, and the sector contributes about 17% to the region's GDP ([FAO, 2021](#); [Statista, 2022](#)).

However, the region's agricultural sector is deeply reliant on favorable climatic conditions, rendering it highly susceptible to climate change. Erratic weather patterns, such as temperature shifts and precipitation variability, have led to reduced productivity, exacerbating food security challenges. For instance, studies indicate that in SSA and other developing regions, a 1°C increase in temperature has been linked to an annual decline of nearly two percentage points in GDP per capita and a 2.66% reduction in agricultural output, underscoring the far-reaching impact of climate variability on both economic growth and food systems ([Dell et al., 2012](#); [Serdeczny et al., 2017b](#)).

The ripple effects of these challenges extend beyond agriculture, disrupting supply chains in agro-processing industries, reducing export revenues, and affecting service-sector activities related to trade and logistics ([Serdeczny et al., 2017b](#); [Wenz & Willner, 2022](#)). While SSA has made progress in diversifying its economy, with increasing contributions from manufacturing, industry, and services, this growth remains uneven ([Chamma, 2024](#); [Sabola, 2024](#)).

Despite these advances, climate variability, driven by El Niño and La Niña, further exacerbates poverty and hampers development in SSA, with extreme weather events like droughts and floods ([Anderson et al., 2023](#); [Sazib et al., 2020](#)). In Ethiopia,

for instance, frequent climate shocks, including the 2011 drought, severely impact smallholder farmers, causing crop failures, livestock mortality, and worsening food insecurity ([Markova et al., 2018](#); [Nakamura et al., 2019](#)). As a result, smallholders are particularly vulnerable to both individual (idiosyncratic) and widespread (covariate) shocks ([Gentle & Maraseni, 2012](#); [Günther & Harttgen, 2009](#)).

At the same time, effective institutional quality, including corruption control and political stability, plays a crucial role in mitigating the impacts of climate change on economic growth and sector-specific performance. Strong institutions enforce environmental regulations, promoting practices that reduce CO₂ emissions and curb temperature rise ([Acemoglu et al., 2001](#); [North, 1990](#); [Stern, 2006](#)). Empirical studies show that countries with strong corruption control have lower CO₂ emissions per unit of GDP than those with weaker governance ([Devlina et al., 2022](#); [Gani, 2012](#); [Sekrafi & Sghaier, 2018](#)). Political stability fosters investor confidence, encouraging long-term investments in renewable energy and climate-resilient infrastructure, which boosts productivity across sectors ([Uddin et al., 2017](#); [Wang & Chang, 2023](#)).

In agriculture and other sectors, stable institutions play a crucial role in promoting the adoption of climate-smart technologies, which can enhance yields even under challenging climatic conditions and reduce poverty vulnerability ([Wakweya, 2023](#)). Additionally, robust institutional frameworks help mitigate the economic impacts of climate change, thereby minimizing potential GDP losses ([Acemoglu, 2005](#); [Acemoglu & Robinson, 2013](#); [Hsiang et al., 2015](#); [Patterson, 2020](#)). Thus, these sectoral challenges undermine overall economic stability, hindering progress toward long-term economic development and worsening poverty vulnerability.

Despite the urgency of these issues, limited research has holistically examined the intersection of aggregate and sector-specific impacts of climate change in SSA ([Abidoeye & Odusola, 2015](#); [Alagidede & Adu, 2014](#); [Alagidede et al., 2015](#); [Benson & Clay, 1994](#)). This gap hampers efforts to understand how sectoral vulnerabilities translate into broader economic risks. Furthermore, the interconnected roles of weak institutions, corruption, and political instability in exacerbating climate change impacts remain underexplored. Governance deficits limit adaptive capacity, destabilize sectors, and undermine policies aimed at building resilience ([Shiferaw et al., 2014](#); [Sono et al., 2021](#)). Rising CO₂ emissions, which drive temperature increases, further intensify these challenges by exerting sustained pressure on GDP per capita ([Aye & Edoja, 2017](#); [Azam et al., 2016](#); [Rigas & Kounetas, 2024](#)). Addressing these governance and climate

linkages is crucial for understanding whether stronger institutions can mitigate both immediate and long-term climate change impacts on economic growth.

At the grassroots level, as indicated by [C. Herrera et al. \(2018\)](#), [Thornton et al. \(2014\)](#), and [Skoufias and Vinha \(2013\)](#) climate variability intensifies poverty vulnerability by disproportionately affecting smallholder farmers and rural communities. Furthermore, [Bellon et al. \(2020\)](#) emphasizes that environmental shocks disrupt household consumption, threaten livelihoods, and increase the risk of poverty vulnerability. These shocks magnify the effects of idiosyncratic factors (household-specific) and covariate factors (community-wide), creating a cascading effect that entrenches poverty and destabilizes regional economies ([Azam & Imai, 2012](#); [Günther & Harttgen, 2009](#); [Kailash Chandra & Shrabani, 2018](#)). Hence, persistent fragility at the grassroots level weakens economic resilience and hinders progress toward regional development.

This dissertation addresses these interconnected challenges by analyzing the impacts of climate change on aggregate and sector-specific growth, examining the role of institutional quality in determining climate-related economic risks, and investigating how climate variability influences poverty vulnerability in SSA, with a focus on Ethiopia. By bridging these dimensions, it seeks to provide a comprehensive framework for addressing the economic and social vulnerabilities posed by climate change in SSA.

Therefore, this dissertation uses the following guiding hypotheses¹: First, climate change negatively affects both aggregate and sector-specific economic growth in SSA, with agriculture being the most vulnerable sector. Second, stronger institutional quality, including corruption control and political stability, moderates the negative effects of climate change on economic growth, particularly in reducing long-term impacts on GDP per capita. Lastly, climate variability, combined with socioeconomic factors, significantly increases poverty vulnerability in Ethiopia, especially through its effects on household consumption and exposure to climate-related shocks.

¹ The data used in each paper reflect the distinct temporal and analytical focus of the corresponding hypothesis. For the first and second hypotheses, which address climate change and its long-term impacts on economic growth in Sub-Saharan Africa, the analysis employs macro-panel data spanning multiple decades (e.g., 1970–2019 and 1996–2019) to capture systematic and persistent climatic trends. In contrast, the third hypothesis focuses on climate variability and its short-term effects on household-level poverty vulnerability in Ethiopia, drawing on high-frequency micro-panel data (2010–2016) and localized climate records. This distinction reflects the conceptual difference between climate change, as long-term structural shifts, and climate variability, as short-term, often unpredictable fluctuations within the climate system.

1.2 Objectives of the Study

1.2.1 General Objective:

This dissertation investigates the impact of climate change on economic growth in Sub-Saharan Africa, the role of institutional quality in mitigating its effects, and the influence of climate variability on poverty vulnerability in the region.

1.2.2 Specific Objectives

1. To analyze the impact of climate change on both aggregate and sector-specific economic growth, focusing on agriculture, industry, manufacturing, and service sectors in Sub-Saharan African countries.
2. To examine how institutional characteristics, specifically corruption and political instability, affect the relationship between climate change and economic growth, with particular emphasis on short- and long-term impacts on GDP per capita.
3. To investigate how climate variability affects poverty vulnerability in Ethiopia by analyzing household consumption patterns and the influence of climate and socio-economic factors at both the household and regional levels.

1.3 Significance of the Study

This study contributes to the scientific literature by offering an integrated, multi-level analysis of climate change and variability impacts in Sub-Saharan Africa (SSA). First, it advances the empirical understanding of how climate change affects economic growth not only at the aggregate level but also across key economic sectors, a perspective often overlooked in macro-level studies. Second, it contributes to the institutional economics literature by empirically examining how governance quality, particularly corruption control and political stability, conditions the economic consequences of climate shocks. This adds value by moving beyond descriptive assessments to quantify the role of institutions in climate resilience.

Furthermore, by analyzing the interaction between climate variability and poverty vulnerability using household-level panel data from Ethiopia, the study provides a novel contribution to micro-level climate vulnerability research. It highlights how localized socioeconomic factors and regional climate patterns jointly shape vulnerability outcomes. This level of disaggregation enhances the policy relevance of the findings, particularly for designing targeted adaptation strategies.

Thus, the dissertation offers a unique contribution by bridging macroeconomic panel analysis with micro-level household vulnerability assessment, thereby generating insights that can inform both theoretical frameworks and evidence-based climate adaptation policy across SSA.

1.4 Scope of the Study

The scope of this dissertation is geographically focused on Sub-Saharan Africa, with particular emphasis on Ethiopia as a case study for analyzing poverty vulnerability due to climate variability, using household per-unit consumption as the primary measure. It examines the impact of climate change on various economic sectors, including agriculture, industry, manufacturing, and services within SSA. It also investigates the role of institutional quality in mitigating these impacts, particularly focusing on how governance factors, such as corruption control and political stability, affect the region's capacity to cope with climate change. Methodologically, the dissertation employs a combination of quantitative empirical analyses, including econometric models such as fixed-effects, seemingly unrelated regressions (SUR), dynamic system GMM, and two-level random coefficient models to assess the short- and long-term effects of climate change on economic growth and poverty vulnerability. It adopts a dual approach, integrating both macroeconomic and microeconomic perspectives. It analyzes the aggregate and sector-level impacts of climate change, alongside household- and regional-level outcomes, with a focus on the effects of idiosyncratic and covariate shocks, especially in relation to poverty vulnerability caused by climate variability.

1.5 Limitations of the Study

Despite its comprehensive approach, this dissertation has the following limitations. First, given the vastness and diversity of Sub-Saharan Africa, the findings may not fully capture the specific impacts of climate change across all countries in the region. At the micro level, the dissertation focuses on Ethiopia, which, while offering valuable insights, may not fully represent the experiences of other SSA countries, indicating the need for further research across the region. Additionally, while it addresses institutional factors, it does not account for all governance-related variables, such as the role of the informal sector in climate adaptation or the variations in local governance structures across regions. Lastly, the dissertation relies on available climate data and economic indicators, which may have limitations in terms of accuracy and

completeness, particularly in areas where data collection is sparse or inconsistent, such as the micro-level data from Ethiopia. Nonetheless, it provides valuable insights into the intersection of climate change, institutional quality, economic growth, and poverty vulnerability in Sub-Saharan Africa, offering a comprehensive understanding of how these factors interact and shape the region's economic development.

In addition, the dissertation does not explicitly disaggregate climate impacts by gender, particularly at the macro level. While Paper 3 (Chapter 4:) offers some indirect insights through household-level analysis, it does not incorporate gender-specific metrics. This limits the understanding of how climate shocks may differentially affect women and marginalized groups. Future research could benefit from integrating gender-disaggregated data or mixed-method approaches to better capture inequality dimensions of climate vulnerability.

1.6 Structure of the Study

This dissertation explores key issues at the intersection of climate change, economic growth, institutional quality, and poverty vulnerability. The remaining chapters are structured as follows: Chapter Two examines the impacts of climate change on both aggregate and sector-specific economic growth. This analysis has been published in the peer-reviewed *Journal of Social and Economic Development*. Chapter Three investigates the relationship between institutional quality, measured by corruption and political instability, economic growth, and climate change, specifically CO₂ emissions. Chapter Four explores the impact of climate variability on poverty vulnerability, hypothesizing that climate variability has a greater influence than socioeconomic factors, while also considering the role of both. The papers in Chapters Three and Four are at a publishable level and will be submitted to reputable journals. Finally, the dissertation concludes with a general discussion of the major findings, drawing conclusions and offering policy implications based on the study's results.

Chapter 2: CLIMATE CHANGE AND ECONOMIC GROWTH IN SUB-SAHARAN AFRICA: AN EMPIRICAL ANALYSIS OF AGGREGATE AND SECTOR LEVEL GROWTH

Abstract

This paper utilizes a panel dataset encompassing 43 sub-Saharan African countries spanning from 1970 to 2019 to investigate the impact of climate change on both aggregate and sector-specific economic growth. Via fixed effects and Seemingly Unrelated Regression (SUR) models, the study shows that climate change, characterized by rising temperatures and diminishing precipitation, exerts a detrimental influence on both aggregate and sectoral growth, albeit with varying degrees of severity. Such diverse effects emanate from the significant impacts of climate change on the agricultural sector, resulting in discernible alterations in output. Conversely, the industry, manufacturing, and service sectors demonstrate comparatively minor susceptibility to climate-induced change. Furthermore, the analysis highlights that the sub-Saharan African countries most vulnerable to climate change experience the greatest economic repercussions, and the most sensitive countries suffer the most.

JEL: Q54; Q56; C23; C33; F43

Keywords: Climate change; economic growth; fixed effect; SUR; GDP per capita

2.1 Introduction

Climate change is a significant global challenge, primarily driven by increased greenhouse gas (GHG) emissions, such as carbon dioxide, methane, nitrous oxide, and fluorinated gases, originating from human activities and, to a lesser extent, natural factors, each contributing differently to global warming ([Keenan, 2015](#); [UNFCCC, 2009](#)). Unregulated economic activities exacerbate climate change, negatively impacting the environment. This, in turn, affects per capita income in developing countries, leading to a decline in the sustainability of growth in critical sectors such as agriculture ([Dell et al., 2012](#); [Singh et al., 2022](#)). The impact of climate change is unevenly distributed worldwide, particularly in developing nations, where it poses a significant threat to economic growth and sustainability ([Abidoye & Odusola, 2015](#); [Dell et al., 2012](#)).

Africa has been significantly affected by climate change, resulting in poverty for millions of people, and it is expected to pull additional millions into poverty, particularly in the sub-Saharan African (SSA) region ([Hope Sr, 2009](#)). Despite the countries' efforts to reduce poverty by 2030, especially in decreasing the number of people living on less than \$1.25 a day to zero ([Conceição, 2020](#)), the challenge remains pressing due to climate change ([Bicaba et al., 2017](#)).

SSA countries are highly vulnerable to the adverse effects of climate change because of the high cost of mitigation and their low adaptive capacities and coping strategies ([Welborn, 2018](#)). Despite their negligible contribution to global GHG emissions, SSA countries bear high social, economic, environmental, and cultural costs of climate change ([Bruce et al., 1996](#); [Webster et al., 2008](#)). This poses another challenge for SSA countries struggling with high population growth ([Peterson, 2017](#)), low human capital ([Vinod & Kaushik, 2007](#)), and trade imbalances ([Zahonogo, 2016](#)). The impact of climate change is not limited to the agriculture², forestry, and fishery sectors. Through multifaceted sectoral channels, it also affects the water, infrastructure, tourism, energy, services, and health sectors. For instance, the impact on agriculture can affect the productivity of related sectors ([S. Ali et al., 2019](#); [Huddleston et al., 2022](#); [McMichael et al., 2006](#); [Ramin & McMichael, 2009](#); [Watts et al., 2015](#)).

² According to the extended definition provided by the World Bank's Development Indicators, the agricultural sector encompasses not only the cultivation of crops and livestock production but also includes forestry, hunting, and fishing activities. As such, this scholarly article's references to the agricultural sector must be interpreted in alignment with this comprehensive illustration.

<https://databank.worldbank.org/metadataglossary/world-development-indicators/series/NV.AGR.TOTL.KD>

Recently, the SSA region experienced a significant decline of nearly two percentage points in its GDP per capita annually for every one-degree Celsius increase in temperature. This alarming trend poses a substantial risk to the region's economic stability and exacerbates the population's already-existing vulnerability to poverty ([Winsemius et al., 2018](#)). However, studies have yet to determine to what extent agriculture, manufacturing, industry, and service sectors are affected differently, depending on the respective countries' sensitivity to climate change. Most existing studies on climate change's impact on economic growth primarily analyze its economic effects on aggregate growth rates at the national or regional levels ([Abidoye & Odusola, 2015](#); [Alagidede et al., 2015](#); [Piontek et al., 2019](#)). However, the impact of climate change can vary between different sectors of the economy.

Following the climate-economics literature ([Dell et al., 2014](#)), this study defines climate change, or equivalently, climate variation, as long-term changes in the average levels or distributions of temperature and precipitation relative to historical norms. These persistent shifts in climate conditions are distinct from weather variation, which refers to short-term, seasonal fluctuations. The analysis focuses on climate change, as it captures the enduring impact of changing climate patterns on economic outcomes, rather than temporary weather shocks.

This study analyzes the impact of climate change on aggregate and sector-specific economic growth (agriculture, industry, manufacturing, and service sectors) in SSA countries. This analysis enables us to determine the sensitivity of different sectors to climate change and identify potential aggregate economic growth 'lock-ins'³ caused by the dominance of specific sectors. In other words, some sectors may be hindering overall economic growth.

The study's contribution is two-fold: first, it identifies factors that affect economic growth at the regional level using climate change variables – temperature, precipitation, the coefficient of variations in precipitation, and its square – conditional on other macroeconomic variables, such as human capital. To do this, the study applies a country and year fixed-effect model. Second, it estimates the effects of climate change

³ The productivity of agriculture is directly influenced by climate change, which has a gradual ripple effect on other sectors such as industry, manufacturing, and services. Consequently, the economic growth of SSA countries is constrained by their dependence on agriculture, and any negative impact on this sector can directly and indirectly affect the growth of other sectors, ultimately impacting overall economic growth.

on sector-level growth of several major sectors, including agriculture, industry, manufacturing, and service sectors, using a seemingly unrelated regression (SUR) model.

The findings show that climate change hinders aggregate and sector-specific⁴ economic growth in the region, as measured by GDP per capita. Variations in temperature and squared precipitation are inversely related to aggregate growth across all model specifications. Specifically, a decline in precipitation adversely impacts economic growth, while excessive precipitation can lead to flooding and substantial economic losses. Both insufficient and excessive precipitation increase the risks of droughts and floods, further exacerbating economic vulnerabilities.

The sectors of an economy are intricately connected to climate change patterns, particularly precipitation variations and temperature changes. The impacts of such patterns on individual sectors vary significantly depending on each sector's unique characteristics. The agriculture sector's growth is primarily and negatively affected by increased temperatures and decreased precipitation. However, the squared term for precipitation variations does not have a significant effect despite the overall negative association.

A weaker, statistically insignificant negative association exists between temperature and growth in the industry, manufacturing, and services sectors. However, these sectors are substantially influenced by the squared coefficient of the variation in precipitation. Any such influence could be due to interactions and links with temperature changes affecting the agriculture sector's growth.

The intricate connections among different economic sectors suggest that direct climate change effects on agriculture could extend beyond it, potentially impacting the broader economy. This finding illustrates the importance of considering the non-linear relationship between precipitation and sectoral output in the context of climate change's impact on the economy. Therefore, these changes adversely impact agriculture-based industries, manufacturing, and service sector activities, causing significant economic loss.

⁴ Climate change has been recognized as a crucial challenge in various sectors, including agriculture, which is directly impacted. However, it is essential to note that the effects of climate change are not limited to the agriculture sector alone, as other sectors are also indirectly affected. In this regard, it is worth considering the potential adverse spillover effects that the agriculture sector might have on other sectors, given that it is the primary output source for different sectors. It serves as the backbone of the economic growth of sub-Saharan African countries. This underscores the need for a holistic approach to climate change mitigation and adaptation, considering the interdependent nature of different economic sectors.

This indicates that climate change may have far-reaching effects on various sectors and, ultimately, on overall economic growth. The rest of this paper is structured as follows: Section 2.2 reviews related literature, and Section 2.3 describes the theoretical and empirical framework of the study. Section 2.4 presents data sources and variable measurement, Section 2.5 discusses the results, and Section 2.6 concludes with possible policy implications and suggestions.

2.2 Literature Review:

2.2.1 Effects of Climate Change on Aggregate and Sector-level Growth

[IPCC \(1996\)](#) and [Masson-Delmotte et al. \(2021\)](#) stated that climate change involves long-term shifts in temperature and precipitation over several decades. Changes in precipitation patterns and rising temperatures, compared to pre-industrial levels, negatively impact economic growth and public health regardless of a country's altitude and location ([Mann et al., 2017](#); [McCarthy et al., 2001](#); [Pachauri et al., 2014](#); [Stocker et al., 2013](#)). For example, increased temperatures in Africa can lead to health concerns such as malaria and exacerbate poverty ([Ikefuji et al., 2010](#)).

Studies indicate that climate change poses a significant threat to the economic growth of less developed countries (LDCs) due to their limited adaptive capacities and weak mitigation strategies ([Alagidede et al., 2015](#)). [Stern \(2013\)](#) asserts that increased temperatures disproportionately affect the growth rates of low-income countries compared to developed nations on an aggregate level. Consequently, low-income countries incur higher social costs due to elevated greenhouse gas (GHG) emissions than high-income countries, and their per capita consumption exhibits high volatility ([Althor et al., 2016](#); [Barro, 2003](#); [Barro & McCleary, 2003](#)). This volatility adversely impacts their resource potential ([Nordås & Gleditsch, 2007](#)) and hinders the achievement of Sustainable Development Goals (SDGs) ([IPCC, 2014b](#); [Pachauri et al., 2014](#); [Pachauri & Meyer, 2014](#)). An illustrative example of the detrimental effects of climate change is the disruption of ecosystem services, which are crucial for the livelihoods and well-being of rural communities in developing countries ([Nautiyal et al., 2016](#)).

Climate change leads to frequent and recurring droughts and damages soil fertility in most SSA countries ([Alagidede & Adu, 2014](#); [Alvarado & Toledo, 2017](#)). Additionally, due to their geographical locations and economic bases, SSA countries, along with some Asian countries, are more vulnerable to temperature shocks and variations in rainfall ([Eboli et al., 2010](#)). Climate change significantly contributes to the poverty trap in the

most exposed countries due to productivity shocks ([Hallegatte & Rozenberg, 2017](#); [Hope Sr, 2009](#)). For example, agricultural failures are linked to higher temperatures, varying rainfall, and frequent floods and droughts ([Hallegatte et al., 2016](#)). This results in price fluctuations, which increase consumption volatility ([Eboli et al., 2010](#); [Serdeczny et al., 2017a](#)).

Many scholars agree that a definitive channel through which climate change affects economic growth remains elusive despite numerous studies addressing this issue ([Bowen et al., 2012](#); [Dietz & Stern, 2015](#); [Fankhauser & Tol, 2005](#); [Pindyck, 2012](#); [Stern et al., 2006](#)). This is because economic growth is simultaneously influenced by various macroeconomic determinants⁵ beyond climate change ([Dell et al., 2012](#)). Isolating the impact of climate change on economic growth and poverty is challenging due to its multifaceted nature ([Wilkinson & Peters, 2015](#)). In addition to climate change, factors such as energy security and population growth hinder SSA's economic growth ([Lutz et al., 2017](#)). Nevertheless, climate change is believed to affect economic growth by altering resource endowments and modifying patterns of resource consumption and utilization ([Eboli et al., 2010](#)). Studies indicate practical resilience to climate change requires comprehensive mitigation and adaptation strategies to ensure smooth economic growth ([Moore & Diaz, 2015](#); [Sono et al., 2021](#)).

The impact of climate change on economic growth depends on a country's coping mechanisms, mitigation⁶ policies, adaptation⁷ strategies, and the availability and utilization of various technologies ([Pachauri et al., 2014](#); [Rosen & Guenther, 2015](#); [Smit & Pilifosova, 2003](#); [UNFCCC, 2007](#)). According to [Zhang and Ayyub \(2021\)](#), adaptation strategies can be implemented at both national and individual levels to enhance mitigation mechanisms. These strategies include reducing greenhouse gas emissions through energy-efficient technologies and changing consumption behaviors. However, [Dell et al. \(2012\)](#) indicate that climate change affects the productivity of the agriculture,

⁵ For instance, at the macroeconomic level, various factors affect economic growth qualitatively (state of political stability and governance) and quantitatively (level of savings, investments, and human capital).

⁶ Mitigation is an effort to reduce or avoid the impact of climate change using different adaptation strategies, such as reducing or cutting GHG emissions and using improved technologies (Rosen & Guenther, 2015).

⁷ Adaptation refers to the adjustments made in response to changes in the climate system, which may include changes in behavior and the mobilization of resources for coping with such changes (Pachauri et al., 2014).

industry, service, and manufacturing sectors in various ways. For instance, high temperatures can reduce workers' available working hours, thereby limiting their ability to work. This indicates that climate change affects the productivity of the agriculture, industry, service, and manufacturing sectors in various ways. For instance, high temperatures can reduce workers' available working hours, thereby limiting their ability to work.

The agricultural sector is more vulnerable to climate change's effects than other sectors ([Nastis et al., 2012](#)). For example, changes in soil fertility result in decreased crop and livestock production ([Y. Zhang et al., 2022](#)). However, a study in India found that variations in rainfall and extreme temperatures have not significantly impacted agricultural output, although temperature fluctuations show a positive association. However, a study in India indicated that variations in rainfall and extreme temperatures have not significantly impacted agricultural output, though temperature fluctuations show a positive association ([Sridhar, 2016](#)). Erratic precipitation and rising temperatures threaten secure water sources ([Eboli et al., 2010](#)) essential for increasing agricultural production, implementing small- and large-scale irrigation schemes ([Hussein & Suttie, 2016](#)), and supporting livestock production ([Hallegatte et al., 2016](#)). Shortfalls in the agriculture sector may hinder GDP growth ([Conforti et al., 2018](#)) and impede the growth of interdependent sectors ([Mongiovi, 2011](#)). For instance, increased heat waves can affect health, reducing productivity across various sectors ([Greenough et al., 2001](#)).

Studies indicate that the impact of climate change varies across LDCs, sectors, and even within sectors following various factors. These factors include economic policies, strategies, geographical location, institutions, trade, religious influences, political stability, environmental conditions, population growth, adaptation and mitigation measures, economic development, and human capital status ([Abidoye & Odusola, 2015](#); [Barro, 2003](#); [Barro & McCleary, 2003](#); [Bloom et al., 2004](#); [McCleary & Barro, 2006](#); [Rodrik, 2003](#)).

Climate change significantly affects the primary economic drivers in most SSA countries ([Alagidede & Adu, 2014](#); [Eboli et al., 2010](#); [Gylfason, 2001](#)). For instance, rising temperatures and unpredictable precipitation patterns profoundly impact sector-specific growth ([Dell et al., 2012](#)). While much of the macroeconomic literature focuses on the direct and indirect effects of climate change on growth and sectoral output, fewer studies address the socioeconomic consequences of climate-induced migration. Emerging research highlights how environmental stressors, such as droughts and floods,

contribute to population displacement, altering labor markets, urbanization trends, and household-level economic resilience ([Black et al., 2011](#); [Rigaud et al., 2018](#)). These dynamics are particularly relevant in the Sub-Saharan African context, where migration serves both as an adaptation strategy and a source of vulnerability. Although this study does not model migration directly, these micro-level implications are addressed in Paper 3 (Chapter 4:), which investigates household vulnerability to climate shocks using a different unit of analysis.

Thus, this study aims two-fold. Firstly, it investigates the impact of climate change by analyzing the effects of temperature and precipitation fluctuations on aggregate economic growth. Secondly, it examines climate change's impact on specific sectors such as agriculture, industry, manufacturing, and services.

Deviations in rainfall and temperature from historical norms can exacerbate economic challenges in SSA countries, necessitating additional mechanisms and strategies to cope with these changes ([Abidoye & Odusola, 2015](#)). Most studies confirm that climate change negatively impacts overall economic growth ([Alagidede & Adu, 2014](#); [Dell et al., 2012](#); [J & Anaba, 2022](#); [Moore & Diaz, 2015](#); [Rezai et al., 2018](#)). However, the specific impacts on economic sectors are not always straightforward. Agriculture is particularly vulnerable to climate change, and its repercussions can affect other sectors such as industry, manufacturing, and services.

2.3 Theoretical and Empirical Background

2.3.1 Theoretical Framework

Numerous studies have established that human activities are the primary cause of global warming, driven by increased atmospheric CO₂ concentration, contributing to climate change (*see* Figure 2.1, the first two loops), particularly temperature and precipitation, deviating from the historical norms ([Harris et al., 2007](#); [Mishra et al., 2010](#); [Sathaye et al., 2006](#); [Vanderheiden, 2008](#)). Consequently, factors of production such as land, labor, and natural resources are increasingly affected, leading to reduced economic growth (*see* Figure 2.1)⁸. Addressing these challenges requires effective public policies to mitigate environmental impact ([Harris et al., 2007](#)).

⁸ For instance, in the case of LDCs, including SSA, climate change could directly impact the agriculture sector (shown with a solid arrow), and indirect effects could be observed in other sectors (indicated with broken arrows).

The causality between economic development, particularly the Industrial Revolution, and climate change dates back to the 1830s ([Abram et al., 2016](#)). French scientist [Fourier \(1827\)](#) initially described the natural greenhouse effect, aligning it with the natural climate system. Later, Swedish scientist [Arrhenius \(1896\)](#) predicted that increased concentrations of CO₂ in the atmosphere could have adverse effects on the global climate system, a prediction now supported by scientific studies. However, [Kimball and Idso \(1983\)](#) found that elevated CO₂ levels could potentially enhance crop yields while also increasing the risk of droughts due to transpiration, highlighting climate change's sector-specific impacts.

The evidence indicates that the primary indicators of climate change, such as temperature and precipitation, significantly influence economic growth. Many studies have demonstrated how climate change adversely affects a country's GDP per capita using various indicators (*see* footnote 6). Among these, the damage function shows that the shock in the climate system adversely affects every economic system through increasing mitigation and adaptation costs ([Weitzman, 2010](#)). Studies suggest that high-level aggregation of the relationship between climate change and economic growth using the CGE model is less informative for policymakers than sector-level estimation. Sector-level estimation helps develop targeted action plans to mitigate the adverse effects of climate change on different economic sectors ([Gillingham et al., 2008](#); [Kimuli et al., 2022](#)).

Additionally, aggregate-level measurements often fail to account for the magnitude of climate variations' effects on sector-level growth, making it complex and ambiguous to identify possible entry points for policy interventions ([Dell et al., 2014](#); [Lemoine & Traeger, 2012](#)). Climate change directly reduces the sustainability of production in major economic sectors such as agriculture ([Kumar et al., 2016](#)) while indirectly affecting tourism, industry, service, and manufacturing sectors ([Dell et al., 2012, 2014](#); [Singh et al., 2022](#)).

Climate change impacts economic growth directly and indirectly (Figure 2.1) through the complexity and interdependence between different potential channels, making it hard to identify the mechanisms at work precisely ([Alagidede et al., 2015](#); [S. Ali et al., 2019](#); [Dell et al., 2012, 2014](#); [Moore & Diaz, 2015](#); [Nordhaus, 2019](#); [Rezai et al., 2018](#)). Researchers have used various models to analyze the effects, including the Integrated Assessment Model (IAM) for forecasting and the Computable General Equilibrium Model (CGE) for economy-wide impact analyses. Additionally, some

studies have applied the Solow growth model's theoretical framework and integrated the climate change damage function, $D_{it} = \vartheta_1 C_{it} + \vartheta_2 C_{it}^{\vartheta_3}$ in their research, where D denotes the damage inflicted by climate change C in country i at a time t compared to the historical (pre-industrial period) average temperature and precipitation changes, and ϑ is the constant term for each specification ([Solow, 1957](#); [Tsigaris & Wood, 2016](#); [Warren et al., 2006](#)). Another study used the multiplicative disutility function framework to represent the damage function of global warming ([Weitzman, 2010](#)).

In most studies, the damage function considers climate change's impact on economic growth primarily through temperature changes. However, climate change also involves fluctuations in precipitation and extreme events like floods and droughts, which can significantly affect economic growth. Therefore, due to their substantial impacts, economic growth models should emphasize climate change indicators, particularly in less developed countries ([Estrada et al., 2019](#); [Lecocq & Shalizi, 2007](#); [Tsigaris & Wood, 2016](#); [Warren et al., 2006](#)).

Some studies have expanded economic growth models to incorporate climate change factors. For example, in the Ramsey-Cass-Koopmans model, climate change indicators significantly impact economic growth through their effects on labor productivity and capital accumulation. However, this approach does not account for the lock-in effect or the direct channels through which climate change affects growth ([Lecocq & Shalizi, 2007](#)).

Economic theory suggests climate change reduces sector-wide productivity and worsens poverty, especially in LDCs, including those in SSA ([Barro & Sala-i-Martin, 2004](#); [Letta & Tol, 2019](#)). This could result in economic rigidity. This rigidity demonstrates the need to understand economic growth models fully ([Nordhaus, 1977, 1993](#); [Piontek et al., 2019](#)). For example, developing countries are particularly vulnerable to climate-related shocks, especially in agriculture. At the same time, the industry, manufacturing, and service sectors are less affected by product prices and labor wages ([Bosello & Parrado, 2022](#); [Lecocq & Shalizi, 2007](#)).

Increased human activities driven by unlimited wants have resulted in higher greenhouse gas (GHG) emissions, such as atmospheric CO₂ concentrations, causing climate change. Figure 2.1 illustrates these theoretical relationships. This reciprocal dynamic intensifies the detrimental impacts on human activities, creating a feedback loop that worsens our environmental challenges. Consequently, climate change adversely

affects sector-specific and aggregate economic growth directly and indirectly. The agricultural sector is essential for the interconnectedness and development of various economic sectors, supplies key inputs, and engages in mutual interactions that impact overall economic growth. Thus, Figure 2.1 depicts the significant direct impact of climate change on agriculture and its subsequent effects across multiple sectors and on economic growth.

In the figure, an encircled B shows the counter-clockwise effects of GHG emissions and climate change on human activities. This illustration subtly conveys a balancing dynamics, wherein the rise of CO₂ emissions and its consequent climatic ramifications influence human activities. This interplay shows the complex feedback mechanisms between anthropogenic actions and environmental responses. It highlights how increasing levels of CO₂ intensify climate change and, consequently, its impact on human activities and economic growth. It emphasizes how rising CO₂ levels exacerbate climate change, impacting human activities and economic growth.

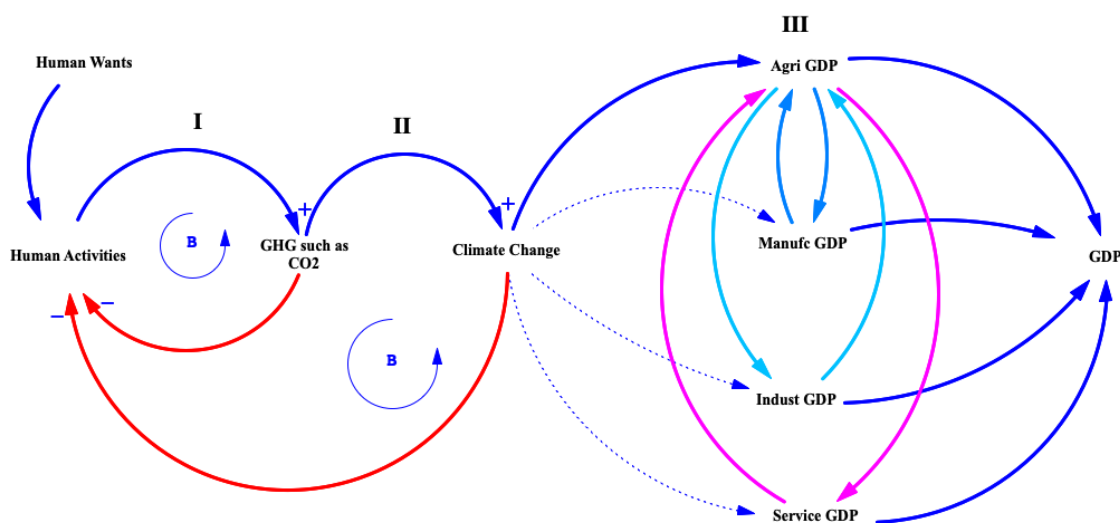


Figure 2.1: The direct and indirect effects of climate change on the economic growth of SSA countries at both the sector and aggregate levels.

Notes: The solid arrows show direct effects, while the broken arrows depict indirect effects. The colored arrows in the last loop of the diagram illustrate the intersectoral interaction and relationship within the economy.

2.3.2 Empirical Framework

In most studies, the effects of climate change on economic growth are estimated using the Cobb-Douglas production function with the inclusion of climate change variables such as temperature and rainfall (Zhang et al., 2017). Some studies incorporate control

and climate change variables ([Barrios et al., 2010](#); [Dell et al., 2014](#)). This study employs the analytical framework pioneered by [Bond et al. \(2010\)](#) and [Dell et al. \(2012\)](#), commonly known as a simple production model in an economy. This framework is strategically utilized within the present study to estimate the effects of climate change on economic growth. Thus, the simple economy model is as follows:

$$Y_{it} = e^{\alpha C_{it}} A_{it} L_{it} \quad \text{Eq.1.}$$

In eq (1), Y_{it} represents the gross domestic product (GDP), and L represents labor, which measures the labor supply based on the total population, representing human capital; A represents technology or labor productivity, and C indicates climate factor, considering temperature and precipitation in country i in year t . The growth of an economy is indirectly affected by the state of its institutions ([Acemoglu et al., 2001](#); [Dell et al., 2012](#)). For instance, labor productivity is affected by climate factors (C_{it}) and unobserved country-specific institutional factors and captured by y_i . This influence is represented as:

$$\frac{\Delta A_{it}}{A_{it}} = y_i + \beta C_{it} \quad \text{Eq.2.}$$

Equation 1 captures the direct effects of climate factors on agricultural production. This includes specific impacts on crop yields and livestock productivity, illustrating how variations in temperature and precipitation directly influence agricultural outputs ([Greenstone & Deschenes, 2006](#); [Schlenker & Roberts, 2009](#)). Equation 2 captures the indirect effects of climate change on economic growth via labor productivity. For instance, the impact of climate change potentially affects labor productivity, which in turn affects economic growth ([Dell et al., 2012](#); [Kjellstrom et al., 2009](#)). Hence, Equation 1 can be rewritten after taking its log and differencing with respect to time such that (*See Appendix 1*):

$$Y_{it} = y_i + (\alpha + \beta)C_{it} - \alpha C_{it-1} \quad \text{Eq.3.}$$

Therefore, a simplified model without the lagged effect⁹ can be based on Eq.3 is:

$$Y_{it} = \eta + y_i + \delta_t + (\alpha + \beta)C_{it} + \epsilon_{it} \quad \text{Eq.3a.}$$

where Y_{it} is the per capita output, η represents the overall intercept, y_i denotes the country-specific fixed effects, and δ_t is the time-specific fixed effect. The direct impact of climate change on economic growth appears through α , and indirect appears through β (that is, the effect of growth) ([Bond et al., 2010](#); [Dell et al., 2012](#)).

⁹ Estimates that include lagged variables are presented in Appendix 4. The lagged parameter estimates are very small and statistically insignificant. Including the lags does not significantly alter the estimated direct parameters.

Estimation Strategy

As indicated here and in the theoretical section, temperature and precipitation, including precipitation variations, primarily serve as proxies for climate change that affect economic growth (aggregate and sector-level growth) (Kimball & Idso, 1983). In Equations 1-3, climate change variables are explained as a vector C_{it} , which includes temperature and precipitation. Therefore, consider the following functional form of the empirical model to estimate the effects of climate change on economic growth:

$$Y_{it} = \beta_0 + \beta_1 TEMP_{it} + \beta_2 AnnPreMz_{it} + \beta_3 CVPM_{it} + \beta_4 CVPM^2_{it} + \beta_5 X_{it} + \varepsilon_{it} \quad \text{Eq. 4.}$$

where Y is the gross domestic product growth per capita of country i at time t , $TEMP$ and $AnnPreMz$ denote average annual temperature and precipitation, respectively. $CVPM$ represents the coefficient of variations in precipitation and captures the annual variability in precipitation for each country, X is the vector of other macroeconomic variables such as population and human capital (in terms of gross national percentage of secondary school enrollments), and ε_{it} is a random error. While this paper primarily focuses on the direct effects of climate change on aggregate and sector-specific economic growth, it does not incorporate institutional moderators, such as corruption or political instability, into the empirical specification. These institutional dynamics are analyzed in depth in Paper 2 (Chapter 3), which employs a dynamic panel GMM approach to examine how institutional quality conditions the climate-growth relationship. Readers are thus referred to Paper 2 (Chapter 3:) for a complementary institutional perspective on climate vulnerability.

The Seemingly Unrelated Regression (SUR) model is asymptotically more efficient than single-equation models when addressing a set of seemingly unrelated equations. This enhanced efficiency stems from the SUR model's capability to leverage potential correlations between the error terms of different equations (Zellner, 1962). It enables achieving joint efficiency relative to single least squares equations (Zellner & Huang, 1962). To estimate the sector-level effects, the SUR model is specified as follows in vector form:

$$Y_{it} = \eta + y_i + \delta_t + \mathbf{B}X_{it} + \varepsilon_{it} \quad \text{Eq.5}$$

where:

$\mathbf{Y}_{it} = \begin{pmatrix} Y_{1,it} \\ Y_{2,it} \\ \vdots \\ Y_{M,it} \end{pmatrix}$ is the $M \times 1$ vector of sector-specific value-added GDP per capita

outcome variables for country i at time t , $\eta = \begin{pmatrix} \eta_1 \\ \eta_2 \\ \vdots \\ \eta_M \end{pmatrix}$ is the $M \times 1$ dimension vector of

intercepts, y_i is the $M \times 1$ vector of country-specific fixed effects for country i , δ_t is the $M \times 1$ vector of year-specific fixed effects for year t , \mathbf{B} is the $M \times k$ matrix of coefficients for the climate change and control variables in \mathbf{X}_{it} , \mathbf{X}_{it} is the $k \times 1$ vector of

climate change and control variables for country i at time t , and $\epsilon_{it} = \begin{pmatrix} \epsilon_{1,it} \\ \epsilon_{2,it} \\ \vdots \\ \epsilon_{M,it} \end{pmatrix}$ is $M \times 1$

vector of error terms.

Including year and country dummies in economic studies, especially in models like the SUR model using panel data, is essential for several reasons. These dummies control for unobserved heterogeneity over time and across countries ([Greene, 2012](#); [Wooldridge, 2010](#)). They capture global trends and shocks that affect all units in the panel data, isolate country-specific characteristics such as cultural, institutional, and historical factors, address omitted variable bias, and improve the reliability and efficiency of the estimates by managing cross-sectional dependence ([Driscoll & Kraay, 1998](#); [Hsiao, 2022](#); [Zellner, 1962](#)).

By including year and country dummies, the model presents as follows:

$$\mathbf{Y}_{it} = \alpha + \mathbf{\Gamma} \mathbf{D}_{\text{country},i} + \mathbf{\Delta} \mathbf{D}_{\text{year},t} + \mathbf{B} \mathbf{X}_{it} + \epsilon_{it} \quad \text{Eq.6}$$

where:

$\mathbf{D}_{\text{country},i}$ is a $J \times 1$ vector of country dummy variables for country i , $\mathbf{\Gamma}$ is the $M \times J$ matrix of coefficients for the country dummy variables, $\mathbf{D}_{\text{year},t}$ is a $K \times 1$ vector of year dummy variables for year t , and $\mathbf{\Delta}$ is the $M \times K$ matrix of coefficients for the year dummy variables. The system of equations in the SUR framework was stacked for each sector's outcome variable and can be represented in the following matrix form for all outcome variables.

$$\begin{pmatrix} Y_{1,it} \\ Y_{2,it} \\ \vdots \\ Y_{M,it} \end{pmatrix} = \begin{pmatrix} \eta_1 \\ \eta_2 \\ \vdots \\ \eta_M \end{pmatrix} + \begin{pmatrix} \gamma_{1,2} & \gamma_{1,3} & \cdots & \gamma_{1,J} \\ \gamma_{2,2} & \gamma_{2,3} & \cdots & \gamma_{2,J} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{M,2} & \gamma_{M,3} & \cdots & \gamma_{M,J} \end{pmatrix} \begin{pmatrix} D_{\text{country},2,i} \\ D_{\text{country},3,i} \\ \vdots \\ D_{\text{country},J,i} \end{pmatrix} + \begin{pmatrix} \delta_{1,2} & \delta_{1,3} & \cdots & \delta_{1,J} \\ \delta_{2,2} & \delta_{2,3} & \cdots & \delta_{2,J} \\ \vdots & \vdots & \ddots & \vdots \\ \delta_{M,2} & \delta_{M,3} & \cdots & \delta_{M,J} \end{pmatrix}$$

Four major sectors contribute to aggregate economic growth: agriculture, industry, manufacturing, and service. Based on this study's objective, the general hypothesis is that climate change has no significant adverse effect on economic growth at the aggregate and sector levels. The sector-level impacts of climate change on economic growth are estimated using the SUR model for several reasons. First, the SUR model enhances the effectiveness and efficiency of the estimation by combining multiple estimation equations ([Moon & Perron, 2008](#)). Second, it facilitates cross-equation hypothesis testing, which is impossible when equations are estimated separately. Additionally, the model accounts for the contemporaneous correlations of the error terms across a set of equations ([Zellner, 1962](#)), thereby helping to avoid endogeneity problems ([Hill et al., 2018](#)). Therefore, a series of equations was established to analyze the impact of climate change at the sector level as follows:

$$Agr_{it} = \beta_0 + \beta_1 TEMP_{it} + \beta_2 AnnPreMz_{it} + \beta_3 CVPM_{it} + \beta_4 CVPM^2_{it} + \beta_5 X_{it} + \zeta_{it} \text{ Eq.7.}$$

$$Ind_{it} = \beta_0 + \beta_1 TEMP_{it} + \beta_2 AnnPreMz_{it} + \beta_3 CVPM_{it} + \beta_4 CVPM^2_{it} + \beta_5 X_{it} + \epsilon_{it} \text{ Eq.8.}$$

$$Mnf_{it} = \beta_0 + \beta_1 TEMP_{it} + \beta_2 AnnPreMz_{it} + \beta_3 CVPM_{it} + \beta_4 CVPM^2_{it} + \beta_5 X_{it} + \eta_{it} \text{ Eq.9.}$$

$$Srv_{it} = \beta_0 + \beta_1 TEMP_{it} + \beta_2 AnnPreMz_{it} + \beta_3 CVPM_{it} + \beta_4 CVPM^2_{it} + \beta_5 X_{it} + v_{it} \text{ Eq.10.}$$

where: Agr_{it} , Ind_{it} , Mnf_{it} , Srv_{it} , refer to agriculture, industry, including construction, manufacturing, and service sectors' value-added GDP per capita respectively.

The FE model is applied for estimating Equation 4, while the SUR technique is used simultaneously to estimate Equations 7-10. Based on the results of the Hausman test (Prob > Chi2 = 0.0098), the FE model was selected for estimating the overall economic growth. This model can handle various cross-sectional and temporal dependence issues, making it a robust option ([Hoechle, 2007](#)). Driscoll/Kraay standard errors were used for the analyses to minimize autocorrelation, heteroskedasticity, and cross-sectional dependence issues ([De Hoyos & Sarafidis, 2006](#); [Hanck et al., 2021](#); [Hoechle, 2007](#)). The cluster robust standard error can better resolve heteroskedasticity and autocorrelated errors across entities than within an entity ([Hanck et al., 2021](#)). To eliminate any possible

problems arising from cross-sectional dependence, the Driscoll/Kraay standard error was used in this study. This method is well-suited for handling such problems in panel data analysis ([Hoechle, 2007](#)). Moreover, the output of the functional form validates that the model's specifications were error-free throughout the estimation process ([Ramsey, 1969](#); [Shehata & Mickaiel, 2015](#)).

2.4 Data Sources and Variable Measurement

Historical climate change datasets for both temperature and precipitation were obtained from the Climate Research Unit (CRU CY v4.03 version) of the University of East Anglia. The data was released and updated on July 2, 2021, from 1901 through 2019 ([Harris et al., 2014](#); [Harris et al., 2007](#)). The dataset is drawn from 1970 to 2019 for 43 SSA countries.¹⁰ Among these, 24 SSA countries are considered high-risk countries (HRCs) following the time-based global climate risk index ranking and re-ranking¹¹ ([David et al., 2017](#); [Eckstein et al., 2017, 2021](#); [Kreft et al., 2016](#)).

The global climate risk index was calculated using the economic losses and environmental damages caused by extreme weather events, including climate change-related damages and risk indicators per different countries' geographical boundaries. The index ranks countries based on the risks that they face. It considers various climate change variables such as rainstorms, floods, extreme droughts, temperature extremes, and heat and cold waves and the impact that these have, like the number of deceased inhabitants per 100,000 persons, economic losses in US\$ in purchasing power parity (PPP), and per-unit GDP losses ([David et al., 2017](#); [Eckstein et al., 2017, 2021](#); [Kreft et al., 2016](#)). The data for each indicator was retrieved from the International Monetary Fund (IMF).¹²

The coefficient of variation in precipitation and its square were generated based on available data on precipitation. The precipitation variation coefficient captures the average points and the extent of variability in precipitation over time. For instance,

¹⁰ Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Dem. Rep., Congo, Rep., Cote d'Ivoire, Equatorial Guinea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe.

¹¹ I re-ranked the selected 43 SSA countries by taking the recent three years' average cumulative CRI reports to identify HRC. https://www.germanwatch.org/sites/default/files/Global%20Climate%20Risk%20Index%202021_1.pdf

¹² Details can be seen at: <https://www.germanwatch.org/sites/default/files/publication/20432.pdf>

increased variations result in either floods if they are higher than the historical average or droughts if they are lower than the historical average.

This study used average temperature and annual precipitation as indicators of climate change,¹³ including the coefficient of precipitation variation¹⁴ and its square to measure its association with economic growth. Temperature and precipitation are fundamental proxies for estimating the effects of climate change on economic growth ([Pachauri et al., 2014](#); [Reidmiller et al., 2017](#)). These indicators' absolute and relative changes can significantly affect the region's economic growth as well as its growth elsewhere ([Parry et al., 2007](#)). Additionally, their reciprocating behavior enables forecasting the intensity and magnitude of floods and droughts and their effect on growth ([Dell et al., 2014](#)). For instance, it is believed that changes in temperature are progressively decreasing the region's economic growth year after year ([Maino & Emrullahu, 2022](#)). Hence, after 2100, Africa's economic growth will reduce by 8.6 percent in response to changes in temperature and erratic precipitation ([Okonjo-Iweala, 2020](#)).

The coefficient of variation in precipitation and its square were generated using data available on precipitation. The precipitation variation coefficient captures the average points and extent of variability in precipitation over time. This means that increased precipitation variations may result in floods if the variation is higher than the historical average or droughts if the variation is lower than the historical average. The FE model captures the effects of unobservable factors of droughts and floods by including the coefficient of variation (CVPM) and its square, $CVPM^2$, in the model for specific locations. These locations are defined by each country's geographical boundaries and the extent of variations in precipitation changes.

Economic growth data, such as GDP per capita and total population, was obtained from the World Bank database (the World Development Indicators' website).¹⁵ The GDP value addition data for agriculture, industry, manufacturing, and service sectors was

¹³ It is imperative to note that this particular study does not delve into the underlying causes of temperature and precipitation variability, such as the impact of greenhouse gas emissions. Further research in this area is necessary to fully understand the complex interplay between various environmental factors and their influence on climate patterns. See Appendix 2 for more details.

¹⁴ Precipitation variation is commonly expressed as a percentage ranging from 0 to 100, or alternatively, from 0 to 1 values. It is typically calculated by multiplying the standard deviation from the historical average norm by the mean precipitation. This approach provides the magnitude of precipitation variation and its pattern to help understand the status of climate change.

¹⁵ <https://datatopics.worldbank.org/world-development-indicators/>

obtained from each country's World Bank WDI database ([WB, 2020](#)). The manufacturing sector is a critical component of the economy, encompassing a range of sub-sectors¹⁶ that contribute to the value-addition process. It is worth noting that the construction sector is not included in the manufacturing sector, but it is included in the industry sector.

The rationale for distinguishing between industry and manufacturing is that, given their composition, the impact of climate change may vary between the two sectors ([Yang, 2018](#); [Zhang et al., 2018](#)). For instance, adverse climate change may significantly impact the production of food, beverages, and tobacco in the manufacturing sector and their contribution to GDP. Whereas the industry sector could be less affected or unaffected by climate change, the sector, especially the construction sub-sector, is a significant contributor to climate change, along with other environmental factors such as air and landfill waste pollution.

The data for human capital was obtained from the Penn World Table (PWT), version 10.0,¹⁷ in terms of the percentage of gross secondary school enrollments ([Feenstra et al., 2015](#)). It states that the total enrollment percentage of all age groups was related to secondary-level education. According to [WB \(2020\)](#), this stage is believed to have an influential impact on the foundation of human development in terms of increasing human capital development.

This study investigated the impact of climate change on growth, both in aggregate and specific sectors. The study considered labor (gross secondary school enrollments) as a covariate in the production function (defined in Equation 1) to ensure its impact was controlled. GDP per capita, which assumes a mid-year or total population variable, was used as the outcome variable. Thus, the study did not include additional control variables to avoid over-controlling, overfitting, and spurious estimations ([Dell et al., 2014](#)). Finally, the data was calibrated and cross-checked for consistency with previous work and output ([Alagidede et al., 2015](#); [Dell et al., 2012](#); [Serdeczny et al., 2017a](#)).

¹⁶ These sub-sectors include textile and clothing, food, beverages and tobacco, chemicals, machinery, and transport equipment, medium and high-tech manufacturing, and other manufacturing, which comprises residual products, wood, paper, petroleum, basic metals, mineral products, fabricated metal products, and professional goods-related products.

¹⁷ The data is available for download at www.ggd.net/pwt

2.5 Results

2.5.1 Descriptive Statistics

Table 2.1 provides a detailed description of the variables that were used in the study. The climate change variables considered include temperature, precipitation, and the coefficient of variations in precipitation and its square. The economic growth variables include GDP per capita, value-added GDP per capita of agriculture, industry (including construction), manufacturing and service sectors, and human capital (gross secondary school enrollments). These variables were analyzed for all the countries in the study.

Table 2.1, Column 3 presents the average and deviations of the various study variables from the mean value. The average temperature across the countries over the specific years was 24.41 degrees Celsius, while precipitation and its coefficient of variation were 1060.68 mm and 0.832, respectively. Temperature deviated from the mean by 3.371 degrees Celsius per year, whereas annual precipitation and its coefficient of variations deviated from the average value by 579.6 mm per year and 0.34 (34 percent) correspondingly. Based on historical data, the average GDP per capita for the region was 6.97, with a standard deviation of 0.94. The average value added of agriculture to SSA's GDP was 5.28, while industry, including construction, manufacturing, and services, was 5.44, 4.68, and 6.18, respectively.

In Table 2.1, the last two columns (4&5) give the change in the mean and standard deviation values of the different economic and climate change variables. The mean temperature value was lower in the first five years (1970-75) than in the final five years (2014-19). However, the changes in precipitation and its coefficient of variation showed the opposite trend. This means that precipitation and its variation coefficient were higher in the last five years than in the earlier period (1970-75). The aggregate and the sector-level GDP per capita value additions were higher in the final five years than in the initial five years. However, the magnitude varied from sector to sector. For instance, the GDP per capita in the agriculture sector was meager and decreased over time compared to the growth in other sectors. Thus, the agricultural sector's contribution to the change in GDP per capita value addition was more negatively affected than that of different sectors in SSA countries. The empirical analysis in this paper also confirms this finding.

Figure 2.2 gives the descriptive results of average temperature, variations in precipitation, and GDPPC by country across the study region. As Figure 2.2 (Panels A &

B) indicates, most countries were below the average value of the region’s GDP per capita. Panel A has four sections or quadrants¹⁸ that explain countries’ descriptive behavior following the nature of the mean values of GDP per capita and temperature. The bottom right quadrant (IV-Quadrant) (below the reference line) indicates countries with low GDPPC and high temperatures. IV-Quadrant is where the GDP per capita is at a low position, whereas a change in temperature on average is very high compared to the other quadrants. For instance, about 34.9 percent of the countries are in the IV-Quadrant. In Panel B, the last quadrant is accompanied by a low GDPPC and a high coefficient of variations in precipitation; about 30.23 percent of the countries faced the effects of high variations in precipitation along with low per capita GDP.

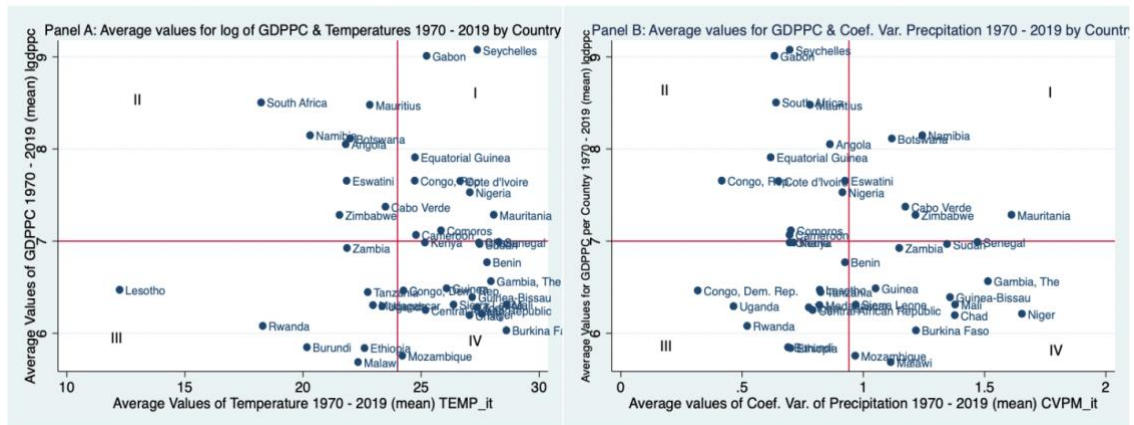


Figure 2.2: Average values of the coefficient of variations for precipitation, temperature, and GDP per capita per country (1970-2019)

Source: Author’s calculation based on CRU and WDI (2021) data. **Notes:** The average temperature values and coefficient of precipitation variations are depicted on the X-axis, while GDPPC is on the Y-axis per country. Panel A shows the average values of temperature and GDPPC, while Panel B shows the mean values of the coefficient of variations in precipitation and GDPPC.

¹⁸ These are the top right (I-Quadrant), top left (II-Quadrant), bottom left (III-Quadrant), and bottom right (IV-Quadrant) quadrants.

Table 2.1: Descriptive statistics and an explanation of the variables

(1)	(2)	(3)		(4)		(5)	
VARIABLES	Description of the Variables	1970-2019		1970-1975		2014-2019	
		Mean	Std.Dev	Mean	Std.Dev	Mean	Std.Dev
<i>Panel A: Historical Climate Change (1970 -2019)</i>							
TEMP _{it}	Annual average temperature in degrees Celsius	24.411	3.371	23.92	3.36	24.84	3.33
AnnPreMz _{it}	Annual average Precipitation in mm	1060.7	579.6	1032.6	587.8	1016.0	570.0
CVPM _{it}	Variation of precipitation	.942	.346	.96	.37	.93	.34
CVPM ² _{it}	Squared variation of precipitation	1.007	.717	1.0	.78	.98	.71
<i>Panel B: Economic growth indicators (1970 -2019)</i>							
Y _{it}	Annual GDP per capita in terms of the natural logarithm	6.973	.941	6.83	.82	7.25	.98
lh _{it}	Gross national percentage of secondary school enrollments (log)	3.078	.872	2.16	.89	3.84	.42
Pop	Total population	15.49	1.55	14.91	1.45	16.04	1.57
lAgr _{it}	Agriculture, forest, and fishing value added per capita	5.282	.542	5.27	.56	5.33	.55
lInd _{it}	Industry GDPPC, including construction	5.444	1.33	5.01	1.19	5.71	1.22
lServ _{it}	Service value added GDPPC	6.18	1.05	5.73	.73	6.49	1.09
lMnuf _{it}	Manufacturing sector value added GDPPC	4.68	1.24	4.37	1.36	4.9	1.21

Source: Author's computation based on CRU and WB WDI (2021).

2.5.2 Empirical Results

Table 2.2 illustrates the impact of climate change on aggregate economic growth, measured by GDP per capita, while controlling for year- and country-fixed effects. Columns 1 and 2 independently assess the impacts of temperature and precipitation, while Column 3 considers both factors. Column 4 adds the variance of precipitation and its square. Column 5 mimics Column 4 but excludes precipitation from the estimation. Column 6 incorporates temperature and precipitation interaction terms with a dummy indicating whether the countries are classified as high-risk.

Temperature (Column 1) is negative, and precipitation (Column 2) is positively related to GDP per capita. An increase in temperature from the historical average (Column 1) is associated with a decrease in aggregate GDP per capita of 0.018 percentage points. In comparison, an increase (decrease) in precipitation enhances (lower) GDP per capita by 0.027 percentage points in the region (Column 2).

Simultaneously accounting for temperature and precipitation (Column 3), a unit change in temperature is associated with a decrease in GDP per capita by 0.0156 percentage points per year, while 100mm higher precipitation per year significantly boosts the GDP per capita by 0.02 percentage points. The similarity in parameter estimates between Column 3 and the first two columns indicates that the estimated effects of temperature and precipitation are relatively independent of each other in magnitude.

Column 4 introduces precipitation variation and its square. However, this does not alter the sign of the estimated coefficients for temperature and precipitation. The result shows the potential adverse effects of temperature on the economic growth in the region. Accordingly, a one-degree-Celsius increase in temperature¹⁹ is associated with a 0.0164 percentage point decrease in GDP per capita. Higher precipitation levels generally support economic growth but can also adversely affect it through flooding, infrastructure damage, high repair costs, and agricultural disruption.

The squared precipitation variation negatively affects economic growth, as the inverted U-shape curve²⁰ shows. The peak of the curve, or inflection point, occurs when the squared coefficient of variation reaches approximately 1.01, indicating an average

¹⁹ The models were also estimated, including the squares of temperature and precipitation, but the resulting parameter estimates of these entities were insignificant (the results are not given in this paper but are available on request from the author).

²⁰ The u-test results show that the presence of an inverted-U shape is significant at less than a 1 percent significance level where the curve attains its extreme point at 1.010549.

variation of 1.007 (see Table 2.1). Thus, the higher the frequency of the variations, the higher the adverse effect on aggregate economic growth through increased floods or droughts. Initially, economic growth increases with squared precipitation variation until reaching a saturation or inflection point. Then, the per capita GDP starts decreasing as long as the coefficient of variation increases.

Table 2.2: Estimation results of the fixed effects model

The dependent variable, lgdppc, represents the logarithm of GDP per capita.						
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
TEMP_it	-0.0180*** (0.00439)		-0.0156*** (0.00469)	-0.0164*** (0.00464)	-0.0181*** (0.00460)	2.56e-05 (0.00747)
lAnnPreMz		0.0270** (0.00705)	0.0203** (0.00797)	0.0193** (0.00825)		0.0295* (0.0148)
CVPM_it				0.0559 (0.0542)	0.0677*** (0.0229)	
CVPM_it^2				-0.0177 (0.0212)	-0.0338*** (0.0105)	
HC				-0.00288 (0.00354)		
HRC × TEMP_it						-0.0277*** (0.00528)
HRC × lAnnPreMz						-0.0153 (0.0241)
Constant	0.0411*** (0.00143)	-0.0698** (0.0303)	-0.0440 (0.0337)	-0.0650 (0.0533)	0.00829 (0.0113)	0.262 (0.197)
Observations	2,014	2,014	2,014	2,004	2,014	2,014
R-squared	0.074	0.072	0.076	0.078	0.074	0.084
Number of Countries	43	43	43	43	43	43
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Functional form	0.5916	0.0031	0.6925	0.3450	0.8239	0.9413

*Notes*²¹: In the estimations, the dependent variable is the annual GDP per capita in terms of the natural logarithm. Variable TEMP_it is temperature, lAnnPreMz is average monthly annual precipitation, CVPM_it is the coefficient of variations in precipitation, CVPM_it^2 is the coefficient of variations in precipitation squared, HC is the gross national percentage of secondary school enrollments (natural log), HRC refers to the countries with high climate risk effect's dummies according to the Global Climate Risk ranking. Thus, both average temperature and precipitation interacted to estimate the effects of climate change on growth. Year FE implies year-fixed effects inclusion, and country FE is a country-fixed effect. The functional form refers to Ramsey's RESET test with 3 degree of freedom distribution. Driscoll/Kraay Standard errors in parentheses *** p<0.01, ** p<0.05, and * p<0.1.

Source: *Author's computation based on CRU and WB WDI (2021) data.*

Column 5 shows the effect of temperature and the coefficient of variations in precipitation and its square. The estimation was conducted without precipitation to verify the economic feasibility of its positive sign regarding growth in previous columns. The results indicate that high variations in precipitation significantly adversely affect growth

²¹ Estimation results with and without lagged effect are provided in the Appendix 4: Table 2.1

through increased floods or droughts. Thus, temperature and the squared coefficient of precipitation substantially and negatively affect SSA countries' GDP per capita.

In Table 2.2's last column, temperature and precipitation interact with a dummy variable indicating high-risk countries most affected economically by climate change. Low-risk countries experience fewer adverse effects compared to high-risk ones. High-risk countries are more vulnerable to temperature changes, with a unit increase associated with a 0.028 percentage point decline in GDP per capita. This impact is less pronounced in low-risk countries. Thus, temperature's effect on GDP per capita is significant mainly in high-risk countries, while precipitation shows no substantial difference between high- and low-risk countries.

After estimation, the effects of temperature and the squared coefficient of variations in precipitation on GDP per capita are given in Figure 2.3 to supplement the results in Table 2.2

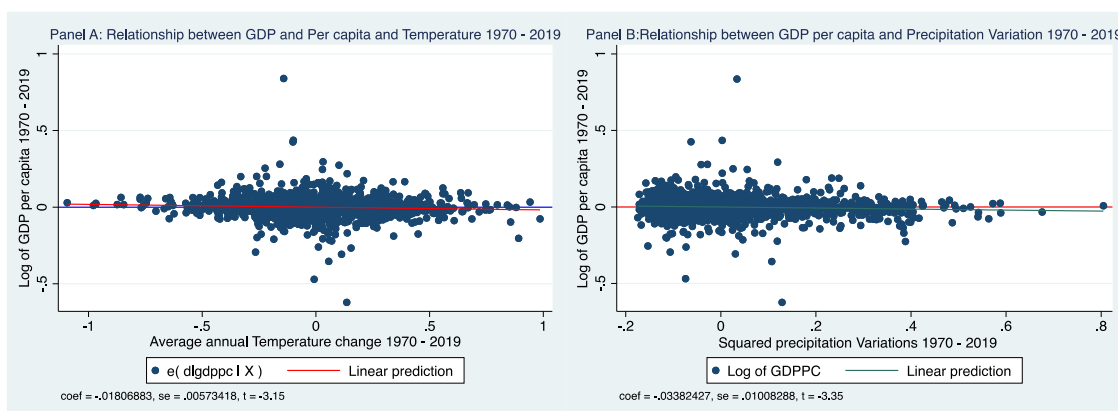


Figure 2.3: Effects of temperature and the squared coefficient of variations in precipitation on per capita GDP.

Source: Author's computation based on CRU and WB WDI (2021) data.

Notes: The relationship between climate variables such as average annual temperature change (Panel A), coefficient of variations in precipitation squared (Panel B), and GDP per capita of SSA countries for 1970-2019 using CRU (climate data) and WDI growth data. Panel A shows GDP per capita against mean temperature change, and Panel B shows GDP per capita against the coefficient of variations in precipitation squared for each country across the years. Blue-black dots are the GDP per capita of each country against respective predictors in the model.

Following FE estimation methods, Figure 2.3 presents how changes in temperature and squared coefficient of precipitation variations affect SSA countries' aggregate economic growth. The graphs in Panel A and Panel B explain the correlation between GDP per capita and temperature, as well as the squared coefficient of variations in precipitation. The FE model reveals a negative correlation between climate change and economic growth, adjusted for year and country-specific effects (Table 2.2). The

plotted linear line has the same slope as the FE model's estimation values, indicating a decline (Table 2.2, Column 5). The impact of climate change varies depending on whether the data point is above or below the fitted line, implying that both temperature and the squared coefficient of variations in precipitation affect SSA countries' per capita GDP.

In Figure 2.3, Panel A shows a negative correlation between temperature and GDPPC in SSA countries, and Panel B shows the adverse effects of the squared variations in precipitation on GDPPC over time. Thus, a higher temperature and an increased square of variations in precipitation are linked to the recurring effects of droughts and floods in the region. This is significantly correlated with the region's declining per capita output.

Table 2.3 gives the sector-level effects of climate change on agriculture, industry, manufacturing, and services using various specifications for each sector. All explanatory variables are identical to those in the fixed-effects model presented in Table 2.3, facilitating the identification of the joint effects of the climate variables on different sectors. For comparative reasons, each sector has estimates from four distinct models (represented in four columns). The first column of each sector provides an estimate without including year and country dummies, resulting in a naive pooled model. The second column of each sector consists of a country- dummies but no year dummies. Most importantly, the third column of each sector includes both country- and year-fixed effects and provides the major results of the study, discussed in more detail below (Columns 3, 7, 11, and 15). Finally, the last column of all the sectors includes year- dummies but no country- dummies.

Across all sectors, temperature is negatively associated with growth, but this association is significant only for agriculture (Columns 3, 7, 11, and 15). The agriculture sector's GDP per capita is subject to a decline of 0.033 percentage points following a one-degree Celsius rise in temperature. A 100mm increase (decrease) in precipitation would increase (decrease) GDP per capita by 0.068 percentage points. Conversely, increased precipitation adversely affects the service sector's GDP per capita, but it has no significant relationship with sectors such as industry and manufacturing in SSA countries. Considering country and year fixed effects and including temperature and precipitation levels in the estimations, the associations between precipitation variations and its square and economic growth are statistically insignificant in all sectors.

Table 2.3: Estimation results of Seemingly Unrelated Regression Model

Dependent Var.	Log of Agriculture Per Capita GDP				Log of Industry Per Capita GDP				Log of Manufacturing Per Capita GDP				Log of Service Per Capita GDP			
VARIABLES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
TEMP_it	-0.0293*** (0.0075)	-0.0226*** (0.0076)	-0.0335*** (0.0098)	-0.0406*** (0.0098)	-0.0047 (0.0085)	-0.0028 (0.0085)	-0.0021 (0.0112)	-0.0018 (0.0113)	-0.0091 (0.0100)	-0.0077 (0.0100)	-0.0099 (0.0132)	-0.0096 (0.0132)	-0.0008 (0.0056)	0.0009 (0.0056)	-0.0076 (0.0072)	-0.0059 (0.0072)
lAnnPreMz	0.0051 (0.0047)	0.0754*** (0.0186)	0.0680*** (0.0194)	0.0045 (0.0046)	-0.0025 (0.0053)	0.0215 (0.0208)	0.0025 (0.0222)	-0.0032 (0.0053)	-0.0045 (0.0062)	0.0091 (0.0246)	-0.0016 (0.0262)	-0.0052 (0.0062)	-0.0047 (0.0035)	0.0075 (0.0137)	-0.0277* (0.0141)	-0.0076** (0.0034)
CVPM_it	0.0344 (0.0354)	-0.0271 (0.0809)	-0.0375 (0.0800)	0.0322 (0.0344)	0.0958** (0.0401)	-0.0038 (0.0907)	-0.0031 (0.0913)	0.0924** (0.0397)	0.1294*** (0.0471)	0.1217 (0.1074)	0.1439 (0.1077)	0.1328*** (0.0465)	0.0764*** (0.0263)	0.0009 (0.0596)	0.0236 (0.0582)	0.0797*** (0.0254)
CVPM_it^2	-0.0140 (0.0184)	0.0107 (0.0374)	0.0201 (0.0370)	-0.0138 (0.0180)	-0.0502** (0.0209)	0.0023 (0.0419)	0.0097 (0.0422)	-0.0480** (0.0207)	-0.0715*** (0.0245)	-0.0456 (0.0497)	-0.0499 (0.0497)	-0.0737*** (0.0243)	-0.0340** (0.0137)	0.0163 (0.0275)	0.0119 (0.0269)	-0.0389*** (0.0133)
HC	-0.0011 (0.0034)	0.0016 (0.0051)	-0.0034 (0.0085)	-0.0029 (0.0039)	-0.0008 (0.0038)	-0.0017 (0.0058)	-0.0020 (0.0097)	0.0009 (0.0045)	0.0006 (0.0045)	-0.0002 (0.0068)	-0.0136 (0.0114)	0.0001 (0.0053)	0.0056** (0.0025)	0.0077** (0.0038)	-0.0008 (0.0062)	0.0033 (0.0029)
Constant	-0.0361 (0.0293)	-0.3014*** (0.0951)	-0.2780*** (0.1039)	-0.0546 (0.0477)	-0.0127 (0.0332)	-0.0805 (0.1066)	0.0906 (0.1185)	0.0869 (0.0550)	-0.0182 (0.0390)	-0.0868 (0.1263)	-0.0376 (0.1399)	-0.0078 (0.0645)	-0.0182 (0.0218)	-0.0564 (0.0700)	0.0489 (0.0756)	-0.0352 (0.0352)
Observations	1,387	1,387	1,387	1,387	1,387	1,387	1,387	1,387	1,387	1,387	1,387	1,387	1,387	1,387	1,387	1,387
R-squared	0.0132	0.0490	0.1169	0.0845	0.0044	0.0599	0.0961	0.0409	0.0068	0.0463	0.0898	0.0478	0.0141	0.0666	0.1532	0.0966
Year FE	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes
Country FE	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes	No
Number of Countries	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43	43

Notes: Climate change variables are obtained from CRU and all other growth data is retrieved from WDI. The dependent variables are *lAgr_itpc* which is the log of agriculture, forestry, and fishing value added per capita, *lInd_itpc* is log of industry value added per capita including construction, *lManf_itpc* is log of manufacturing value added per capita, and *lServ_itpc* is log of services value-added per capita GDP. Independent variables include TEMP_it = average annual temperature change in degree Celsius, lAnnPreMz = average monthly annual precipitation in mm/year, CVPM_it = the coefficient of variations in precipitation, CVPM_it^2 = squared coefficient of variations in precipitation, HC = human capita measured in terms of the gross secondary school enrollment ratio. Year FE is year dummies (yes or no), Country FE is country dummies (yes or no) across the columns. *** p<0.01 (significant at the 1 percent level), ** p<0.05 (significant at the 5 percent level), and * p<0.1 (significant at the 10 percent level). Robust Standard errors are in parentheses.

Source: Author's computation based on CRU and WB WDI (2021) data.

2.5.3 Discussion

This study addresses how temperature, precipitation, and the squared coefficient of precipitation variations influence economic growth overall and in different sectors. The main finding is that higher temperatures and lower precipitation adversely affect growth, primarily due to a strong association between these entities and growth in the agricultural sector.

Increased variations in squared precipitation indicate more irregular rainfall (lower or higher than the historical average), which may well also impact economic growth in the long term. Such variations result in disasters like floods and droughts, which can alter land productivity and usage and decrease per capita output, particularly in the agricultural sector. This, in turn, may indirectly affect the per capita growth of the industry, manufacturing, and service sectors, as many industrial and manufacturing inputs are sourced from agriculture²² (Osuagwu, 2018, 2020). On the other hand, the growth of other sectors may also affect the growth of the agriculture sector (Nwani et al., 2020). Additionally, the service sector may face challenges due to disruptions in the value chain caused by climate change, impairing product delivery systems and transportation.

Increased positive deviations in precipitation from the historical mean can lead to more floods and landslides, which is consistent with Winter and Shearer's (2013) findings; conversely, increased negative deviations and low-intensity precipitation cause droughts and economic shocks, impacting the agricultural sector²³ and reducing per capita income. The effects of temperature and the squared coefficient of precipitation

²² While the estimated effects focus on direct sectoral impacts, it is important to acknowledge the potential for indirect effects, especially through the agriculture sector's role in input provision, income generation, and rural demand. For instance, disruptions in agricultural output due to climate shocks may affect input supply chains for agro-based industries, raise food prices, or reduce rural household incomes, which in turn can depress demand for services such as retail, finance, or transport. These spillovers are not explicitly modeled in this study but may be significant, particularly in economies with strong forward and backward linkages across sectors. Future work using structural or general equilibrium approaches could help illuminate these channels more fully.

²³ Increased droughts and floods result in substantial crop and livestock production loss and aggravate poverty. The higher the frequency of droughts and floods, the higher the recurrent starvation. For instance, increased variations in precipitation and temperature from the mean value in any direction lead to a higher poverty level.

variations on economic growth are significant for aggregate and sector-specific economic growth.

In summary, Table 2.2 shows that changes and fluctuations in temperature and the squared coefficient of precipitation negatively affect the aggregate economic growth of Sub-Saharan African nations in terms of GDP per capita. In the region, a decrease in the average annual precipitation tends to have a negative impact on overall economic growth. In contrast, moderate precipitation levels can positively influence agricultural productivity and boost economic growth. However, temperature consistently shows a negative association across all estimation points²⁴.

According to the SUR model's estimation in Table 2.3, different sectors are variably affected by climate change, with the agricultural sector being most adversely impacted by rising temperatures. For other sectors, the estimated impact of a temperature increase is negative but statistically insignificant. Speculatively, the negative association between temperature and output in these sectors may partly result from spillovers from the agricultural sector. This underscores the agricultural sector's crucial role in aggregate economic growth in the SSA context.

At the sector level, Table 2.3 shows that agricultural productivity is highly vulnerable to climate change, particularly temperature changes and decreased precipitation, which hamper the agriculture sector's growth contribution. The findings also reveal a nuanced interaction between precipitation patterns and sectoral growth. Apart from moderate precipitation levels compared to historical norms, increased precipitation is associated with negative consequences for economic growth metrics. It damages and reduces per capita output, exacerbating the detrimental impacts of temperature rise in the region.

To further validate the core findings and account for potential non-linear climate-growth relationships, a threshold-based analysis was conducted. This approach assessed whether exceeding critical levels of temperature and precipitation imposes disproportionate economic costs in Sub-Saharan Africa. Drawing from established literature, thresholds were set at 25°C for mean annual temperature and 1100 mm/year for precipitation, benchmarks associated with heat-induced productivity losses ([Burke et](#)

²⁴ Overall economic growth is negatively impacted by climate change variables, such as temperature and the squared coefficient of precipitation variations, regardless of whether year and country-fixed effects are considered, even though the focus is solely on the fixed effects.

al., 2015; [Schlenker & Roberts, 2009](#)) and agro-ecological water needs in rain-fed agricultural systems ([FAO, 2016](#); [Rockström et al., 2007](#)). The results show that countries with average annual temperatures above 25°C experience a statistically significant decline in GDP per capita approximately by 3.6–3.7 percentage points. Similarly, countries receiving less than 1100 mm of precipitation per year face substantial growth constraints. These findings, summarized in Table 2.5, serve as a robustness check that supports the linear model's main conclusions and highlights the heightened vulnerability to climatic extremes.

In parallel, a deviation-based analysis reveals that even modest warming above historical norms (e.g., +0.5°C relative to a country's long-term mean) has a significant negative effect on growth. However, larger deviations (+1.0°C to +2.0°C) are not statistically significant, potentially reflecting regional differences in exposure, adaptation, or distributional dynamics (Table 2.6, Appendix 2.4). Together, the two approaches offer complementary insights: while deviation-based thresholds signal early-onset economic vulnerability, absolute thresholds highlight the compounded risks of prolonged climatic stress. This dual evidence underscores the urgency of policy interventions that address both incremental and extreme climate impacts in the region.

Conversely, increased droughts and floods lead to crop failures and livestock deaths. In Sub-Saharan African (SSA) countries, high-risk and low-income nations face the maximum consequences of climate change compared to low-risk and high-income countries. However, different scenarios have recently been observed due to recurrent floods and droughts. For instance, despite their strong economic positions and diversified sectors beyond agriculture, South Africa and Nigeria have recently experienced frequent droughts and floods, affecting the rural economy and livelihoods ([Chersich & Wright, 2019](#)). In other SSA countries, where agriculture is the primary growth-contributing sector and is dominated by small-scale farmers, the sector is highly vulnerable to climate change.

These findings show that temperature changes significantly affect agriculture's growth contribution. These results have important implications for policymakers and stakeholders concerned with the sustainable development of the agriculture sector, highlighting the need to incorporate climate change considerations into policy and planning frameworks.

Table 2.3 shows that temperature changes influence growth across different sectors, with agriculture particularly affected. Higher temperatures negatively impact

agricultural output, while increased precipitation benefits it, as seen in Column 3. In Column 15, rising temperatures and increased precipitation negatively affect the service sector. The decline in agricultural growth due to climate change can adversely affect various sectors, including industry, manufacturing, and services, illustrating climate change's broad direct and indirect impacts.

Diagnostic tests support the robustness of the SUR estimates Table 2.7. The Breusch–Pagan test confirmed significant cross-equation correlation, justifying the use of SUR over separate OLS regressions. VIF values showed no concerns of multicollinearity. Heteroskedasticity was not detected in most equations, while two exhibited only weak evidence. Despite residuals deviating from normality, the large sample sizes ($N > 1400$) support the validity of inference under the Central Limit Theorem (CLT).

Thus, climate change variables exhibit different behaviors at the sector level. On one hand, the adverse effects are most pronounced in the agriculture sector, which has extended spillover effects on other sectors. On the other hand, the cumulative negative impact on agriculture drags down the aggregate GDP per capita of every country in the region. Thus, the effects on agriculture negatively affect other sectors' growth contributions and, consequently, overall economic growth.

2.6 Conclusion and Recommendation

SSA countries' economic growth depends more on climate-sensitive sectors like agriculture, including forests and fisheries. Most inputs for the industry and manufacturing sectors come from this sector. Consequently, an impact on the agriculture sector affects the aggregate GDP per capita and sector-specific economic growth.

This study examined the effects of climate change on SSA countries' aggregate and sector-level economic growth in terms of GDP per capita. The findings show that climate change adversely affected aggregate and specific sectors' growth contributions. The impact on specific sector-level growth differed from one sector to the other and was not uniform. However, a significant effect of climate change was observed in the agriculture sector's GDP per capita compared to the different sectors, such as industry, manufacturing, and services. The countries most sensitive to climate change suffered the most due to rising temperatures and decreasing precipitation.

This study arrived at four main conclusions based on the major results. First, at all estimation levels, increased temperatures negatively and significantly affected

growth. Second, the region's aggregate GDP per capita was positively associated with average annual precipitation. Third, under all conditions, the squared coefficient of variations in precipitation negatively affected the GDP per capita. Fourth, low-risk countries experienced less vulnerability to precipitation shocks than high-risk countries, which were more vulnerable to temperature shocks. Thus, there is a meaningful link between temperature variations and GDP per capita, but this connection predominantly impacts high-risk countries. Meanwhile, countries with lower risk profiles appear less influenced or entirely unaffected by these temperature changes.

The following conclusions are based on the results of the sector-specific analysis. First, regardless of the estimation specification, temperature change negatively affected the agriculture sector's growth. Second, annual precipitation was linked to a positive return and enhanced the agriculture sector's growth. Third, the squared coefficient of variations in precipitation negatively impacted the growth of the rest of the sectors. Fourth, the industry, manufacturing, and service sectors experienced negative effects from temperature changes; however, these effects were not statistically significant. Fifth, the squared coefficient of precipitation variations was significantly and negatively associated with sector-level growth.

The SSA countries are significantly overwhelmed by and vulnerable to climate change. Thus, the region should adopt mitigation strategies or adaptation mechanisms²⁵ to tackle the increase in the impact of climate change at all levels. To put it differently, SSA countries should have intensive adaptation strategies and plausible economic policies and implementations to promote sustainable economic growth, such as a green economy.

Therefore, to address the growing risks of climate change on economic growth, the region must:

- Build green, sustainable, and lasting economic growth policies and implement them to promote accelerated and integrated economic growth.
- Construct a proactive disaster risk management system to protect the fragile agriculture sector's output and the productivity of the industry, manufacturing, and service sectors.

²⁵ Adaptation policies such as irrigation, resilient infrastructure, and early warning systems are recognized as vital responses to climate risks. However, due to data unavailability, this study limits itself to impact assessment. Future research could integrate these resilience-building mechanisms into empirical models to quantify their economic benefits.

- Integrate climate and economic policies to avoid environmental and economic development hostility.²⁶
- Implement various adaptation strategies such as reforestation and different natural resource rehabilitation practices, such as reforestation and natural resources.
- Develop innovative technologies that could pertain to the changing climate and practice climate-smart agriculture (CSA), including implementing holistic natural resource management.
- Launch intensive agriculture technologies in rural areas such as drip irrigation, climate-resilient crops, livestock production, harvesting rainwater for different purposes, and using scarce resources efficiently.
- Implement innovative technologies to overcome the problems associated with more droughts and floods since there is an increased coefficient of precipitation and temperature variations.
- Seek international support and funding for adaptation strategies, focusing particularly on countries at high risk that are more vulnerable to the impacts of climate shocks.
- Increase political commitment and willingness to launch and implement comprehensive climate-resilient technologies and economic policies and create regional integration for implementing a holistic and integrated development plan.

Appendix 2.1: Supplementary Logarithmic Transformations and Differentiation in the Model

As stated in [Bond et al. \(2010\)](#) and [Dell et al. \(2012\)](#), the general growth equation for the log-level GDP per capita growth is as follows:

$$Y_{it} = A_{it} + \alpha_1 Y_{it-1} + \alpha_2 Y_{it-2} + \dots + \alpha_p Y_{it-p} + \beta_0 C_{it} + \beta_1 C_{it-1} + \beta_2 C_{it-2} \dots + \beta_p C_{it-p} + \varepsilon_{it} \quad 1.1.$$

Thus, Equation 1.1 simplifies Equation 1. In the equation, A_{it} is a dynamic process with p -lags, although it does not undertake the lags for this case. Since we consider that A is labor productivity, either the current or the past (lagged) climate change can affect its growth. Thus, equation 2 can be simplified accordingly.

$$\Delta A_{it} = y_i + \beta_0 C_{it} + \beta_1 C_{it-1} + \beta_2 C_{it-2} + \dots + \beta_p C_{it-p} \quad 2.1.$$

²⁶ One potential strategy for achieving a more sustainable future is implementing policies that take an integrated approach to the climate and economic growth nexus. Such an approach can facilitate a mutual reinforcement between these two factors, with the ultimate goal of achieving a zero-harm outcome for both the environment and economic development. By adopting this approach, policymakers can work towards a more harmonious relationship between economic growth and environmental sustainability, thereby promoting society's and the planet's long-term well-being.

By first differencing Equation 1.1., and substituting Equation 2.1. into Equation 1.1, the following form of estimation can be obtained:

$$\Delta Y_{it} = y_i + \alpha_1 \Delta Y_{it-1} + \alpha_2 \Delta Y_{it-2} + \dots + \alpha_p \Delta Y_{it-p} + \gamma_0 C_{it} + \gamma_1 C_{it-1} + \gamma_2 C_{it-2} + \dots + \gamma_p C_{it-p} + \beta_0 \Delta C_{it} + \beta_1 \Delta C_{it-1} + \beta_2 \Delta C_{it-2} \dots + \beta_p \Delta C_{it-p} + \Delta \varepsilon_{it} \quad 2.2.$$

By rewriting the vector of climate change term $\Delta C = C$ results in:

$$\Delta Y_{it} = y_i + \alpha_1 \Delta Y_{it-1} + \alpha_2 \Delta Y_{it-2} + \dots + \alpha_p \Delta Y_{it-p} + (\gamma_0 + \beta_0) C_{it} + (\gamma_1 + \beta_1 - \beta_0) C_{it-1} + (\gamma_2 + \beta_2 - \beta_1) C_{it-2} + \dots + (\gamma_p + \beta_p - \beta_{p-1}) C_{it-p} + \beta_p C_{t-p-1} + \Delta \varepsilon_{it} \quad 2.3.$$

Reorganizing the coefficients on climate change C :

$$\Delta Y_{it} = y_i + \alpha_1 \Delta Y_{it-1} + \alpha_2 \Delta Y_{it-2} + \dots + \alpha_p \Delta Y_{it-p} + \sum_{j=0}^{p+1} \varrho_j C_{ij} + \Delta \varepsilon_{it} \quad 2.4.$$

Following the formulations of [Dell et al. \(2012\)](#), we can check out the effects of climate change on growth when growth is at a steady-state ($\Delta Y_{it-j} = \Delta Y$) and climate change is constant ($C_{ij} = C$). Then, solving Equation 2.4. yields:

$$\Delta Y_{it} = \frac{y_i}{1-\alpha_1-\dots-\alpha_p} + \frac{\sum_{j=0}^{p+1} \varrho_j}{1-\alpha_1-\dots-\alpha_p} C_i ; \quad 2.5.$$

The growth effects of climate change are $\frac{\sum_{j=0}^{p+1} \varrho_j}{1-\alpha_1-\dots-\alpha_p}$. Thus, since we canceled out all β in Equation 2.3. the $\frac{\sum_{j=0}^{p+1} \varrho_j}{1-\alpha_1-\dots-\alpha_p}$ is almost similar to $\frac{\sum_{j=0}^p \gamma_j}{1-\alpha_1-\dots-\alpha_p}$.

Appendix 2.2: Additional information on climate change data indicators

In addition to the factors outlined in this article, several other elements play a role in the increase in temperature and precipitation fluctuations. These elements are primarily linked to releasing greenhouse gases such as carbon dioxide, methane, and nitrous oxide. These emissions stem predominantly from human activities such as deforestation and burning fossil fuels ([Sathaye et al., 2006](#)). As a result, increased temperatures and changes in precipitation have led to more frequent natural disasters, rising sea levels, droughts, and floods.

Although this study focuses solely on changes in temperature and precipitation, it is worth noting that data for other factors often needs to be completed or available. For example, mean sea level data is unavailable at the country level and is available only at the regional or continental level. The share of forest area data is available, but many values must be added for all SSA countries. The same is true of disaster risk data from the international EM-DAT database (droughts, flooding, forest fires). The EM-DAT data is comprehensive in terms of area coverage and periods. The data is limited due to insufficient worldwide disaster reports, making it challenging to construct all variables over time fully.

Nevertheless, this data remains valuable for most scientific studies on disaster risk management (Jones et al., 2023; Mazhin et al., 2021). These variables are intermittently available across the years and countries and require another methodology and hypothesis, which is not the interest of this study. The CO2 data is fully available for the selected countries. However, I used it solely to hypothesize the impact of temperature and precipitation on economic growth; therefore, this variable was not included in this study.

On the other hand, carbon dioxide is a cause of the rise in temperature with a high contribution to GHG emissions, and it is the cause of historical variations in precipitation relative to the pre-industrial period, given the region's insignificant CO2 emission (Raihan et al., 2022; Ritchie et al., 2020). Thus, to avoid the multicollinearity problem of the predictors, CO2 was not selected for the study. In addition, it is primarily used in causality studies examining the relationship between CO2, economic growth, and energy, measuring the impact of economic growth on CO2 and vice versa (J & Anaba, 2022). Thus, this study does not focus on the root causes of climate change but rather on the causes and impacts of climate change resulting from those root causes.

Appendix 2.3: List of Countries in the Study

List of Countries included in the study

Countries according to their level of Climate risks		
	High Risk Countries	Low Risk Countries
1	Burundi	Angola
2	Congo, Dem. Rep.	Benin
3	Cote d'Ivoire	Botswana
4	Ethiopia	Burkina Faso
5	Ghana	Cabo Verde
6	Kenya	Cameroon
7	Lesotho	Central African Republic
8	Madagascar	Chad
9	Malawi	Comoros
10	Mauritania	Congo, Rep.
11	Mauritius	Equatorial Guinea
12	Mozambique	Eswatini
13	Namibia	Gabon
14	Niger	Gambia, The
15	Nigeria	Guinea
16	Rwanda	Guinea-Bissau

Countries according to their level of Climate risks		
	High Risk Countries	Low Risk Countries
17	Senegal	Mali
18	Sierra Leone	Seychelles
19	South Africa	Togo
20	Sudan	
21	Tanzania	
22	Uganda	
23	Zambia	
24	Zimbabwe	

Appendix 2.4: Estimation results of the fixed effects model With and Without Lag

Table 2.4: Estimation results of the fixed effects model With and Without Lag

The dependent variable, lgdppc, represents the logarithm of GDP per capita.						
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Without Lag						
lgdppc = L,	0.210*** (0.022)	0.210*** (0.022)	0.211*** (0.022)	0.210*** (0.023)	0.265*** (0.022)	0.204*** (0.022)
TEMP_it	-0.022*** (0.006)		-0.019*** (0.006)	-0.019*** (0.006)	-0.022*** (0.006)	-0.010 (0.008)
lAnnPreMz		0.030*** (0.011)	0.022** (0.011)	0.021* (0.011)		0.023* (0.014)
CVPM_it				0.057 (0.046)	0.082** (0.035)	
CVPM_itSqr				-0.019 (0.020)	-0.038** (0.015)	
HC				0.014 (0.019)		
HRC#TEMP_it						-0.019** (0.009)
HRC#lAnnPreMz						-0.001 (0.021)
With Lag						
TEMP_it = L,	-0.003 (0.006)		-0.003 (0.006)	-0.002 (0.006)	-0.002 (0.006)	-0.003 (0.007)
lAnnPreMz = L,		-0.013 (0.011)	-0.009 (0.011)	-0.007 (0.011)		0.011 (0.014)
CVPM_it_ = L,				-0.056 (0.045)	-0.037 (0.035)	
CVPM_itSqr = L,				0.032 (0.020)	0.015 (0.015)	
HC = L,				-0.016 (0.019)		
HRC#TEMP_it = L						0.015 (0.010)
HRC#lAnnPreMz = L						-0.049** (0.021)
Constant	0.012 (0.011)	-0.050 (0.062)	-0.041 (0.062)	-0.048 (0.071)	-0.012 (0.015)	-0.041 (0.239)
Observations	1,971	1,971	1,971	1,961	1,971	1,971
R-squared	0.114	0.111	0.116	0.120	0.138	0.125
Number of Countries	43	43	43	43	43	43

The dependent variable, <i>lgdppc</i> , represents the logarithm of GDP per capita.						
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes

Note: In the estimations, the dependent variable is the annual GDP Per Capita in terms of the natural logarithm. Variable *TEMP_it* is temperature, *lAnnPreMz* is average monthly annual precipitation, *CVPM_it* is the coefficient of variations in precipitation, *CVPM_it^2* is the coefficient of variations in precipitation squared, *HC* is the gross national percentage of secondary school enrollments (natural log), *L* denotes lag, *HRC* refers to the countries with high climate risk effect's dummies according to the Global Climate Risk ranking. Thus, both average temperature and precipitation interacted to estimate the effects of climate change on growth. Year FE implies year-fixed effects inclusion, and country FE is a country-fixed effect. Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

Source: *Author's computation based on CRU and WB WDI (2021) data.*

Table 2.5 Threshold-Based Analysis of Climate Exteremes on GDP Per Capita

The dependent variable, <i>lgdppc</i> , represents the logarithm of GDP per capita.							
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>TEMP_gt_25</i>	-0.037*** (0.013)	-0.036*** (0.013)			-0.036*** (0.013)	-0.036*** (0.013)	-0.036*** (0.013)
<i>TEMP_it</i>		-0.017*** (0.004)				-0.015*** (0.005)	-0.017*** (0.005)
<i>Prec_ANN_1100</i>			-0.012** (0.005)	-0.009 (0.005)	-0.012** (0.005)	-0.008 (0.005)	-0.009* (0.005)
<i>lAnnPreMz</i>				0.023*** (0.007)		0.017** (0.008)	0.000 (0.000)
<i>CVPM_it</i>							0.019 (0.020)
<i>CVPM_it^2</i>							-0.011 (0.023)
<i>HC</i>							-0.005 (0.003)
Constant	0.062*** (0.006)	0.058*** (0.006)	0.051*** (0.003)	-0.050 (0.032)	0.068*** (0.006)	-0.008 (0.033)	0.072*** (0.011)
Observations	2,014	2,014	2,014	2,014	2,014	2,014	2,004
Number of groups	43	43	43	43	43	43	43
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: In the estimations, the dependent variable is the annual GDP Per Capita in terms of the natural logarithm. Variable *TEMP_gt_25* is Temperature Threshold ($>25^{\circ}\text{C}$): A dummy variable = 1 if annual average temperature $> 25^{\circ}\text{C}$, 0 otherwise, *Prec_ANN_1100* is Precipitation Threshold (<1100 mm/year) = 1 if annual precipitation < 1100 mm, 0 otherwise, *TEMP_it* is temperature, *lAnnPreMz* is average monthly annual precipitation, *CVPM_it* is the coefficient of variations in precipitation, *CVPM_it^2* is the coefficient of variations in precipitation squared, *HC* is the gross national percentage of secondary school enrollments (natural log), Year FE implies year-fixed effects inclusion. Driscoll/Kraay Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Source: *Author's computation based on CRU and WB WDI (2021) data.*

Table 2.6 Effects of Temperature Thresholds on GDP Per Capita

VARIABLES	The dependent variable is logarithm of GDP per capita			
	(1)	(2)	(3)	(4)
TEMP_it	-0.012** (0.006)	-0.011* (0.006)	-0.011* (0.006)	-0.012** (0.006)
lAnnPreMz	0.022 (0.014)	0.022 (0.014)	0.021 (0.015)	0.021 (0.015)
CVPM_it	0.043 (0.042)	0.053 (0.047)	0.055 (0.048)	0.054 (0.048)
CVPM_it^2	-0.012 (0.019)	-0.016 (0.020)	-0.016 (0.020)	-0.016 (0.020)
HC	-0.006 (0.006)	-0.004 (0.006)	-0.003 (0.006)	-0.003 (0.006)
Temp0_5°C_exceed	-0.033*** (0.011)			
Temp_1_0°C_exceed	-0.018 (0.012)			
Temp_1_5°C_exceed	-0.006 (0.007)			
Temp_2°C_exceed	-0.013 (0.007)			
Constant	0.246 (0.170)	0.205 (0.174)	0.209 (0.176)	0.227 (0.174)
Observations	2,004	2,004	2,004	2,004
R-squared	0.083	0.077	0.075	0.076
Number of id	43	43	43	43

Note: In the estimations, the dependent variable is the annual GDP per capita in terms of the natural logarithm. Variable TEMP_it is temperature, lAnnPreMz is average monthly annual precipitation, CVPM_it is the coefficient of variations in precipitation, CVPM_it^2 is the coefficient of variations in precipitation squared, HC is the gross national percentage of secondary school enrollments (natural log), Temp0_5°C_exceed, Temp_1_0°C_exceed, Temp_1_5°C_exceed, Temp_2°C_exceed is a dummy variable equal to 1 if the annual temperature exceeds the long-term average by 0.5°C, 1°C, 1.5°C, 2°C in a given country-year, and 0 otherwise, Year FE implies year-fixed effects inclusion. Driscoll/Kraay Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Source: Author's computation based on CRU and WB WDI (2021) data.

Table 2.7 Summary Table of Diagnostic Tests for SUR

Diagnostic Test	Equation	Test Statistic	df	p-value	Conclusion	Remarks
Breusch–Pagan Test of Independence	All equations	$\chi^2(6) = 470.93$	df = 6	0.0000	Residuals not independent	Justifies use of SUR over separate OLS regressions.
Shapiro–Wilk Normality Test	Agriculture	W = 0.93103	n = 1712	0.00000	Not normally distributed	Central Limit Theorem (CLT) applies → Large n ensures valid inference despite non-normality.
	Industry	W = 0.81377	n = 1645	0.00000	Not normally distributed	Sample size > 1000 → Robustness via CLT.
	Manufacturing	W = 0.70703	n = 1487	0.00000	Not normally distributed	Robust estimation still valid under large n.
	Service	W = 0.83639	n = 1584	0.00000	Not normally distributed	Consider robust SEs or transformation if needed.
Breusch–Pagan / Cook–Weisberg Test (Heteroskedasticity)	Agriculture	$\chi^2(1) = 0.75$	df = 1	0.3850	No heteroskedasticity	Fails to reject H_0 (constant variance).
	Industry	$\chi^2(1) = 1.55$	df = 1	0.2135	No heteroskedasticity	
	Manufacturing	$\chi^2(1) = 2.97$	df = 1	0.0850	Weak evidence of heterosked.	Slightly suggestive, but not significant at 5% level.
	Service	$\chi^2(1) = 3.21$	df = 1	0.0700	Weak evidence of heterosked.	Borderline; consider robust SEs.
VIF (Multicollinearity Check)	Agriculture	VIF = 1.34	–	–	No multicollinearity	All VIFs < 2 → Multicollinearity is not a concern.
	Industry	VIF = 1.37	–	–	No multicollinearity	
	Manufacturing	VIF = 1.30	–	–	No multicollinearity	
	Service	VIF = 1.38	–	–	No multicollinearity	

Source: Author's computation based on CRU and WB WDI (2021) data.

Reference:

- Abidoye, B. O., & Odusola, A. F. (2015). Climate change and economic growth in Africa: an econometric analysis. *Journal of African economies*, 24(2), 277-301. <https://doi.org/10.1093/jae/eju033>
- Abram, N. J., McGregor, H. V., Tierney, J. E., Evans, M. N., McKay, N. P., Kaufman, D. S., & Consortium, P. k. (2016). Early onset of industrial-era warming across the oceans and continents. *Nature*, 536(7617), 411-418. <https://doi.org/10.1038/nature19082>
- Acemoglu, D., Johnson, S., & Robinson, J. A. (2001). The Colonial Origins of Comparative Development: An Empirical Investigation. *American Economic Review*, 91(5), 1369-1401. <https://doi.org/10.1257/aer.91.5.1369>
- Alagidede, P., & Adu, G. (2014). Climate change and economic growth in sub-Saharan Africa: nonparametric evidence. *Economic Research Southern Africa (ERSA), South Africa.*, 1(1), 1-20. https://econrsa.org/wp-content/uploads/2022/06/working_paper_460.pdf
- Alagidede, P., Adu, G., & Frimpong, P. B. (2015). The effect of climate change on economic growth: evidence from Sub-Saharan Africa. *Environmental Economics and Policy Studies*, 18(3), 417-436. <https://doi.org/10.1007/s10018-015-0116-3>
- Ali, S., Ying, L., Nazir, A., Ishaq, M., Shah, T., Ilyas, A., Khan, A. A., Din, I. U., & Tariq, A. (2019). The effect of climate change on economic growth: evidence from Pakistan. *Pacific International Journal*, 2(2), 21-30. <https://doi.org/10.55014/pij.v2i2.70>
- Althor, G., Watson, J. E., & Fuller, R. A. (2016). Global mismatch between greenhouse gas emissions and the burden of climate change. *Scientific reports*, 6(1), 20281. <https://doi.org/10.1038/srep20281>
- Alvarado, R., & Toledo, E. (2017). Environmental degradation and economic growth: evidence for a developing country. *Environment, Development and Sustainability*, 19(4), 1205-1218. <https://doi.org/10.1007/s10668-016-9790-y>
- Arrhenius, S. (1896). XXXI. On the influence of carbonic acid in the air upon the temperature of the ground. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 41(251), 237-276. <https://doi.org/10.1080/14786449608620846>
- Barrios, Salvador, Bertinelli, Luisito, Strobl, & Eric. (2010). Trends in rainfall and economic growth in Africa: A neglected cause of the African growth tragedy. *The Review of Economics Statistics*, 92(2), 350-366.
- Barro, R., & Sala-i-Martin, X. (2004). Economic growth second edition. In: The MIT Press, Cambridge, Massachusetts; London, England. Chapter 12, pp. 535-542.
- Barro, R. J. (2003). Determinants of economic growth in a panel of countries. *Annals of economics and finance*, 4, 231-274.
- Barro, R. J., & McCleary, R. (2003). Religion and economic growth. *American sociological review*, 68(5), 760-781.
- Bicaba, Z., Brixiová, Z., & Ncube, M. (2017). Can extreme poverty in Sub-Saharan Africa be eliminated by 2030? *Journal of African Development*, 19(2), 93-110. <https://doi.org/10.5325/jafrideve.19.2.0093>
- Bloom, D. E., Canning, D., & Sevilla, J. (2004). The effect of health on economic growth: a production function approach. *World development*, 32(1), 1-13. <https://doi.org/10.1016/j.worlddev.2003.07.002>

- Bond, S., Leblebicioğlu, A., & Schiantarelli, F. (2010). Capital accumulation and growth: a new look at the empirical evidence. *Journal of applied econometrics*, 25(7), 1073-1099. <https://doi.org/10.1002/jae.1163>
- Bosello, F., & Parrado, R. (2022). Climate Change Impacts and Market-Driven Adaptation: The Costs of Inaction Including Market Rigidities. In *Climate and Development* (pp. 137-175). World Scientific Publishing. https://doi.org/10.1142/9789811240553_0006
- Bowen, A., Cochrane, S., & Fankhauser, S. (2012). Climate change, adaptation and economic growth. *Climatic change*, 113(2), 95-106.
- Bruce, J., Lee, H., & Haites, E. (1996). Climatic change 1995: economic and social dimensions of climate change. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change, 13-14. United Kingdom.
- Chersich, M. F., & Wright, C. Y. (2019). Climate change adaptation in South Africa: a case study on the role of the health sector. *Global Health*, 15(1), 22. <https://doi.org/10.1186/s12992-019-0466-x>
- Conceição, P. (2020). Human development report 2020: The next frontier – Human development and the Anthropocene. United Nations Development Programme, New York, NY. <https://hdr.undp.org/en/2020-report>.
- Conforti, P., Ahmed, S., & Markova, G. (2018). Impact of disasters and crises on agriculture and food security, 2017 (pp. 136-143). Rome, Italy: FAO. <http://www.fao.org/3/i8656en/i8656EN.pdf>
- David, E., Vera, K., & Laura, S. (2017). Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2016 and 1997 to 2016. In Germany:: Germanwatch. Retrieved from <https://policycommons.net/artifacts/1555064/risk-index-2018/2244873/> on 10 Jan 2024. CID: 20.500.12592/vmwj4p.
- De Hoyos, R. E., & Sarafidis, V. (2006). Testing for cross-sectional dependence in panel-data models. *The stata journal*, 6(4), 482-496. <https://doi.org/10.1177/1536867X06006004>
- Dell, Melissa, Jones, F. B., Olken, & A. B. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3), 66-95. <https://doi.org/10.1257/mac.4.3.66>
- Dell, Melissa, Jones, F. B., Olken, & A. B. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature*, 52(3), 740-798. <https://doi.org/10.1257/jel.52.3.740>
- Dietz, S., & Stern, N. (2015). Endogenous growth, convexity of damage and climate risk: how Nordhaus' framework supports deep cuts in carbon emissions. *The Economic Journal*, 125(583), 574-620. <https://doi.org/10.1111/eoj.12188>
- Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics*, 80(4), 549-560. <https://doi.org/10.1162/003465398557825>
- Eboli, F., Parrado, R., & Roson, R. (2010). Climate-change feedback on economic growth: explorations with a dynamic general equilibrium model. *Environment and Development Economics*, 15(5), 515-533. <https://doi.org/10.1017/S1355770X10000252>
- Eckstein, D., Künzel, V., & Schäfer, L. (2017). Global climate risk index 2018. Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2016 and 1997 to 2016, Germanwatch. Bonn, Germany. Retrieved from <https://policycommons.net/artifacts/1555064/risk-index-2018/2244873/> on 08 Aug 2021. CID: 20.500.12592/vmwj4p.

- Eckstein, D., Künzel, V., & Schäfer, L. (2021). The global climate risk index 2021. In: Bonn, Germany: Germanwatch. Retrived from <https://bvearmb.do/handle/123456789/1306> on 10 Jan 2022.
- Estrada, F., Tol, R. S., & Botzen, W. W. (2019). Extending integrated assessment models' damage functions to include adaptation and dynamic sensitivity. *Environmental Modelling & Software*, 121, 104504. <https://doi.org/10.1016/j.envsoft.2019.104504>
- Fankhauser, S., & Tol, R. S. (2005). On climate change and economic growth. *Resource and Energy Economics*, 27(1), 1-17. <https://doi.org/10.1016/j.reseneeco.2004.03.003>
- Feenstra, R. C., Inklaar, R., & Timmer, M. P. (2015). The next generation of the Penn World Table. *American Economic Review*, 105(10), 3150-3182. <https://doi.org/10.1257/aer.20130954>
- Fourier, J. (1827). General remarks on the temperatures of the Earth's globe and planetary spaces. *Memoirs of the Royal Academy of Sciences of the Institute of France*, 7, 569-604.
- Gillingham, K., Newell, R. G., & Pizer, W. A. (2008). Modeling endogenous technological change for climate policy analysis. *Energy Economics*, 30(6), 2734-2753. <https://doi.org/10.1016/j.eneco.2008.03.001>
- Greene, W. H. (2012). *Econometric Analysis. 7th Edition, Prentice Hall, Upper Saddle River.* (Chap-14), 351-361.
- Greenough, G., McGeehin, M., Bernard, S. M., Trtanj, J., Riad, J., & Engelberg, D. (2001). The potential impacts of climate variability and change on health impacts of extreme weather events in the United States. *Environ Health Perspect*, 109 Suppl 2(Suppl 2), 191-198. <https://doi.org/10.1289/ehp.109-1240666>
- Greenstone, M., & Deschenes, O. (2006). The economic impacts of climate change: Evidence from agricultural profits and random fluctuations in weather. *American Economic Review*, 97(1), 354-385. <https://doi.org/10.2139/ssrn.876929>
- Gylfason, T. (2001). Natural resources, education, and economic development. *European economic review*, 45(4-6), 847-859. [https://doi.org/10.1016/S0014-2921\(01\)00127-1](https://doi.org/10.1016/S0014-2921(01)00127-1)
- Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., & Vogt-Schilb, A. (2016). *Shock Waves: Managing the Impacts of Climate Change on Poverty In* (pp. 31-68). Washington, DC: The World Bank.
- Hallegatte, S., & Rozenberg, J. (2017). Climate change through a poverty lens. *Nature Climate Change*, 7(4), 250-256. <https://doi.org/10.1038/nclimate3253>
- Hanck, C., Arnold, M., Gerber, A., & Schmelzer, M. (2021). *Introduction to Econometrics with R*. Universität Duisburg-Essen; 225-243.
- Harris, I., Jones, P. D., Osborn, T. J., & Lister, D. H. (2014). Updated high-resolution grids of monthly climatic observations—the CRU TS3. 10 Dataset. *International journal of climatology*, 34(3), 623-642. <https://doi.org/10.1002/joc.3711>
- Harris, J. M., Roach, B., & Anne-Marie, C. (2007). *The economics of global climate change: Global Development And Environment Institute Tufts University Medford, MA 02155* <http://ase.tufts.edu/gdae>.
- Hill, R. C., Griffiths, W. E., & Lim, G. C. (2018). *Principles of econometrics*. pp. 531-549. John Wiley & Sons.

- Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. *The stata journal*, 7(3), 281-312. <https://doi.org/10.1177/1536867X070070>
- Hope Sr, K. R. (2009). Climate change and poverty in Africa. *International Journal of Sustainable Development & World Ecology*, 16(6), 451-461. <https://doi.org/10.1080/13504500903354424>
- Hsiao, C. (2022). *Analysis of panel data*. Cambridge university press. pp. 291-310.
- Huddleston, P., Smith, T., White, I., & Elrick-Barr, C. (2022). Adapting critical infrastructure to climate change: A scoping review. *Environmental Science & Policy*, 135, 67-76. <https://doi.org/10.1016/j.envsci.2022.04.015>
- Hussein, K., & Suttie, D. (2016). FAD Research Series 5-Rural-urban linkages and food systems in sub-Saharan Africa: The rural dimension. IFAD Research series. ISBN 978-92-9072-676-0 , Available at SSRN: <https://ssrn.com/abstract=3284460>
- Ikefuji, M., Magnus, J. R., & Sakamoto, H. (2010). Climate change, economic growth, and health. ISER Discussion Paper, No. 785, Osaka University, Institute of Social and Economic Research (ISER), Osaka. (Paper No.: 785). <https://doi.org/10.2139/ssrn.1665102>
- IPCC. (1996). Economic and social dimensions of climate change. *Contribution of Working Group3 to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, 13-14.
- IPCC. (2014). *Mitigation of Climate Change*. In Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., ... & Minx, J.C. (Eds.), *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1454, 147). . Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- J, R. A., & Anaba, M. I. (2022). The effects of economic growth on carbon dioxide emissions in selected Sub-Saharan African (SSA) countries. *Heliyon*, 8(11), e11193. <https://doi.org/10.1016/j.heliyon.2022.e11193>
- Jones, R. L., Kharb, A., & Tubeuf, S. (2023). The untold story of missing data in disaster research: a systematic review of the empirical literature utilising the Emergency Events Database (EM-DAT). *Environmental Research Letters*, 8(10), 103006. <https://doi.org/10.1088/1748-9326/acfd42>
- Keenan, R. J. (2015). Climate change impacts and adaptation in forest management: a review. *Annals of Forest Science*, 72(2), 145-167. <https://doi.org/10.1007/s13595-014-0446-5>
- Kimball, B., & Idso, S. (1983). Increasing atmospheric CO₂: effects on crop yield, water use and climate. *Agricultural water management*, 7(1-3), 55-72. [https://doi.org/10.1016/0378-3774\(83\)90075-6](https://doi.org/10.1016/0378-3774(83)90075-6)
- Kimuli, I., Lubwama, M., Sebbit, A., & Kirabira, J. B. (2022). Macroeconomic effects of a low carbon electrification of greater Kampala Metropolitan area energy policy: A computable general equilibrium analysis. *Energy Strategy Reviews*, 43, 100909. <https://doi.org/10.1016/j.esr.2022.100909>
- Kjellstrom, T., Kovats, R. S., Lloyd, S. J., Holt, T., & Tol, R. S. (2009). The direct impact of climate change on regional labor productivity. *Arch Environ Occup Health*, 64(4), 217-227. <https://doi.org/10.1080/19338240903352776>
- Kreft, S., Eckstein, D., & Melchior, I. (2016). *Global climate risk index 2017: Who suffers most from extreme weather events? weather-related loss events in 2015 and 1996 to 2015*. Germanwatch, Bonn, Germany. Retrieved from

- <https://policycommons.net/artifacts/1555054/global-climate-risk-index-2017/2244863/> on 08 Aug 2021. CID: 20.500.12592/1cp03c.
- Kumar, S., Kumar, N., & Vivekadhish, S. (2016). Millennium development goals (MDGS) to sustainable development goals (SDGS): Addressing unfinished agenda and strengthening sustainable development and partnership. *Indian journal of community medicine: official publication of Indian Association of Preventive & Social Medicine*, 41(1), 1. <https://doi.org/10.4103/0970-0218.170955>
- Lecocq, F., & Shalizi, Z. (2007). How might climate change affect economic growth in developing countries? The World Bank Development Research Group: WPS4315. Washington D.C., USA. .
- Lemoine, D. M., & Traeger, C. P. (2012). *Tipping points and ambiguity in the economics of climate change. National Bureau of Economic Research (No.W18230): Working Paper 18230, 25-34. Cambridge Massachusetts, USA.* <http://www.nber.org/papers/w18230>
- Letta, M., & Tol, R. S. (2019). Weather, climate and total factor productivity. *Environmental and Resource Economics*, 73(1), 283-305. <https://doi.org/10.1007/s10640-018-0262-8>
- Lutz, W., Sanderson, W., & Andruchowitz, S. (2017). Moving Frontiers in Population Forecasting and Aging: Sergei Scherbov 65. Annotated Reprints of Key Publications. In: International Institute for Applied Systems Analysis, Laxenburg, Austria.
- Maino, R., & Emrullahu, D. (2022). *Climate change in Sub-Saharan Africa fragile states: Evidence from panel estimations. International Monetary Fund.* <https://doi.org/10.5089/9798400204869.001>.
- Mann, M. E., Schurer, A. P., Hawkins, E., Tett, S., & Hegerl, G. C. (2017). Importance of the Pre-Industrial Baseline in Determining the Likelihood of Exceeding the Paris Limits. In AGU Fall Meeting Abstracts (Vol. 2017, pp. GC51H-03).
- Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., & Gomis, M. (2021). Climate change 2021: the physical science basis. *Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change, 2(1), 2391. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.* <https://doi.org/10.1017/9781009157896>
- Mazhin, S. A., Farrokhi, M., Noroozi, M., Roudini, J., Hosseini, S. A., Motlagh, M. E., Kolivand, P., & Khankeh, H. (2021). Worldwide disaster loss and damage databases: A systematic review. *J Educ Health Promot*, 10(1), 329. https://doi.org/10.4103/jehp.jehp_1525_20
- McCarthy, J. J., Canziani, F. O., Leary, A. N., Dokken, J. D., White, & S. K. (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2). Cambridge University Press.
- McCleary, R. M., & Barro, R. J. (2006). Religion and economy. *Journal of economic perspectives*, 20(2), 49-72. <https://doi.org/10.1257/jep.20.2.49>
- McMichael, A. J., Woodruff, R. E., & Hales, S. (2006). Climate change and human health: present and future risks. *The Lancet*, 367(9513), 859-869. [https://doi.org/10.1016/S0140-6736\(06\)68079-3](https://doi.org/10.1016/S0140-6736(06)68079-3)
- Mishra, K. A., Singh, P. V., Jain, & K, S. (2010). Impact of global warming and climate change on social development. *Journal of Comparative Social Welfare*, 26(2-3), 239-260. <https://doi.org/10.1080/17486831003687626>

- Mongiovi, G. (2011). Demand, structural interdependence, and economic provisioning. *American Journal of Economics and Sociology*, 70(5), 1147-1174. <https://doi.org/10.1111/j.1536-7150.2011.00812.x>
- Moon, H., & Perron, B. (2008). Seemingly Unrelated Regressions. *The new Palgrave dictionary of economics*, 1(9), 19.
- Moore, F. C., & Diaz, D. B. (2015). Temperature impacts on economic growth warrant stringent mitigation policy. *Nature Climate Change*, 5(2), 127. <https://doi.org/10.1038/nclimate2481>
- Nastis, S. A., Michailidis, A., & Chatzitheodoridis, F. (2012). Climate change and agricultural productivity. *African Journal of Agricultural Research*, 7(35), 4885-4893. <https://doi.org/10.5897/AJAR11.2395>
- Nautiyal, S., Schaldah, R., Raju, K., Kaechele, H., Pritchard, B., & Rao, K. S. (2016). *Climate change challenge (3C) and social-economic-ecological interface-building—exploring potential adaptation strategies for bio-resource conservation and livelihood development: Epilogue (pp. 631-639)*. Springer International Publishing. https://doi.org/10.1007/978-3-319-31014-5_37
- Nordås, R., & Gleditsch, N. P. (2007). Climate change and conflict. *Political geography*, 26(6), 627-638. https://doi.org/10.1007/978-3-319-10954-1_3
- Nordhaus, W. (2019). Climate change: The ultimate challenge for economics. *American Economic Review*, 109(6), 1991-2014.
- Nordhaus, W. D. (1977). Economic growth and climate: the carbon dioxide problem. *The American Economic Review*, 341-346. <https://www.jstor.org/stable/1815926>
- Nordhaus, W. D. (1993). Optimal greenhouse-gas reductions and tax policy in the "DICE" model. *The American Economic Review*, 83(2), 313-317. <https://www.jstor.org/stable/2117683>
- Nwani, S. E., Kelikume, I., & Osuji, E. (2020). Does service sector growth cause agricultural and industrial development? A dynamic econometric approach. *International Journal of Management, Economics and Social Sciences (IJMESS)*, 9(2), 58-75. <https://doi.org/10.32327/IJMESS/9.2.2020.4>
- Okonjo-Iweala, N. (2020). Africa can play a leading role in the fight against climate change. *Brookings Institution, United States of America*. Retrieved from <https://policycommons.net/artifacts/4140371/africa-can-play-a-leading-role-in-the-fight-against-climate-change/4948897/> on 10 Jan 2024. CID: 20.500.12592/bmr4q1.
- Osuagwu, E. S. (2018). Evidence of long-run relationship between agriculture and manufacturing industry output in Nigeria (May 29, 2018). Available at SSRN: <https://ssrn.com/abstract=3186381> or <http://dx.doi.org/10.2139/ssrn.3186381>
- Osuagwu, E. S. (2020). Empirical evidence of a long-run relationship between agriculture and manufacturing industry output in Nigeria. *SAGE Open*, 10(1), 2158244019899045. <https://doi.org/10.1177/2158244019899045>
- Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., & Dasgupta, P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151)*. *Ipcc*.
- Pachauri, R. K., & Meyer, L. (2014). IPCC, 2014: climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the intergovernmental panel on Climate Change. *IPCC, Geneva, Switzerland*, 151.
- Parry, M., Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P., & Hanson, C. (2007). *Climate change 2007-impacts, adaptation and vulnerability: Working group II*

- contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge University Press.
- Peterson, E. W. F. (2017). The role of population in economic growth. *SAGE Open*, 7(4), 2158244017736094. <https://doi.org/10.1177/2158244017736094>
- Pindyck, R. S. (2012). Uncertain outcomes and climate change policy. *Journal of environmental economics management*, 63(3), 289-303.
- Piontek, F., Kalkuhl, M., Kriegler, E., Schultes, A., Leimbach, M., Edenhofer, O., & Bauer, N. (2019). Economic growth effects of alternative climate change impact channels in economic modeling. *Environmental and Resource Economics*, 73, 1357-1385. <https://doi.org/10.1007/s10640-018-00306-7>
- Raihan, A., Muhtasim, D. A., Farhana, S., Hasan, M. A. U., Pavel, M. I., Faruk, O., Rahman, M., & Mahmood, A. (2022). Nexus between economic growth, energy use, urbanization, agricultural productivity, and carbon dioxide emissions: New insights from Bangladesh. *Energy Nexus*, 8, 100144. <https://doi.org/10.1016/j.nexus.2022.100144>
- Ramin, B. M., & McMichael, A. J. (2009). Climate change and health in sub-Saharan Africa: a case-based perspective. *EcoHealth*, 6(1), 52-57. <https://doi.org/10.1007/s10393-009-0222-4>
- Ramsey, J. B. (1969). Tests for specification errors in classical linear least-squares regression analysis. *Journal of the Royal Statistical Society Series B: Statistical Methodology*, 31(2), 350-371. <https://doi.org/10.1111/j.2517-6161.1969.tb00796.x>
- Reidmiller, D. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Lewis, K. L., Maycock, T. K., & Stewart, B. C. (2017). Impacts, risks, and adaptation in the United States: Fourth national climate assessment, volume II. *U.S. Global Change Research Program*. <https://nca2018.globalchange.gov/>. <https://doi.org/10.7930/NCA4.2018>
- Rezai, A., Taylor, L., & Foley, D. (2018). Economic growth, income distribution, and climate change. *Ecological Economics*, 146, 164-172. <https://doi.org/10.1016/j.ecolecon.2017.10.020>
- Ritchie, H., Roser, M., & Rosado, P. (2020). CO₂ and Greenhouse Gas Emissions. *Our World in Data*. <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions>.
- Rodrik, D. (2003). Institutions, integration, and geography: In search of the deep determinants of economic growth. In *Search of Prosperity: Analytic Country Studies on Growth*, 1-30. Princeton, NJ Princeton University Press.
- Rosen, R. A., & Guenther, E. (2015). The economics of mitigating climate change: What can we know? *Technological Forecasting and Social Change*, 91, 93-106. <https://doi.org/10.1016/j.techfore.2014.01.013>
- Sathaye, J., Makundi, W., Dale, L., Chan, P., & Andrasko, K. (2006). GHG mitigation potential, costs and benefits in global forests: a dynamic partial equilibrium approach. *The Energy Journal*, 127-162. <https://doi.org/10.5547/ISSN0195-6574-EJ-VolSI2006-NoSI3-7>
- Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of Sciences*, 106(37), 15594-15598. <https://doi.org/10.1073/pnas.0906865106>
- Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., & Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*, 17(6), 1585-1600. <https://doi.org/10.1007/s10113-015-0910-2>
- Shehata, E., & Mickael, S. (2015). RESETXT: Stata Module to Compute Panel Data Regression Specification Error Tests (RESET). <https://ideas.repec.org/c/boc/bocode/s457954.html>.

- Singh, A. K., Kumar, S., & Jyoti, B. (2022). Influence of climate change on agricultural sustainability in India: A state-wise panel data analysis. *Asian Journal of Agriculture*, 6(1), 15-27. <https://doi.org/10.13057/asianjagric/g060103>
- Smit, B., & Pilifosova, O. (2003). Adaptation to climate change in the context of sustainable development and equity. *Sustainable Development*, 8(9), 9.
- Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics*, 39(3), 312-320. <https://doi.org/10.2307/1926047>
- Sono, D., Wei, Y., & Jin, Y. (2021). Assessing the Climate Resilience of Sub-Saharan Africa (SSA): A Metric-Based Approach. *Land*, 10(11), 1205. <https://doi.org/10.3390/land10111205>
- Sridhar, K. S. (2016). Economic impacts of climate change in India's cities. *Climate Change Challenge (3C) and Social-Economic-Ecological Interface-Building: Exploring Potential Adaptation Strategies for Bio-resource Conservation and Livelihood Development*, 279-295.
- Stern, N. (2013). The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models. *Journal of Economic Literature*, 51(3), 838-859. <https://doi.org/10.1257/jel.51.3.838>
- Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S., & Edmonson, N. (2006). *Stern Review: The economics of climate change* (Vol. 30). London: HM treasury.
- Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P. M. (2013). Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change (pp. 33-115). *Climate change: Cambridge university press*.
- Tsigaris, P., & Wood, J. (2016). A simple climate-Solow model for introducing the economics of climate change to undergraduate students. *International Review of Economics Education*, 23, 65-81. <https://doi.org/10.1016/j.iree.2016.06.002>
- UNFCCC. (2007). Impacts, Vulnerabilities and Adaptation in Developing Countries. UN FCCC-United Nations Framework Convention on Climate Change. Bonn, Germany.
- UNFCCC, U. (2009). *UNFCCC, UN Framework Convention on Climate Change, (2009), Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amount*, (Working Papers, eSocialSciences, <https://EconPapers.repec.org/RePEc:ess:wpaper:id:2296>., Issue.
- Vanderheiden, S. (2008). *Atmospheric justice: A political theory of climate change*. OUP USA pp. 9-15.
- Vinod, H. D., & Kaushik, S. K. (2007). Human capital and economic growth: evidence from developing countries. *The American Economist*, 51(1), 29-39. <https://doi.org/10.1177/056943450705100>
- Warren, R., Hope, C., Mastrandrea, M., Tol, R., Adger, N., & Lorenzoni, I. (2006). Spotlighting impacts functions in integrated assessment. (*Working paper; No. 91*). *Tyndall Centre on Climate Change*.
- Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A., Cox, P. M., Depledge, J., Drummond, P., Ekins, P., Galaz, V., Grace, D., Graham, H., Grubb, M., Haines, A., . . . Costello, A. (2015). Health and climate change: policy responses to protect public health. *Lancet*, 386(10006), 1861-1914. [https://doi.org/10.1016/S0140-6736\(15\)60854-6](https://doi.org/10.1016/S0140-6736(15)60854-6)
- WB, W. B. (2020). *World Development Indicators, Washington DC: The World Bank Group*. <https://databank.worldbank.org/source/world-development-indicators> : Accessed 28 October 2021.

- Webster, M., Ginnetti, J., Walker, P., Coppard, D., & Kent, R. (2008). The humanitarian costs of climate change. *Strengthening the Humanity and Dignity of People in Crisis through Knowledge and Practice*. Medford, MA: Feinstein International Center, Tufts University.
- Weitzman, M. L. (2010). What Is The " Damages Function" For Global Warming—And What Difference Might It Make? *Climate Change Economics*, 1(01), 57-69. <https://doi.org/10.1142/S2010007810000042>
- Welborn, L. (2018). Africa and climate change-projecting vulnerability and adaptive capacity: ISS Africa Report, 2018(14), 1-24. <https://hdl.handle.net/10520/EJC-1486f763e1>
- Wilkinson, E., & Peters, K. (2015). Climate extremes and resilient poverty reduction: development designed with uncertainty in mind. *London: Overseas Development Institute*.
- Winsemius, H. C., Jongman, B., Veldkamp, T. I., Hallegatte, S., Bangalore, M., & Ward, P. J. (2018). Disaster risk, climate change, and poverty: assessing the global exposure of poor people to floods and droughts. *Environment and Development Economics*, 23(3), 328-348. <https://doi.org/10.1017/S1355770X17000444>
- Winter, M., & Shearer's, B. (2013). *Climate change and landslide hazard and risk-a Scottish perspective*. (No. PPR650).
- Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press. Chapter 20 pp. 703-706.
- Yang, X. C. a. L. (2018). Temperature and Economic Performance of Chinese Manufacturing Firms. *Environment for Development: Discussion Paper Series, EFD DP 18-04*. <https://www.jstor.org/stable/resrep17123.3>
- Zahonogo, P. (2016). Trade and economic growth in developing countries: Evidence from sub-Saharan Africa. *Journal of African Trade*, 3(1-2), 41-56. <https://doi.org/10.1016/j.joat.2017.02.001>
- Zellner, A. (1962). An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *Journal of the American statistical association*, 57(298), 348-368. <https://doi.org/10.1080/01621459.1962.10480664>
- Zellner, A., & Huang, D. S. (1962). Further properties of efficient estimators for seemingly unrelated regression equations. *International Economic Review*, 3(3), 300-313. <https://doi.org/10.2307/2525396>
- Zhang, Peng, Deschenes, Olivier, Meng, Kyle, Zhang, & Junjie. (2018). Temperature effects on productivity and factor reallocation: Evidence from a half million Chinese manufacturing plants. *Journal of Environmental Economics and Management*, 88, 1-17. <https://doi.org/10.1016/j.jeem.2017.11.001>
- Zhang, P., Zhang, J., & Chen, M. (2017). Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. *Journal of Environmental Economics and Management*, 83, 8-31. <https://doi.org/10.1016/j.jeem.2016.12.001>
- Zhang, Y., & Ayyub, B. M. (2021). Temperature extremes in a changing climate. *Climate Change and Extreme Events*, 9-23. <https://doi.org/10.1016/B978-0-12-822700-8.00001-9>
- Zhang, Y., Liang, A., Wang, Y., Chen, X., Zhang, S., Jia, S., Zhang, X., Yang, X., & McLaughlin, N. (2022). Climate change impacts on soil fertility in Chinese Mollisols. In *Sustainable Crop Productivity and Quality Under Climate Change* (pp. 275-293). Elsevier. <https://doi.org/10.1016/B978-0-323-85449-8.00010-5>

Chapter 3: CORRUPTION, POLITICAL INSTABILITY, CLIMATE CHANGE, AND ECONOMIC GROWTH IN SUB-SAHARAN AFRICAN COUNTRIES

Abstract

This study explores how climate factors, institutional quality, and economic growth interact in Sub-Saharan Africa (SSA), examining whether strong institutions can mitigate climate change's economic impact. Using System GMM and a long-run multiplier approach on data from 43 SSA countries (1996–2019), the analysis highlights institutions' role in resilience and risk mitigation. While institutional quality enhances economic stability, it cannot fully offset the negative effects of rising temperatures. Corruption and political instability weaken climate governance, increase CO₂ emissions, and exacerbate economic challenges. Though economic growth can strengthen institutions by reducing corruption and instability, emissions-intensive growth undermines this progress. Therefore, institutional reforms and climate adaptation are essential for economic resilience and sustainable development in SSA.

Keywords: *Institutional Quality; Political Instability; Economic Growth; Climate Crisis*

JEL: *D72; D73; O47; Q54.*

3.1 Introduction

The development trajectories of countries are shaped by complex interactions that extend beyond traditional economic determinants. In particular, climate change and institutional quality, defined by governance effectiveness, corruption control, and political stability, play a critical role in shaping resilience and economic adaptability ([Iheonu et al., 2017](#); [Tol, 2009](#)). Economic growth, in turn, both influences and is influenced by these factors, reinforcing their long-term impact on development ([Acemoglu & Robinson, 2013](#); [Stern, 2008](#)).

Countries with robust institutions, characterized by low corruption and strong governance, demonstrate greater resilience to climate challenges and sustain economic growth ([Bruinshoofd, 2016](#); [Ferrini, 2012](#); [Wu & Yan, 2018](#)). Conversely, LDCs, particularly in SSA, grapple with weak institutional capacity, which hinders effective governance, service delivery, and regulatory enforcement. These deficiencies exacerbate corruption, political instability, and economic stagnation, limiting long-term development prospects ([Acemoglu et al., 2001](#); [Barro, 1991](#); [Kaufmann et al., 2011](#)).

Moreover, institutional weaknesses in SSA not only undermine economic growth but also weakens climate change mitigation. Corruption and instability impede policy effectiveness, particularly in climate-sensitive sectors like agriculture ([Chamma, 2024](#); [Jaramillo et al., 2023](#); [Rhein & Jansesberger, 2024](#); [Sono et al., 2021](#)). These dysfunctions exacerbate social unrest and economic instability ([Bello-Schünemann & Moyer, 2018](#); [Gakpa, 2020](#)). Transparency International reports that 22% of SSA's population pays bribes for essential services, while 80% of the region's countries have seen no corruption reduction in the past decade ([TI-CPI, 2021](#)), perpetuating stagnation ([Pring, 2015](#)).

Although extensive research examines corruption, instability, and climate change, most studies analyze them in isolation, overlooking their interconnectedness and long-term effects on economic growth ([Abdel-Latif et al., 2018](#); [Ahmad et al., 2012](#); [Aisen & Veiga, 2013](#); [H. S. Ali et al., 2019](#); [Arminen & Menegaki, 2019](#); [d'Agostino et al., 2016](#); [Del Monte & Pennacchio, 2020](#); [Haydaroglu, 2016](#); [Nest et al., 2020](#); [Welsch, 2004](#)). Emerging literature highlights governance-environment linkages, revealing how weak institutions drive deforestation, CO₂ emissions, and policy inefficacy ([Fredriksson & Neumayer, 2016](#); [Galinato & Galinato, 2012](#); [Smallwood, 2018](#)).

This study examines the interrelation of corruption, political instability, climate change (via CO₂ emissions), and economic growth (GDP per capita) in SSA. Specifically, it seeks to investigate the causal relationships among corruption, political instability, and climate change, as well as their collective impact on economic growth; analyze how these factors, along with economic growth, influence climate change over time; and assess the effects of economic growth and climate change on institutional quality and governance outcomes.

Based on these objectives, the study proposes the following hypotheses:

H1: Corruption, political instability, and climate change collectively exert significant effects on short- and long-term economic growth.

H2: Corruption, political instability, and economic growth significantly influence climate change via CO₂ emission, with distinct immediate and long-term impacts.

H3: Economic growth and climate change dynamically affect institutional quality, determining governance outcomes over time.

Using data from 43 SSA countries (1996–2019), this study employs System GMM and a long-run multiplier approach to ensure robust estimation, incorporating GDP per capita, CO₂ emissions, FDI, corruption, political instability, temperature, precipitation, and human and physical capital.

The findings confirm that corruption, political instability, and climate change significantly impact economic growth. While 39% of GDP per capita variation is self-reinforcing²⁷, the remainder is influenced by external factors. A one-rank deterioration in corruption and political instability reduces GDP per capita by 0.49% and 0.42%, respectively, resulting in a combined decline of 0.91% (Table 3.2 Column 3). Additionally, a one-degree Celsius rise in temperature reduces GDP per capita by 0.54%, demonstrating the intensifying effects of environmental and institutional challenges.

Furthermore, corruption, instability, and economic growth drive CO₂ emissions, fueling short-term development at the expense of long-term sustainability. Rising

²⁷ This reflects the "inertia" or persistence of economic growth over time, showing how much of the current economic growth depends on its own historical values and the economy has a momentum, where past growth continues to shape current outcomes.

temperatures exacerbate economic slowdowns, while weak institutions fail to regulate emissions²⁸ and enforce climate policies.

The rest of the paper unfolds as follows: Section 3.2 reviews the literature, Section 3.3 outlines the theoretical framework and conceptual model illustration, and Section 3.4 covers data sources and variables. Section 3.5 presents methods, including empirical framework and model specifications, while Section 3.6 presents results and their discussion. Lastly, Section 3.7 concludes with key findings and outlines policy implications.

3.2 Literature

3.2.1 Climate change, Institutional quality, and Economic Growth

Several studies highlight the role of institutional quality in shaping climate resilience and economic performance. [H. S. Ali et al. \(2019\)](#) emphasize that well-functioning institutions promote effective climate policies, while [d'Agostino et al. \(2016\)](#) argue that corruption and instability stifle economic progress by distorting resource allocation. In SSA, weak governance structures limit adaptation strategies, intensifying climate-related economic disruptions ([Abidoye & Odusola, 2015](#); [Dell et al., 2012](#)). Further, research by [Fosu \(1992\)](#) and [Gyimah-Brempong \(2002\)](#) suggests that poor institutional frameworks not only hinder economic efficiency but also exacerbate socio-political tensions, reinforcing a cycle of underdevelopment. Extending this, recent research explores how institutional quality directly influences climate finance effectiveness and environmental sustainability ([Nest et al., 2020](#); [D. Zhang et al., 2022](#)).

Climate finance further illustrates the complexities of institutional dynamics in SSA. While intended to enhance climate resilience, substantial inflows often correlate with higher corruption levels, fueling social unrest and political instability, thereby delaying economic progress ([Abdel-Latif et al., 2018](#); [Fosu, 1992](#); [Nest & Mullard, 2021](#)). However, when managed effectively, climate finance strengthens adaptive capacities and mitigation efforts, contributing to sustainable growth ([Kotchen, 2020](#)).

²⁸ CO₂ emissions from activities like deforestation, fossil fuel use, and agriculture drive rising temperatures in SSA, which, in turn, exacerbate emissions through feedback mechanisms such as increased energy demand, forest loss, and shifts in agricultural productivity

Corruption in SSA manifests in both centralized and decentralized forms, with decentralized²⁹ corruption posing more severe consequences by exacerbating poverty, stalling infrastructure development, and increasing vulnerability to climate shocks (Edoun & Mbohwa, 2016; Farrag & Ezzat, 2016; Gyimah-Brempong, 2002). The agricultural sector, a cornerstone of many SSA economies, is particularly affected, as climate variability and political instability reduce productivity and food security (Regan & Young, 2022; Warsame et al., 2022). Rising temperatures further intensify instability by triggering conflicts, a pattern that diverges from historical trends (O’Loughlin et al., 2012). These governance and environmental disruptions also drive migration, destabilizing already fragile communities (Freeman, 2017).

Weak institutional responses to climate crises result in significant human and infrastructural costs, including resource depletion and environmental degradation (Walter & Luebke, 2013; Wang et al., 2019). Effective anti-corruption policies can mitigate these impacts, improving governance and economic resilience (Nest et al., 2020). However, persistent corruption amplifies environmental risks, destabilizing economies and undermining sustainable growth. While moderate corruption may yield short-term economic benefits, excessive corruption ultimately reverses these gains, reinforcing inefficiencies (Ahmad et al., 2012). This disproportionately affects the poor, worsening socio-economic inequalities (Gyimah-Brempong, 2002). Furthermore, corruption often fuels political instability, eroding institutional credibility and preventing investment (Abeyasinghe, 2004; Aisen & Veiga, 2013; Alesina et al., 1996; Fosu, 1992; Gakpa, 2020). Thus, weak institutions drive greenhouse gas emissions, hinder adaptive capacity, and slow economic growth (Gazdar & Cherif, 2015; Maduka et al., 2022). However, improved governance fosters resilience, reduces emissions, and enhances growth prospects (D. Zhang et al., 2022).

3.3 Theoretical Framework

Understanding the interplay between corruption, political instability, climate change, and economic growth in SSA necessitates an integrated theoretical approach. Endogenous Growth Theory highlights the role of human capital, innovation, and knowledge accumulation in long-term economic expansion, contingent on institutional

²⁹ According to Farrag & Ezzat (2016), centralized corruption involves a single bribe payment to a person or entity who ensures the deal's completion. On the other hand, decentralized corruption refers to unorganized bribes that may be paid to various individuals without guaranteeing the deal's conclusion.

quality ([Acemoglu et al., 2001](#); [Lucas Jr, 1988](#); [North, 1990](#); [Romer, 1990](#)). Weak institutions deter investment, reduce productivity, and increase transaction costs, ultimately stifling growth, whereas strong institutions enhance investor confidence and policy stability ([Acemoglu et al., 2004](#); [Mauro, 1995](#); [Zhang et al., 2023](#)). However, persistent governance inefficiencies in SSA reinforce economic stagnation.

Political Economy Theory underscores how political instability disrupts economic growth, particularly in fragile states. Frequent government changes, policy uncertainty, and civil unrest create volatility and delaying economic reforms ([Alesina et al., 1996](#); [Fosu, 2002](#)). Corruption further erodes institutional credibility, embedding SSA's vulnerability to economic downturns ([Aisen & Veiga, 2013](#); [Sabir et al., 2019](#)).

From an environmental economics perspective, climate change exacerbates economic constraints in SSA, where reliance on agriculture and natural resources increases vulnerability to extreme weather and shifting agricultural zones ([Burke et al., 2015](#); [Dell et al., 2012](#); [Stern, 2006](#)). Moreover, weak governance and corruption misallocate climate adaptation resources, intensifying economic fragility ([IPCC, 2014a](#); [Tol, 2009](#)).

The Neoclassical Economic Growth Model emphasizes labor, capital, and technology ([Barro, 1996](#); [Solow, 1956](#)) but overlooks governance and environmental factors. Given SSA's institutional weaknesses and climate risks, a broader analytical framework is necessary ([Moral-Benito, 2012](#)).

Empirical research identifies three competing hypotheses linking institutional quality, climate change, and economic growth. The Neutrality Hypothesis suggests no causal relationship, implying that institutional and climate factors do not significantly affect economic performance ([Egbetokun et al., 2019](#)). In contrast, the Growth Hypothesis argues that economic expansion strengthens institutions and environmental policies, driving long-term improvements ([Aisen & Veiga, 2013](#); [Arminen & Menegaki, 2019](#)). Meanwhile, the Feedback Hypothesis posits a dynamic, bidirectional relationship where institutional quality, economic growth, and climate change continuously reinforce each other ([Payne, 2010](#); [Ulusoy & Pirgaip, 2019](#)).

A clearer understanding of how institutional quality and economic growth interact is central to this study's conceptual framework. On one hand, strong institutions, characterized by low corruption and political stability, support economic growth by enhancing investor confidence, reducing transaction costs, and improving

policy implementation ([Acemoglu et al., 2001](#); [Mauro, 1995](#)). On the other hand, sustained economic growth can improve institutional quality by expanding public resources, strengthening administrative capacity, and increasing demand for transparency and accountability ([Aisen & Veiga, 2013](#); [Keefer & Knack, 2002](#)).

However, this relationship is not uniformly virtuous. When growth is driven by resource extraction or carbon-intensive sectors, it may establish rent-seeking behavior and weaken institutional checks ([Sachs & Warner, 1995](#); [Stern, 2006](#)). This dynamic feedback mechanism is captured in the empirical model via the endogeneity of institutional and economic variables and supports the “feedback hypothesis” identified in the literature ([Payne, 2010](#); [Ulusoy & Pirgaip, 2019](#)).

The study’s System GMM framework allows for testing these interdependencies, where corruption and political instability are modeled as both outcomes and determinants of growth, and long-run multipliers are used to assess their cumulative impact.

3.3.1 Conceptual Model Illustration

The model in Figure 3.1 illustrates the dynamic interplay among climate factors, institutional quality, and economic growth in SSA. Climate factors include CO₂ emissions, which drive long-term global changes ([Stern, 2008](#)), and temperature and precipitation, which create immediate economic risks through variability and extremes ([Burke et al., 2015](#); [Dell et al., 2012](#)). Institutional quality, encompassing corruption control and political stability, mediates these climate impacts on economic growth ([Acemoglu & Robinson, 2013](#)). Economic growth (GDP per capita) interacts dynamically with climate and institutional factors, influencing regional capacity for adaptation and sustainability ([Berrang-Ford et al., 2011](#)).

In Pathway Triad 1, climate factors directly impact economic growth (Path A), with rising CO₂ emissions, temperature, and precipitation extremes disrupting productivity and infrastructure ([Burke et al., 2015](#)). Strong institutions mitigate these effects (Path B) by enforcing climate policies, while weak governance heightens vulnerabilities ([Acemoglu & Robinson, 2013](#)).

Pathway Triad 2 explores economic growth’s feedback on climate resilience. Growth can exacerbate emissions and resource exploitation without safeguards (Path C) ([Stern, 2008](#)). However, strong institutions (Path D) promote sustainability by enforcing environmental regulations and fostering adaptive strategies ([Berrang-Ford et al., 2011](#); [Sovacool et al., 2015](#)). Institutions may also directly shape climate outcomes

(Path D') by advancing sustainable practices or, conversely, enabling environmental degradation through weak oversight.

Pathway Triad 3 examines how climate and economic growth shape institutional quality. Climate stressors³⁰ like floods and droughts weaken governance by fostering corruption and instability (Path E) (Buhaug & Urdal, 2013). Conversely, higher GDP per capita can enhance governance by reducing corruption and fostering stability, though emissions-intensive growth may degrade institutional integrity (Path F) (Keefer & Knack, 2002).

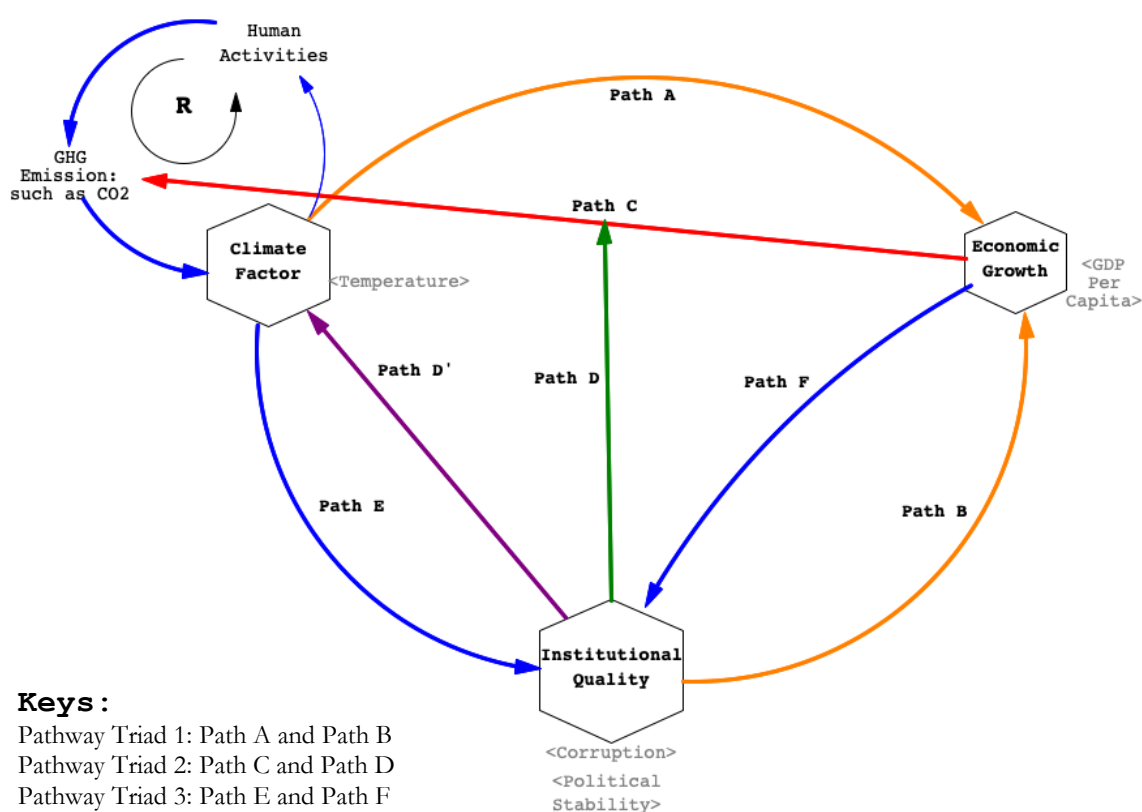


Figure 3.1. Integrated Conceptual Model: Climate, Institutions, and Growth Dynamics

3.4 Data Sources and Variables

This study utilizes data from 43 SSA countries (1996–2019), sourced based on availability. GDP per capita, CO₂ emissions, and FDI inflows are sourced from the

³⁰Climate change acts as a multiplier of existing vulnerabilities within institutions, exacerbating corruption and political instability through resource scarcity, economic stress, weakened governance, and social disruptions.

World Bank's World Development Indicators³¹, while corruption control and political stability data come from the World Governance Indicators³². Climate data (temperature, precipitation) is obtained from the CRU database ([Harris et al., 2014](#)), and the physical and human capital data are obtained from the Penn World Table (PWT) version 10.0 ([Feenstra et al., 2015](#)).

To smooth short-term fluctuations and enhance estimation precision, the study averages data over two-year periods (1996–2019), reducing periods from 24 to 12 ([Baltagi, 2008](#); [Roodman, 2009](#)). This approach minimizes noise from volatility while preserving dynamic relationships, crucial for System GMM estimation. Two-year averages balance short-term fluctuations and maintain data sufficiency, mitigating serial correlation and ensuring robust panel estimates ([Arellano & Bond, 1991](#); [Roodman, 2009](#)).

The study analyzes four primary dependent variables: GDP per capita (2015 constant USD), CO₂ emissions (metric tons per capita), corruption control (C), and political stability (Pi). Each dependent variable also serves as an independent variable in causal analysis. Other control variables include physical capital stock (2017 constant USD) (K), human capital (H) measured in years of schooling, temperature (°C) (Temp), precipitation (mm), and FDI inflows (Inve). To enhance interpretability and model robustness, corruption control and political stability are rescaled to a 1 (weak) – 10 (strong) scale ([Kaufmann et al., 2011](#)). This standardization prevents distortions from scale differences, enhancing clarity and accuracy in dynamic panel data analysis ([Blundell & Bond, 1998](#); [Wooldridge, 2010](#)). Institutional data were biennial (1996–2002) and annual (2003–2020), with missing values for 1997, 1999, and 2001 interpolated for continuity ([Lepot et al., 2017](#); [Salgado et al., 2016](#)).

3.5 Methods

3.5.1 Empirical Framework

This paper investigates the dynamic interactions among economic growth, institutional quality, and climate change in Sub-Saharan Africa, employing a System Generalized Method of Moments (System GMM) approach. The analysis starts with a Cobb-Douglas-based framework, key to modeling economic growth relationships ([Cobb & Douglas, 1928](#); [Solow, 1956](#)):

³¹ <https://databank.worldbank.org/source/world-development-indicators/preview/on>

³² <https://info.worldbank.org/governance/wgi/>

$$Y_{it} = A_{it}K_{it}^{\alpha_1}(HCL_{it})^{\alpha_2}CC_{it}^{\alpha_3}Pi_{it}^{\alpha_4} \quad \text{Eq.1}$$

Where Y_{it} is GDP per capita for country i at time t , A_{it} denotes technological progress, K_{it} is the physical capital stock, HC_{it} represents human capital per worker (combining human capital HC and labor L), CC_{it} corruption, and Pi political instability. The parameters $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are elasticities, reflecting the responsiveness of GDP per capita to each input, and do not necessarily sum to one, allowing for non-constant returns to scale.

For empirical estimation, Equation (1) is log transformed into a static linear model:

$$\ln(Y_{it}) = \ln(A_{it}) + \alpha_1 \ln(K_{it}) + \alpha_2 \ln(HCL_{it}) + \alpha_3 \ln(CC_{it}) + \alpha_4 \ln(Pi_{it}) \quad \text{Eq.2}$$

Although While CO_2 emissions CO_{2it} lack a direct theoretical role in the Cobb-Douglas production function due to their indirect link to productivity ([Brock & Taylor, 2005](#); [Stern, 2008](#); [Xepapadeas, 2005](#)), they are modeled separately as an outcome influenced by economic activity, institutional quality, and climate factors. To capture persistence and dynamic interactions, the framework incorporates lagged variables (e.g., $Y_{i,t-1}, CO_{2i,t-1}$), leading a dynamic specification that, when differenced, becomes:

$$\Delta \ln(Y_{it}) = \beta_1 \Delta \ln(Y_{i,t-1}) + \gamma_1 \Delta \ln(CO_{2it}) + \delta_1 \Delta \ln(Z_{it}) + \Delta \epsilon_{it} \quad \text{Eq.3}$$

While the scalar model for GDPPC (Equation 3) captures short-run dynamics, it forms part of a broader system where CO_{2it}, CC_{it} , and Pi_{it} are also endogenous variables, necessitating a multivariate approach. Static models like Equation (2) fail to address endogeneity, reverse causality, and persistence ([Antonakis et al., 2010](#); [Wooldridge, 2010](#)), prompting the use of System GMM. This approach outperforms alternatives such as Granger causality and Structural Equation Modeling (SEM) by mitigating simultaneity³³ bias, restrictive exogeneity assumptions, and challenges in modeling lagged dependent variable dynamics, as noted in dynamic panel studies ([Antonakis et al., 2010](#); [Arminen & Menegaki, 2019](#); [Bollen, 2014](#); [Greene, 2012](#); [Wooldridge, 2010](#)).

3.5.2 Model Specification

Consequently, the empirical framework specifies System GMM in matrix form as:

³³ Simultaneity occurs when endogenous variables influence each other contemporaneously, making it difficult to identify the causal direction between them and complicating causal inference.

$$\Delta \mathbf{Y}_{it} = \mathbf{B}_0 + \mathbf{B}_1 \Delta \mathbf{Y}_{i,t-1} + \mathbf{\Gamma} \Delta \mathbf{Z}_{it} + \Delta \boldsymbol{\epsilon}_{it} \quad \text{Eq.4}$$

where: $\Delta \mathbf{Y}_{it} = [\Delta \ln(Y_{it}), \Delta \ln(\text{CO}_{2it}), \Delta \ln(\text{CC}_{it}), \Delta \ln(\text{Pi}_{it})]^T$ is a 4×1 vector of differenced endogenous variable GDPPC, CO₂ emissions, corruption, political instability. \mathbf{B}_0 is a 4×1 vector of constants, \mathbf{B}_1 is a 4×1 diagonal matrix of autoregressive coefficients (e.g., $B_{1y}, B_{1c}, B_{1r}, B_{1p}$), capturing persistence of each variable. $\Delta \mathbf{Z}_{it}$ is a $k \times 1$ vector of differenced explanatory variables such as temperature, precipitation, capital stock, human capital, FDI. $\mathbf{\Gamma}$ is a $4 \times k$ matrix of short-run coefficients, and $\Delta \boldsymbol{\epsilon}_{it}$ is a 4×1 vector of differenced errors.

System GMM estimates this system by integrating moment conditions from both level and differenced equations, using lagged levels as instruments for differences and lagged differences for levels, enhancing efficiency while controlling for unobserved country-specific heterogeneity, heteroskedasticity, and serial correlation ([Arellano & Bover, 1995](#); [Blundell & Bond, 1998](#)). Robustness is verified through the Hansen Test for Overidentifying Restrictions, assessing instrument validity, and the Arellano-Bond Test for Serial Correlation, confirming no second-order correlation in error terms ([Roodman, 2009](#)).

3.5.3 Long-Run Multiplier

Within the System GMM framework (Equation 4), short-run effects of climate and institutional variables on economic growth are captured by $\mathbf{\Gamma}$, while long-run multipliers (LRMs) reflect their cumulative impact over time. The long-run effects are derived from the steady-state level model, $\mathbf{Y}_{it} = \mathbf{B}_0 + \mathbf{B}_1 \mathbf{Y}_{i,t-1} + \mathbf{\Gamma} \mathbf{Z}_{it} + \boldsymbol{\epsilon}_{it}$, where in equilibrium ($\mathbf{Y}_{it} = \mathbf{Y}_{i,t-1} = \mathbf{Y}_i^*$), the long-run multiplier according to [Wooldridge \(2010\)](#) is:

$$\text{LRM} = (\mathbf{I} - \mathbf{B}_1)^{-1} \mathbf{\Gamma} \quad \text{Eq.5}$$

where \mathbf{I} is the 4×4 identity matrix, \mathbf{B}_1 is a matrix of coefficients on lagged dependent variables ($\Delta \mathbf{Y}_{i,t-1}$), and $\mathbf{\Gamma}$ is a matrix of short-run coefficients from Eq.4. For a single variable $Z_{k,it}$, this generalizes the scalar LRM, $\psi_k = \frac{\beta_k}{1 - \Sigma \gamma_j}$, where β_k is the short-run effect and $\Sigma \gamma_j$ reflect persistence ([Greene, 2012](#)). The term $(\mathbf{I} - \mathbf{B}_1)^{-1}$ adjusts these short-run effects for persistence³⁴, yielding the cumulative impact in equilibrium. This

³⁴ For instance, a sustained 1°C temperature increase's long-run effect on GDPPC is given by $\psi_{temp} = \frac{\gamma_{y,temp}}{1 - B_{1y}}$, where $\gamma_{y,temp}$ (from $\mathbf{\Gamma}$) is the short-run effect and B_{1y} from (from \mathbf{B}_1) reflects persistence, amplifying the impact as B_{1y} approaches unity.

approach, common in dynamic panel econometrics ([Arellano & Bond, 1991](#); [Blundell & Bond, 1998](#)), measures the cumulative effects of GDP per capita, climate factors, and institutional quality on GDPPC, CO₂, corruption, and political instability, reflecting their interdependence.

3.6 Results and Discussion

3.6.1 Descriptive Results

Table 3.1 presents descriptive statistics for the study variables across all cross-sections and time periods in SSA. GDP per capita averages \$2,103.219, with a substantial standard deviation of \$2,806.214, indicating relatively low levels and significant variability across SSA countries. Between-country variation emphasizes structural differences, while smaller within-country variation suggests persistent national GDP levels, despite occasional shifts, e.g., a negative minimum. Per capita CO₂ emissions average 0.96 but vary widely. Political instability and corruption average 6.15 and 4.79, respectively, with standard deviations of 2.05 and 1.98, highlighting significant heterogeneity.

Table 3.1: Table Descriptive Statistics Two-year averaged

Variable	distribution	Mean	Std. dev.	Min	Max	Observations
GDPPC	Overall	2103.21	2806.21	246.31	16172.57	N = 516
	Between		2704.99	306.36	12322.26	n = 43
	within		845.04	-5897.20	8337.374	T = 12
Physical Capital Per capita	overall	0.02	0.03	0.001	0.182	N = 516
	between		0.03	0.001	0.165	n = 43
	within		0.01	-0.039	0.070	T = 12
CO2 emission per capita	overall	0.96	1.79	0.0004	11.168	N = 516
	between		1.74	0.035	7.554	n = 43
	within		0.50	-3.53	4.947	T = 12
FDI per capita	overall	98.67	306.56	-178.34	3790.638	N = 516
	between		243.02	1.19	1449.680	n = 43
	within		190.21	-817.16	2439.638	T = 12
Average temperature in °C	overall	24.69	3.37	11.70	29.250	N = 516
	between		3.40	12.51	28.900	n = 43
	within		0.21	23.89	25.486	T = 12
	overall	1074.54	571.19	86.85	2654	N = 516

Variable	distribution		Mean	Std. dev.	Min	Max	Observations
Precipitation in millimetre	between			570.21	96.75	2514.12	n = 43
	within			89.46	667.34	1551.94	T = 12
Human Capital (lsch2rygross_gen)	overall		3.52	0.61	1.70	4.706	N = 516
	between			0.50	2.44	4.528	n = 43
	within			0.34	2.25	4.528	T = 12
Political Instability (ipi10)	overall		6.15	2.05	1	10	N = 516
	between			1.87	2.16	9.615	n = 43
	within			0.89	2.36	8.935	T = 12
Corruption (icc10)	overall		4.79	1.98	1	10	N = 516
	between			1.91	1.83	9.596	n = 43
	within			0.58	2.49	7.423	T = 12

Source: Author's computation based on CRU, WGI, and WDI (2021) data.

3.6.2 Empirical Results

This study explores causal links between climate change (CO₂ emissions), institutional quality (political instability and corruption), and economic growth in SSA. It assesses how climate change interacts with institutional weaknesses, impacting economic growth. The two-step GMM estimation method was employed for efficiency, adjusting lag counts from 1 to 4 and integrating period dummies to manage time-specific disruptions as recommended by [Roodman \(2009\)](#).

Instrument balance was ensured to prevent over-instrumentation, validated by the Hansen test ([Hansen, 1982](#)). Additionally, the absence of second-order serial correlation was confirmed through the Arellano-Bond tests (AR(1) and AR(2)), crucial for reliable System GMM estimates. The study prioritized system GMM for its robustness in handling endogeneity and persistence, supported by methodological insights, and conducted sensitivity analyses using difference GMM, pooled OLS, and fixed-effects models for comparison ([Arellano & Bond, 1991](#); [Roodman, 2009](#)).

Table 3.2: Dynamic panel-data estimation results of GDPPC model

VARIABLES	(1) C	(2) PI	(3) SysGMM	(4) DifGMM	(5) Pooled-OLS	(6) FE
Lagged, GDPPC	0.375*** (0.104)	0.375*** (0.078)	0.389*** (0.095)	0.362*** (0.084)	0.370*** (0.069)	0.301*** (0.065)
FDI	0.001** (0.000)	0.001** (0.000)	0.001** (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Capital	0.225* (0.128)	0.239** (0.109)	0.224* (0.119)	0.680*** (0.099)	0.313*** (0.055)	0.483*** (0.101)
HumanCap	0.026 (0.036)	0.032 (0.032)	0.035 (0.031)	0.028 (0.050)	0.029 (0.027)	0.075* (0.043)
Corruption	-0.638* (0.323)		-0.488* (0.285)	-0.001 (0.325)	-0.449** (0.207)	-0.348 (0.246)
Political instability		-0.468*** (0.143)	-0.423*** (0.144)	-0.482*** (0.129)	-0.469*** (0.116)	-0.514*** (0.107)
Temperature	-0.578* (0.331)	-0.535* (0.301)	-0.548* (0.314)	-0.501** (0.219)	-0.506* (0.281)	-0.569* (0.317)
Precipitation	0.018 (0.033)	0.024 (0.030)	0.024 (0.030)	0.020 (0.025)	0.024 (0.028)	0.016 (0.028)
Constant	-0.004 (0.010)	0.005 (0.009)	0.032*** (0.011)		-0.004 (0.006)	-0.003 (0.007)
Observations	430	430	430	387	430	430
R-squared					0.458	0.406
Number of countries	43	43	43	43	43	43
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
AR(1)	0.001	0.002	0.002	0.001		
AR(2)	0.986	0.895	0.964	0.848		
Hansen	0.214	0.240	0.228	0.824		
Number of Instruments	38	38	38	26		

Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Note: Results are presented using System GMM (Columns 1-3), Difference GMM, Pooled OLS, and Fixed Effects (Columns 4-6). System GMM models progressively include corruption (Column 1), political instability (Column 2), and both (Column 3, the focus of interpretation). Columns 4-6 provide comparative results.

Source: *Author's computation based on CRU, WGI, and WDI (2021) data.*

The four simultaneous models are separately presented in Table 3.2 to Table 3.5. Table 3.2 specifically examines factors influencing economic growth in SSA in terms of GDPPC. The positive and significant coefficient 0.39 (in Column 3) for the lagged

dependent variable indicates persistent³⁵ economic growth, suggesting that previous GDPPC levels significantly influence current levels. This persistence suggests a gradual economic adjustment, with approximately 39% of current GDP per capita driven by its past value. This finding aligns with studies emphasizing the cumulative nature of economic growth ([Barro & Sala-i-Martin, 2004](#)).

The significant negative coefficients for corruption and political instability indicate that both factors significantly hinder economic growth. Specifically, a one-unit increase in corruption is associated with a 0.48% decrease, and in instability with a 0.42% decrease in GDP per capita growth, *Ceteris Paribus*. Corruption undermines institutional quality, deters investment, and diminishes economic productivity ([Mauro, 1995](#)). Similarly, political instability fosters uncertainty, disrupts policy implementation, such as climate policies, and discourages long-term investments, further hampering growth ([Aisen & Veiga, 2013](#)). The analysis indicates that a 1°C temperature increase corresponds to a 0.54 percentage point decrease in GDPPC, emphasizing climate and institutional factors' significant roles in economic growth constraints in the region.

Table 3.3: Dynamic Panel Estimation: Institutional Quality (Corruption as Dependent Variable)

VARIABLES	(1) SysGMM	(2) DiffGMM	(3) Poold-OLS	(4) FE
Lagged, Corruption	0.241*** (0.055)	0.290*** (0.082)	0.181*** (0.064)	0.141*** (0.046)
GDPPC	-0.024* (0.013)	-0.031** (0.013)	-0.016** (0.007)	-0.016* (0.009)
FDI	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Capital	0.032 (0.024)	0.039* (0.022)	0.004 (0.007)	0.009 (0.012)
Political Instability	0.071* (0.040)	0.054 (0.048)	0.070*** (0.027)	0.069** (0.031)
Human Capital	0.022	0.059	-0.003	-0.000

³⁵ Persistence suggests a degree of inertia in the economic system, meaning that changes in growth are gradual and influenced by historical levels. Economic growth tends to follow established patterns and does not shift abruptly.

VARIABLES	(1) SysGMM	(2) DiffGMM	(3) Poold-OLS	(4) FE
	(0.025)	(0.093)	(0.006)	(0.006)
Temperature	-0.034	-0.049	-0.011	-0.021
	(0.040)	(0.068)	(0.054)	(0.043)
Constant	-0.004		-0.001	-0.002
	(0.003)		(0.002)	(0.002)
Observations	430	387	430	430
R-squared			0.116	0.098
Number of countries	43	43	43	43
Year FE	Yes	Yes	Yes	Yes
AR(1)	0.000	0.000		
AR(2)	0.361	0.198		
Hansen	0.277	0.151		
Number of Instruments	40	24		

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: The discussion centers on Column 1 (System GMM) with all required variables, while Columns 2–4 present Difference GMM, Pooled OLS, and Fixed Effects results, respectively.

Source: *Author's computation based on CRU, WGI, and WDI (2021) data.*

Table 3.3, using System GMM, reveals several factors influencing corruption. First, past corruption significantly predicts current levels, indicating its persistence in SSA. This aligns with literature suggesting corruption's institutionalization, requiring drastic reforms to reverse ([Mauro, 1995](#); [Treisman, 2000](#)). Second, GDP per capita negatively impacts corruption, supporting modernization theory: economic growth may enhance governance and reduce corruption through higher wages and accountability ([Lipset, 1959](#)). However, weak corruption control undermines environmental regulations, as firms bribe to bypass laws, increasing emissions ([Fredriksson & Svensson, 2003](#)). Finally, political instability exacerbates corruption. It weakens governance, allowing officials to operate with impunity ([Shabbir et al., 2016](#); [Shleifer & Vishny, 1993](#)). In SSA, frequent political changes and conflicts further contribute to this dynamic.

Table 3.4: Dynamic panel-data estimation of Political Instability model

VARIABLES	(1) SysGMM	(2) DifGMM	(3) Pooled_OLS	(4) FE
Lagged, Political Inst	-0.444*** (0.108)	-0.230*** (0.058)	0.086* (0.048)	-0.009 (0.050)
GDPPC	-0.062* (0.031)	-0.051** (0.021)	-0.035** (0.015)	-0.042** (0.018)
HumanCap	-0.042 (0.041)	0.011 (0.026)	0.002 (0.012)	0.004 (0.018)
Corruption	0.391* (0.216)	0.383* (0.191)	0.296*** (0.101)	0.301** (0.132)
Temperature	-0.226 (0.492)	0.035 (0.147)	0.090 (0.133)	0.093 (0.101)
Constant	-0.000 (0.008)		0.006 (0.004)	0.006 (0.004)
Observations	430	387	430	430
R-squared			0.065	0.060
Number of countries	43	43	43	43
Year FE	Yes	Yes	Yes	Yes
AR(1)	0.320	0.005		
AR(2)	0.113	0.013		
Hansen	0.138	0.168		
Number of Instruments	33	39		

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: The interpretation and discussion are based on Column 1 (System GMM), which includes all relevant variables pertaining to Political instability. Columns 2, 3, and 4 are difference GMM, Pooled OLS, and Fixed Effect respectively.

Source: Author's computation based on CRU, WGI, and WDI (2021) data.

Table 3.4, examines factors affecting political instability. The negative coefficient on lagged political instability suggests a 44% reduction in current instability, indicating a partial self-correcting effect³⁶. This implies that past instability in SSA may trigger stabilizing responses, potentially through institutional reforms or international

³⁶ The negative lag of past instability shows it reduces current instability (increases stability), but weakens the impact of other stabilizing factors, such as corruption control and economic growth.

interventions. Additionally, GDP per capita negatively impacts instability, indicating economic growth's stabilizing influence via improved opportunities and governance.

Conversely, corruption positively affects instability, undermining stabilizing efforts by eroding trust and fueling conflict. This negative lag of political instability indicates that high past instability weakens the influence of factors like corruption control and economic growth, while low past instability strengthens them.

Table 3.5 examines the drivers of CO₂ emissions in SSA, revealing how economic and institutional factors interact.

Table 3.5: Dynamic panel-data estimation CO₂ Emission model

VARIABLES	(1) C	(2) PI	(3) SysGMM	(4) Diff GMM	(5) Pooled OLS	(6) FE
CO ₂ , lagged	-0.209** (0.088)	-0.248*** (0.070)	-0.201** (0.081)	-0.434*** (0.129)	0.061 (0.054)	-0.012 (0.055)
GDPPC	3.106*** (0.959)	2.944*** (0.765)	2.776*** (0.695)	4.117** (1.826)	0.573*** (0.117)	0.564*** (0.119)
FDI	0.000 (0.001)	0.000 (0.001)	0.000 (0.001)	0.001 (0.002)	0.000 (0.001)	0.000 (0.001)
Corruption	3.174** (1.252)		2.718** (1.252)	0.999 (2.059)	0.712 (0.534)	0.830 (0.572)
Political Inst.		1.262** (0.526)	1.026* (0.514)	1.759* (0.960)	0.132 (0.284)	-0.049 (0.320)
Temperature	2.130** (0.998)	1.943* (1.016)	1.870* (1.040)	1.576 (1.366)	0.367 (0.605)	0.471 (0.592)
Constant	-0.046 (0.064)	-0.052 (0.060)	-0.066 (0.060)		-0.018 (0.026)	-0.011 (0.025)
Observations	428	428	428	385	428	428
R-squared					0.183	0.153
Number of countries	43	43	43	43	43	43
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
AR(1)	0.005	0.004	0.001	0.049		
AR(2)	0.311	0.187	0.223	0.129		
Hansen	0.132	0.102	0.130	0.076		
Number of Instruments	42	38	43	29		

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: Analysis centers on System GMM (Column 3), which incorporates all CO₂ emission drivers. Columns 1-2 show System GMM with individual corruption and instability effects. Columns 4-6 provide comparative results from alternative models.

Source: *Author's computation based on CRU, WGI, and WDI (2021) data.*

Accordingly, lagged emissions negatively affect current levels suggesting mitigation efforts follow high past emissions, though this self-correction is incomplete. Conversely, GDP per capita strongly increases emissions, indicating SSA's economic growth, reliant on energy-intensive processes, is still on the rising part of the EKC. Moreover, weak governance amplifies emissions; corruption increases emissions by 2.71%, and political instability by 1.02%, reflecting poor environmental regulation and disrupted policy enforcement. Rising temperatures increase emissions by 1.87%, primarily due to increased energy demands for managing agricultural stress (irrigation) and combating rising heat stress on humans and livestock, alongside potential increases in localized cooling demands in urban centers.

The long-run effects³⁷ of key endogenous variables, GDP per capita (GDPPC), CO₂ emissions, corruption, and political instability, were also analyzed to gain a more comprehensive understanding of their relationships beyond short-term dynamics, as indicated in Table 3.6.

Table 3.6: Long-run relationship between GDPPC, CO₂, Corruption, and Political instability

	(1)	(2)	(3)	(4)
Long-Run Effect Variables	GDPPC	CO ₂ pc	Corruption	Political
GDPPC (LRE_gdppc)	..	2.311*** (0.519)	-0.032* (0.017)	-0.043** (0.021)
Corruption (LRE_C)	-0.911* (0.587)	2.263** (0.996)	..	0.271* (0.150)
Political Instability (LRE_pi)	-0.659*** (0.236)	0.854** (0.420)	0.094* (0.063)	..
Temperature (LRE_temp_it)	-0.933* (0.562)	1.557* (0.847)	-0.045 (0.052)	-0.156 (0.340)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: *Author's computation based on CRU, WGI, and WDI (2021) data.*

³⁷ Consider the long-run effect of CO₂ emission on GDPPC is given by; *long – run effect of CO₂* = $\frac{\beta_{CO_2}}{1-\beta_{LGDPPC}}$ where β_{CO_2} refers to coefficient of CO₂ while β_{LGDPPC} is the coefficient of lagged dependent variable GDPPC.

Long-term, GDP per capita is adversely affected by corruption, political instability, and rising temperatures (Column 1). Corruption significantly hinders growth, reducing it by 0.91% due to resource misallocation and discouraged investment. Additionally, political instability and rising temperatures diminish economic productivity by 0.65% and 0.93%, respectively.

Conversely, CO₂ emissions increase with GDP per capita, corruption, political instability, and temperature (Column 2). Economic growth augments emissions by 2.3%, driven by industrialization, consistent with the Environmental Kuznets Curve (EKC). Corruption and instability intensify emissions by 2.3% and 0.85%, respectively, indicating weakened environmental oversight. Temperature drives up emissions by 1.5%, stressing carbon sinks in SSA.

Corruption (Column 3) is slightly reduced by GDP per capita, declining by 0.032%, suggesting that economic growth improves governance. Political instability augments corruption by 0.094%, fostering an environment conducive to corrupt practices.

Conversely, political instability (Column 4) decreases with GDP per capita by 0.043%, as economic growth enhances stability. Corruption increases instability by 0.27%, highlighting their mutually reinforcing relationship.

3.6.3 Discussion

The persistence of GDP per capita growth in sub-Saharan Africa (SSA), as evidenced by the positive lagged coefficient (Table 3.2), aligns with 'path dependence' theory ([Durlauf, 1999](#)). However, a substantial portion of GDP variation is attributed to short-term, external factors, indicating that immediate policies and conditions outweigh historical patterns in shaping economic output. Specifically, rising temperatures negatively impact GDP, both immediately and in the long term, affecting climate-sensitive sectors.

Turning to institutional quality, while economic growth correlates with reduced corruption, persistent corrupt practices necessitate sustained, long-term anti-corruption efforts (Table 3.3). Political instability, in particular, significantly drives corruption, emphasizing the importance of political stability for effective governance. Indeed, the political context directly influences economic growth and institutional quality ([Alesina et al., 1996](#)).

Furthermore, previous episodes of political instability tend to prompt corrective measures, reducing subsequent instability (Table 3.4). Nevertheless, corruption remains a significant driver of instability, highlighting the detrimental impact of weak governance (Bardhan, 2017). This aligns with research indicating that corruption fosters social unrest (Aidt et al., 2008). Additionally, economic growth correlates with improved political stability, though uneven wealth distribution, prevalent in SSA due to corruption and weak institutions (Acemoglu et al., 2019), can counteract this effect.

Regarding environmental factors, the negative lagged coefficient of CO₂ emissions (Table 3.5) suggests a potential self-correcting mechanism. Moreover, CO₂ emissions are linked to GDP per capita, reflecting the early stage of the EKC hypothesis (Stern, 2004). In this phase, economic growth often increases emissions due to reliance on fossil fuels and rapid industrialization. Critically, corruption and political instability exacerbate emissions by weakening environmental regulations and governance.

Long-term analysis (Table 3.6) shows corruption, political instability, and rising temperatures negatively affect GDP per capita, highlighting needs for governance and climate resilience (Column 1). Meanwhile, economic growth, corruption, instability, and temperature rises increase CO₂ emissions, amplifying environmental risks via a temperature-emissions cycle (Column 2). Similarly, corruption and political instability reinforce each other, forming a destabilizing loop (Columns 3 & 4).

3.6.4 Robustness Check and Diagnostic Tests

Granger causality tests (*see* Table 3.8 in Appendix 3.1) confirmed the System GMM results on the direction and magnitude of causality among GDP per capita, CO₂ emissions, corruption, and political instability, aligning with existing literature. Diagnostic tests for all variables are included in their respective models, but for clarity and convenience, the results for GDP per capita, as shown in Table 3.2, are presented here as a representative example. The Hansen J-test ($p=0.228$) confirmed instrument validity, while the Arellano-Bond test indicated first-order autocorrelation (AR(1), $p=0.001$) but no second-order autocorrelation (AR(2), $p=0.964$). These findings ensure the reliability of the System GMM estimator by ruling out serial correlation beyond the first order, reinforcing the study's conclusions (Blundell & Bond, 1998; Roodman, 2009).

3.7 Conclusion and Policy Implications

3.7.1 Conclusion

The findings highlight the adverse impact of corruption, political instability, and climate factors on economic growth in SSA countries. Governance challenges and climate pressures are fundamental in shaping economic trajectories, revealing vulnerabilities to both short-term shocks and sustained pressures. Furthermore, corruption and political instability significantly drive-up CO₂ emissions, which are exacerbated by economic growth, aligning with early Environmental Kuznets Curve stages.

Despite some mitigation efforts, weak institutional quality fails to shield SSA from the adverse effects of high temperatures, intensifying economic and environmental vulnerabilities. Economic growth influences institutional quality, affecting corruption and instability levels, while climate factors indirectly exacerbate these dynamics through increased emissions. As GDP per capita rises, political instability and corruption tend to decrease, though the rate of improvement slows over time.

3.7.2 Policy Implications

To address the interconnected challenges of corruption, instability, and rising CO₂ emissions in SSA, governments must prioritize institutional reforms and sustainable growth. Short-term efforts should focus on anti-corruption measures, political stabilization, and strengthening environmental regulations. Long-term strategies require integrating governance reforms with climate policies, promoting green growth, and adopting climate adaptation measures. Given the reciprocal influence between economic growth and institutional/environmental factors, policies must balance development with sustainability. Regional collaboration and international partnerships are vital for achieving long-term resilience.

Appendix 3.1: Pairwise and Bootstrap Results

Table 3.7: Pairwise Correlations Report

Variables	GDPPC	Capital	CO2	FDI	TEMP	H	PI	C
GDPPC	1.000							
Capital	0.923*	1.000						
CO2 E	0.931*	0.866*	1.000					
FDI	0.031	-0.012	0.065	1.000				
TEMP	-0.066	-0.064	-0.062	0.001	1.000			
HumanCap	0.618*	0.538*	0.630*	0.129*	-0.135*	1.000		
Political	-0.421*	-0.416*	-0.427*	-0.024	0.102	-0.291*	1.000	
Corruption	-0.314*	-0.283*	-0.304*	-0.154*	0.301*	-0.301*	0.679*	1.000

** Shows significance at $p < 0.01$*

Source: Author's computation based on CRU and WB WDI (2021) data.

Table 3.8: Bootstrap results of Granger-causality regression estimation

VARIABLES	(1) GDPPC	(2) GDPPC	(3) CO2Emi	(4) CO2Emi	(5) Corruption	(6) Corruption	(7) Political	(8) Political
GDPPC	..	..	0.841*** (0.130)	0.825*** (0.124)	-0.013 (0.008)	-0.014 (0.009)	-0.037** (0.018)	-0.040** (0.020)
GDPPC, Lagged	0.545*** (0.090)	0.514*** (0.084)	..	..	..	..	..	..
CO2Emi	0.111*** (0.026)	0.089*** (0.026)	..	..	0.003 (0.004)	0.003 (0.004)	0.016 (0.012)	0.015 (0.012)
CO2Emi, Lagged	..	..	0.045 (0.056)	-0.007 (0.056)	..	..	..	..
Corruption	-0.730** (0.291)	-0.523** (0.251)	1.198 (0.961)	1.789** (0.813)	..	..	0.348** (0.151)	0.297* (0.180)
Corruption, Lagged	..	..	..	..	0.154** (0.066)	0.203*** (0.065)	..	..
Politi.Insta	-0.336** (0.167)	-0.424*** (0.152)	0.655* (0.371)	0.613* (0.351)	0.085*** (0.027)	0.073*** (0.023)	..	..
Politi.Insta, Lagged	..	..	..	..	..	..	0.103 (0.077)	0.100 (0.084)
Constant	0.024*** (0.009)	0.041*** (0.004)	0.063*** (0.021)	0.082*** (0.010)	0.002 (0.002)	0.006*** (0.001)	0.018** (0.008)	0.012*** (0.002)
Observations	429	429	428	428	429	429	429	429
Year FE	Yes	No	Yes	No	Yes	No	Yes	No
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Standard errors in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Source: Author's computation based on CRU and WB WDI (2021) data.

Reference:

- Abdel-Latif, H., Elgohari, H., & Mohamed, A. (2018). Corruption, political instability, and growth: Evidence from the Arab Spring. *Available at SSRN 3240211*.
- Abeyasinghe, R. (2004). Democracy, political stability, and developing country growth: Theory and evidence.
- Abidoye, B. O., & Odusola, A. F. (2015). Climate change and economic growth in Africa: an econometric analysis. *Journal of African economies*, 24(2), 277-301. <https://doi.org/10.1093/jae/eju033>
- Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The Environment and Directed Technical Change. *Am Econ Rev*, 102(1), 131-166. <https://doi.org/10.1257/aer.102.1.131>
- Acemoglu, D., Johnson, S., & Robinson, J. A. (2001). The Colonial Origins of Comparative Development: An Empirical Investigation. *American Economic Review*, 91(5), 1369-1401. <https://doi.org/10.1257/aer.91.5.1369>
- Acemoglu, D., Johnson, S., & Robinson, J. A. (2004). Institutions as the Fundamental Cause of Long-Run Growth. *Available at SSRN 571052*.
- Acemoglu, D., Naidu, S., Restrepo, P., & Robinson, J. A. (2019). Democracy does cause growth. *Journal of political economy*, 127(1), 47-100. <https://doi.org/10.1086/700936>
- Acemoglu, D., & Robinson, J. A. (2013). *Why nations fail: The origins of power, prosperity, and poverty*. Crown Currency.
- Ahmad, E., Ullah, M. A., & Arfeen, M. I. (2012). Does corruption affect economic growth? *Latin american journal of economics*, 49(2), 277-305.
- Aidt, T., Dutta, J., & Sena, V. (2008). Governance regimes, corruption and growth: Theory and evidence. *Journal of comparative economics*, 36(2), 195-220. <https://doi.org/10.1016/j.jce.2007.11.004>
- Aisen, A., & Veiga, F. J. (2013). How does political instability affect economic growth? *European Journal of Political Economy*, 29, 151-167. <https://doi.org/10.1016/j.ejpoleco.2012.11.001>
- Alesina, A., Özler, S., Roubini, N., & Swagel, P. (1996). Political instability and economic growth. *Journal of Economic growth*, 1(2), 189-211.
- Alesina, A., & Perotti, R. (1996). Income distribution, political instability, and investment. *European economic review*, 40(6), 1203-1228.
- Ali, H. S., Zeqiraj, V., Lin, W. L., Law, S. H., Yusop, Z., Bare, U. A. A., & Chin, L. (2019). Does quality institutions promote environmental quality? *Environmental Science and Pollution Research*, 26(11), 10446-10456.

- Alimi, R. S. (2015). Financial deepening and economic growth: A System GMM Panel Analysis with application to 7 SSA countries.
- Anderson, T. W., & Hsiao, C. (1981). Estimation of dynamic models with error components. *Journal of the American statistical association*, 76(375), 598-606. <https://doi.org/10.1080/01621459.1981.10477691>
- Antonakis, J., Bendahan, S., Jacquart, P., & Lalive, R. (2010). On making causal claims: A review and recommendations. *The leadership quarterly*, 21(6), 1086-1120. <https://doi.org/10.1016/j.leaqua.2010.10.010>
- Apergis, N., & Payne, J. E. (2014). The causal dynamics between renewable energy, real GDP, emissions and oil prices: evidence from OECD countries. *Applied Economics*, 46(36), 4519-4525. <https://doi.org/10.1080/00036846.2014.964834>
- Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies*, 58(2), 277-297. <https://doi.org/10.2307/2297968>
- Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of econometrics*, 68(1), 29-51.
- Arminen, H., & Menegaki, A. N. (2019). Corruption, climate and the energy-environment-growth nexus. *Energy Economics*, 80, 621-634.
- Baltagi, B. H. (2008). *Econometric analysis of panel data* (Vol. 4). Springer.
- Bardhan, P. (2017). Corruption and development: a review of issues. *Political corruption*, 321-338.
- Barro, R. J. (1991). Economic growth in a cross section of countries. *The quarterly journal of economics*, 106(2), 407-443.
- Barro, R. J. (1996). Determinants of economic growth: A cross-country empirical study. In: National Bureau of Economic Research Cambridge, Mass., USA.
- Barro, R. J., & Sala-i-Martin, X. (2004). Economic growth second edition. In (pp. Chapter 12, pp. 535-542.): The MIT Press, Cambridge, Massachusetts; London, England.
- Bayar, Y., Smirnov, V., Danilina, M., & Kabanova, N. (2021). Impact of institutions and human capital on CO2 emissions in EU transition economies. *Sustainability*, 14(1), 353. <https://doi.org/10.3390/su14010353>
- Bello-Schünemann, J., & Moyer, J. D. (2018). Structural pressures and political instability: Trajectories for sub-Saharan Africa.
- Berrang-Ford, L., Ford, J. D., & Paterson, J. (2011). Are we adapting to climate change? *Global environmental change*, 21(1), 25-33. <https://doi.org/10.1016/j.gloenvcha.2010.09.012>

- Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of econometrics*, 87(1), 115-143. [https://doi.org/10.1016/S0304-4076\(98\)00009-8](https://doi.org/10.1016/S0304-4076(98)00009-8)
- Bollen, K. A. (2014). *Structural equations with latent variables*. John Wiley & Sons.
- Borensztein, E., De Gregorio, J., & Lee, J.-W. (1998). How does foreign direct investment affect economic growth? *Journal of international Economics*, 45(1), 115-135. [https://doi.org/10.1016/0304-4076\(94\)01642-D](https://doi.org/10.1016/0304-4076(94)01642-D)
- Bruinshoofd, A. (2016). Institutional quality and economic performance. *Rabobank Research Economic Report, Utrecht*.
- Buhaug, H., & Urdal, H. (2013). An urbanization bomb? Population growth and social disorder in cities. *Global environmental change*, 23(1), 1-10.
- Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, 527(7577), 235-239.
- Chamma, D. D. (2024). Climate change and economic growth in sub-Saharan Africa: an empirical analysis of aggregate-and sector-level growth. *Journal of Social and Economic Development*, 1-33. <https://doi.org/10.1007/s40847-024-00377-x>
- Chebli, M., & Saidi, K. (2024). Economic Growth in Middle-Income Countries: The Role of Political Stability and Foreign Direct Investment. *Journal of Quantitative Economics*, 1-25. <https://doi.org/10.1007/s40953-024-00394-x>
- Cobb, C. W., & Douglas, P. H. (1928). A Theory of Production. *The American Economic Review*, 18(1), 139-165.
- Collier, P., & Hoeffler, A. (2004). Greed and grievance in civil war. *Oxford Economic Papers*, 56(4), 563-595. <https://doi.org/10.1093/oep/gpf064>
- d'Agostino, G., Dunne, J. P., & Pieroni, L. (2016). Corruption and growth in Africa. *European Journal of Political Economy*, 43, 71-88. <https://doi.org/10.1016/j.ejpoleco.2016.03.002>
- Del Monte, A., & Pennacchio, L. (2020). Corruption, government expenditure and public debt in OECD countries. *Comparative economic studies*, 62(4), 739-771.
- Dell, Melissa, Jones, F. B., Olken, & A. B. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3), 66-95. <https://doi.org/10.1257/mac.4.3.66>
- Dell, M., Jones, B. F., & Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3), 66-95.

- Durlauf, S. (1999). The New Empirics of Economic Growth. *Handbook of Macroeconomics/North-Holland*.
- Edoun, E., & Mbohwa, C. (2016). Correlation between political instability and the rise of poverty in Africa. 3rd International Multidisciplinary Scientific Conference on Social Sciences and Arts SGEM 2016,
- Egbetokun, S., Osabuohien, E., Akinbobola, T., Onanuga, O. T., Gershon, O., & Okafor, V. (2019). Environmental pollution, economic growth and institutional quality: exploring the nexus in Nigeria. *Management of Environmental Quality: An International Journal*, 31(1), 18-31.
- Farooq, U., Gillani, S., Subhani, B. H., & Shafiq, M. N. (2023). Economic policy uncertainty and environmental degradation: the moderating role of political stability. *Environmental Science and Pollution Research*, 30(7), 18785-18797. <https://doi.org/10.1007/s11356-022-23479-7>
- Farrag, N. A., & Ezzat, A. M. (2016). The Impact of Corruption on Economic Growth: A Comparative Analysis between Europe and MENA Countries. In *Handbook of Research on Comparative Economic Development Perspectives on Europe and the MENA Region* (pp. 74-97). IGI Global.
- Feenstra, R. C., Inklaar, R., & Timmer, M. P. (2015). The next generation of the Penn World Table. *American Economic Review*, 105(10), 3150-3182. <https://doi.org/10.1257/aer.20130954>
- Ferrini, L. (2012). The importance of institutions to economic development. *E-International Relations*, 30(8), 142.
- Fosu, A. K. (1992). Political instability and economic growth: evidence from Sub-Saharan Africa. *Economic Development and cultural change*, 40(4), 829-841.
- Fosu, A. K. (2002). Political instability and economic growth: Implications of coup events in Sub-Saharan Africa. *American Journal of Economics and Sociology*, 61(1), 329-348. <https://doi.org/10.1111/1536-7150.00162>
- Fredriksson, P. G., & Neumayer, E. (2016). Corruption and climate change policies: do the bad old days matter? *Environmental and Resource Economics*, 63, 451-469. <https://doi.org/10.1007/s10640-014-9869-6>
- Fredriksson, P. G., & Svensson, J. (2003). Political instability, corruption and policy formation: the case of environmental policy. *Journal of public economics*, 87(7-8), 1383-1405. [https://doi.org/10.1016/S0047-2727\(02\)00036-1](https://doi.org/10.1016/S0047-2727(02)00036-1)

- Freeman, L. (2017). Environmental change, migration, and conflict in Africa: a critical examination of the interconnections. *The Journal of Environment & Development*, 26(4), 351-374.
- Gakpa, L. L. (2020). *Political instability, FDI and economic growth in Sub-Saharan African Countries: evidence from modelling dynamic simultaneous equations*. AERC.
- Galinato, G. I., & Galinato, S. P. (2012). The effects of corruption control, political stability and economic growth on deforestation-induced carbon dioxide emissions. *Environment and Development Economics*, 17(1), 67-90. <https://doi.org/10.1017/S1355770X11000222>
- Gazdar, K., & Cherif, M. (2015). Institutions and the finance–growth nexus: Empirical evidence from MENA countries. *Borsa Istanbul Review*, 15(3), 137-160.
- Grabowski, R., & Self, S. (2020). What factors influence the quality of governance institutions? An Asian perspective. *Journal of Asian Economics*, 70, 101238.
- Graeff, P., & Mehlkop, G. (2003). The impact of economic freedom on corruption: different patterns for rich and poor countries. *European Journal of Political Economy*, 19(3), 605-620.
- Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral method. *Econometrica: journal of the Econometric Society*, 424-438.
- Greene, W. H. (2012). *Econometric Analysis. 7th Edition, Prentice Hall, Upper Saddle River*. (Chap-14), 351-361.
- Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The quarterly journal of economics*, 110(2), 353-377.
- Gründler, K., & Potrafke, N. (2019). Corruption and economic growth: New empirical evidence. *European Journal of Political Economy*, 60, 101810. <https://doi.org/10.1016/j.ejpoleco.2019.08.001>
- Gyimah-Brempong, K. (2002). Corruption, economic growth, and income inequality in Africa. *Economics of governance*, 3(3), 183-209.
- Hansen, L. P. (1982). Large sample properties of generalized method of moments estimators. *Econometrica: journal of the Econometric Society*, 1029-1054.
- Harris, I., Jones, P. D., Osborn, T. J., & Lister, D. H. (2014). Updated high-resolution grids of monthly climatic observations—the CRU TS3. 10 Dataset. *International journal of climatology*, 34(3), 623-642. <https://doi.org/10.1002/joc.3711>
- Haydaroglu, C. (2016). Corruption, Institutions and Economic Growth in Sub-Saharan Africa. *International Journal of Economics and Research*, 7, 14-26.

- Hoque, M. E., Akhter, T., & Yakob, N. A. (2018). Revisiting endogeneity among foreign direct investment, economic growth and stock market development: Moderating role of political instability. *Cogent Economics & Finance*, 6(1), 1492311. <https://doi.org/10.1080/23322039.2018.1492311>
- Iheonu, C., Ihedimma, G., & Onwuanaku, C. (2017). Institutional Quality and Economic Performance in West Africa. University Library of Munich, Germany.
- Jaramillo, L., Cebotari, A., Diallo, Y., Gupta, R., Koshima, Y., Kularatne, C., Lee, J. D., Rehman, S., Tintchev, K., & Tintchev, M. K. I. (2023). *Climate challenges in fragile and conflict-affected states*. International Monetary Fund.
- Kaufmann, D., Kraay, A., & Mastruzzi, M. (2011). The worldwide governance indicators: methodology and analytical issues1. *Hague journal on the rule of law*, 3(2), 220-246.
- Kebede, J. G., & Takyi, P. O. (2017). Causality between institutional quality and economic growth: evidence from Sub-Saharan Africa. *European Journal of Economic and Financial Research*.
- Keefer, P., & Knack, S. (2002). Polarization, politics and property rights: Links between inequality and growth. *Public choice*, 111(1), 127-154.
- Khurshid, N., Fiaz, A., Khurshid, J., & Ali, K. (2022). Impact of climate change shocks on economic growth: A new insight from non-linear analysis. *Frontiers in Environmental Science*, 10, 1039128. <https://doi.org/10.3389/fenvs.2022.1039128>
- Kotchen, M. J. (2020). On the scope of climate finance to facilitate international agreement on climate change. *Economics Letters*, 190, 109070.
- Leitão, A. (2010). Corruption and the environmental Kuznets curve: empirical evidence for sulfur. *Ecological Economics*, 69(11), 2191-2201. <https://doi.org/10.1016/j.ecolecon.2010.06.004>
- Lepot, M., Aubin, J.-B., & Clemens, F. H. (2017). Interpolation in time series: An introductory overview of existing methods, their performance criteria and uncertainty assessment. *Water*, 9(10), 796.
- Li, R., Wang, Q., & Guo, J. (2024). Revisiting the environmental Kuznets curve (EKC) hypothesis of carbon emissions: exploring the impact of geopolitical risks, natural resource rents, corrupt governance, and energy intensity. *Journal of environmental management*, 351, 119663. <https://doi.org/10.1016/j.jenvman.2023.119663>
- Lin, X., Zhao, Y., Ahmad, M., Ahmed, Z., Rjoub, H., & Adebayo, T. S. (2021). Linking innovative human capital, economic growth, and CO2 emissions: an empirical study

- based on Chinese provincial panel data. *International journal of environmental research and public health*, 18(16), 8503. <https://doi.org/10.3390/ijerph18168503>
- Lipset, S. M. (1959). Some social requisites of democracy: Economic development and political legitimacy. *American political science review*, 53(1), 69-105.
- Lucas Jr, R. E. (1988). On the mechanics of economic development. *Journal of monetary economics*, 22(1), 3-42. [https://doi.org/10.1016/0304-3932\(88\)90168-7](https://doi.org/10.1016/0304-3932(88)90168-7)
- Maduka, A. C., Ogwu, S. O., & Ekesiobi, C. S. (2022). Assessing the moderating effect of institutional quality on economic growth—carbon emission nexus in Nigeria. *Environmental Science and Pollution Research*, 1-15.
- Mankiw, N. G., Romer, D., & Weil, D. N. (1992). A contribution to the empirics of economic growth. *The quarterly journal of economics*, 107(2), 407-437.
- Mauro, P. (1995). Corruption and growth. *The quarterly journal of economics*, 110(3), 681-712. <https://doi.org/10.2307/2946696>
- Moral-Benito, E. (2012). Determinants of economic growth: A Bayesian panel data approach. *Review of Economics and Statistics*, 94(2), 566-579.
- Murad, M. S. A., & Alshyab, N. (2019). Political instability and its impact on economic growth: the case of Jordan. *International Journal of Development Issues*.
- Nest, M., & Mullard, S. (2021). Lobbying, corruption and climate finance: The stakes for international development. *U4 Issue*.
- Nest, M., Mullard, S., & Wathne, C. (2020). Corruption and climate finance.
- Nickell, S. (1981). Biases in dynamic models with fixed effects. *Econometrica: journal of the Econometric Society*, 1417-1426.
- Nordhaus, W. D. (1991). To slow or not to slow: the economics of the greenhouse effect. *The Economic Journal*, 101(407), 920-937.
- North, D. C. (1990). *Institutions, institutional change and economic performance* (Vol. 4). Cambridge university press. [https://doi.org/10.1016/0167-2681\(92\)90062-G](https://doi.org/10.1016/0167-2681(92)90062-G)
- O'Loughlin, J., Witmer, F. D., Linke, A. M., Laing, A., Gettelman, A., & Dudhia, J. (2012). Climate variability and conflict risk in East Africa, 1990–2009. *Proceedings of the National Academy of Sciences*, 109(45), 18344-18349.
- Parsa, M., & Datta, S. (2023). Institutional Quality and Economic Growth: A Dynamic Panel Data Analysis of MICs and HICs for 2000–2020. *International Economic Journal*, 37(4), 675-712. <https://doi.org/10.1080/10168737.2023.2261012>
- Payne, J. E. (2010). A survey of the electricity consumption-growth literature. *Applied energy*, 87(3), 723-731.

- Pring, C. (2015). People and corruption: Africa survey. In.
- Regan, J. M., & Young, S. K. (2022). Climate change in the Horn of Africa: causations for violent extremism. *Behavioral Sciences of Terrorism and Political Aggression*, 1-27.
- Rhein, S., & Jansesberger, V. (2024). Does drought exposure erode trust in the political system in Sub-Saharan Africa? *Climatic change*, 177(7), 114. <https://doi.org/10.1007/s10584-024-03768-5>
- Rigas, N., & Kounetas, K. E. (2024). The impact of CO2 emissions and climate on economic growth and productivity: International evidence. *Review of Development Economics*, 28(2), 719-740. <https://doi.org/10.1111/rode.13075>
- Romer, P. M. (1990). Endogenous technological change. *Journal of political economy*, 98(5, Part 2), S71-S102. https://www.nber.org/system/files/working_papers/w3210/w3210.pdf
- Roodman, D. (2009). How to do xtabond2: An introduction to difference and system GMM in Stata. *The stata journal*, 9(1), 86-136.
- Sabir, S., Rafique, A., & Abbas, K. (2019). Institutions and FDI: evidence from developed and developing countries. *Financial Innovation*, 5(1), 1-20. <https://doi.org/10.1186/s40854-019-0123-7>
- Salgado, C. M., Azevedo, C., Proença, H., & Vieira, S. M. (2016). Missing data. *Secondary analysis of electronic health records*, 143-162.
- Shabbir, G., Anwar, M., & Adil, S. (2016). Corruption, political stability and economic growth. *The Pakistan development review*, 689-702.
- Shahbaz, M., Lean, H. H., & Shabbir, M. S. (2012). Environmental Kuznets curve hypothesis in Pakistan: cointegration and Granger causality. *Renewable and Sustainable Energy Reviews*, 16(5), 2947-2953.
- Sharma, C. (2024). Good and bad effects of corruption and political uncertainty on tourism-growth linkage: World-wide evidence. *Tourism Economics*, 30(6), 1423-1447. <https://doi.org/10.1177/13548166231209365>
- Shleifer, A., & Vishny, R. W. (1993). Corruption. *The quarterly journal of economics*, 108(3), 599-617. <https://doi.org/10.2307/2118402>
- Smallwood, J.-M. (2018). Investigating The Relationship Between Corruption and Climate Change: Is Corruption Bad For Climate Change? *Political Science Research Journal*, 2018. Accessed at socialsciences.uoregon.edu. .
- Solow, R. M. (1956). A contribution to the theory of economic growth. *The quarterly journal of economics*, 70(1), 65-94.

- Song, C.-Q., Chang, C.-P., & Gong, Q. (2021). Economic growth, corruption, and financial development: Global evidence. *Economic Modelling*, 94, 822-830. <https://doi.org/10.1016/j.econmod.2020.02.022>
- Sono, D., Wei, Y., & Jin, Y. (2021). Assessing the Climate Resilience of Sub-Saharan Africa (SSA): A Metric-Based Approach. *Land*, 10(11), 1205. <https://doi.org/10.3390/land10111205>
- Sovacool, B. K., Linnér, B.-O., & Goodsite, M. E. (2015). The political economy of climate adaptation. *Nature Climate Change*, 5(7), 616-618. <https://doi.org/10.1038/nclimate2665>
- Soytas, U., Sari, R., & Ewing, B. T. (2007). Energy consumption, income, and carbon emissions in the United States. *Ecological Economics*, 62(3-4), 482-489.
- Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World development*, 32(8), 1419-1439. <https://doi.org/10.1016/j.worlddev.2004.03.004>
- Stern, N. (2008). The economics of climate change. *American Economic Review*, 98(2), 1-37.
- TI-CPI, T. I. C. P. I. (2021). Corruption Perception Index, CPI (cpi2021). https://images.transparencycdn.org/images/CPI2021_Report_EN-web.pdf
- Tol, R. S. (2009). The economic effects of climate change. *Journal of economic perspectives*, 23(2), 29-51.
- Treisman, D. (2000). The causes of corruption: a cross-national study. *Journal of public economics*, 76(3), 399-457. [https://doi.org/10.1016/S0047-2727\(99\)00092-4](https://doi.org/10.1016/S0047-2727(99)00092-4)
- Ullah, S., Akhtar, P., & Zaefarian, G. (2018). Dealing with endogeneity bias: The generalized method of moments (GMM) for panel data. *Industrial Marketing Management*, 71, 69-78. <https://doi.org/10.1016/j.indmarman.2017.11.010>
- Ulusoy, M. K., & Pirgaip, B. (2019). The Causal Relationship between Economic Policy Uncertainty and Stock Market Returns. *Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 23(4), 2239-2251.
- Walter, M., & Luebke, M. (2013). The impact of corruption on climate change: threatening emissions trading mechanisms? *UNEP Global Environmental Alert System, March*.
- Wang, S., Yuan, Y., & Wang, H. (2019). Corruption, hidden economy and environmental pollution: A spatial econometric analysis based on China's provincial panel data. *International journal of environmental research and public health*, 16(16), 2871.
- Warsame, A. A., Sheik-Ali, I. A., Jama, O. M., Hassan, A. A., & Barre, G. M. (2022). Assessing the effects of climate change and political instability on sorghum production: Empirical evidence from Somalia. *Journal of Cleaner Production*, 360, 131893.

- Welsch, H. (2004). Corruption, growth, and the environment: a cross-country analysis. *Environment and Development Economics*, 9(5), 663-693.
- Willis, G. W. (1990). The Effects of Political Instability on Economic Growth: A Case for Sub-Saharan Africa.
- Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press. Chapter 20 pp. 703-706.
- Wu, F., & Yan, X. (2018). Institutional quality and sustainable development of industries' exports: Evidence from China. *Sustainability*, 10(11), 4173.
- Yi, J., Hou, Y., & Zhang, Z. Z. (2023). The impact of foreign direct investment (FDI) on China's manufacturing carbon emissions. *Innovation and Green Development*, 2(4), 100086. <https://doi.org/10.1016/j.igd.2023.100086>
- Yii, K.-J., & Geetha, C. (2017). The nexus between technology innovation and CO2 emissions in Malaysia: evidence from granger causality test. *Energy Procedia*, 105, 3118-3124.
- Zhang, C., & Zhou, X. (2016). Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. *Renewable and Sustainable Energy Reviews*, 58, 943-951. <https://doi.org/10.1016/j.rser.2015.12.226>
- Zhang, D., Ozturk, I., & Ullah, S. (2022). Institutional factors-environmental quality nexus in BRICS: a strategic pillar of governmental performance. *Economic Research-Ekonomska Istraživanja*, 1-13.
- Zhang, M., Zhang, H., Zhang, L., Peng, X., Zhu, J., Liu, D., & You, S. (2023). Corruption, anti-corruption, and economic development. *Humanities and Social Sciences Communications*, 10(1), 1-13. <https://doi.org/10.1057/s41599-023-01930-5>

Chapter 4: CLIMATE VARIABILITY AND POVERTY VULNERABILITY AMONG ETHIOPIAN SMALLHOLDERS: A SHORT-PANEL ANALYSIS

Abstract

This study examines the impact of climate variability on poverty vulnerability in Ethiopia, emphasizing the effects on per unit consumption and accounting for both idiosyncratic and covariate shocks. The work is particularly relevant to those interested in development challenges and poverty alleviation strategies in climate-affected regions. The study addresses the specific question of how climate variability, alongside socioeconomic factors, contributes to poverty vulnerability at both household and regional levels. Using a three-round (2011/12, 2013/14, and 2015/16) Ethiopian Socioeconomic Survey (ESS) panel dataset comprising 3,313 households, the study employs a two-level random coefficient model and a fixed-effects model to analyze these dynamics. The findings reveal that the relative contributions of climate variability to poverty vulnerability surpass those of socioeconomic factors, with this effect being more pronounced at the regional level than the household level. Additionally, poverty-driven vulnerability proves more severe than risk-induced vulnerability. This, in turn, exacerbates household-level vulnerability, as even minor changes in temperature, precipitation, and agroecological conditions significantly reduce consumption. Rural households, particularly those with larger families, higher dependency ratios, and older members, face disproportionate impacts. These results emphasize the importance of integrating climate adaptation, sustainable agricultural practices, and social protection measures to reduce the adverse effects of climate variability on Ethiopia's most vulnerable populations.

JEL: Q54; I32; D12; D81

Keywords: Climate variability; Poverty Vulnerability; Per Unit Consumption; Idiosyncratic and Covariate shocks

4.1 Introduction

Climate variability, marked by short- to medium-term fluctuations in temperature and precipitation due to El Niño and La Niña, poses major risks to agriculture, water resources, and livelihoods in developing regions. El Niño often triggers droughts in southern Africa and heavy rains in eastern Africa, while La Niña brings wetter conditions to southern Africa and droughts to the Horn of Africa ([Ainembabazi, 2018](#); [Anderson et al., 2023](#); [Pachauri et al., 2014](#); [Sazib et al., 2020](#); [Thomson et al., 2003](#)). Unlike long-term climate change, climate variability leads to extreme weather events, disproportionately affecting vulnerable populations, particularly in sub-Saharan Africa (SSA), where it exacerbates poverty vulnerability and impedes development ([Herrera et al., 2018](#); [Parry et al., 2007](#)).

Ethiopia exemplifies this vulnerability due to frequent climate shocks, including temperature fluctuations, erratic rainfall, and extreme weather such as droughts and floods. These shocks significantly impact household income and food security, especially for smallholder farmers. The 2011 drought caused widespread crop failures, a 23% increase in livestock mortality, and worsened food insecurity, pushing millions into poverty ([Markova et al., 2018](#); [Nakamura et al., 2019](#)). More recently, between 2020 and 2023, severe droughts linked to climate change led to the death of approximately 6.8 million livestock in Ethiopia, forcing many pastoralists to abandon traditional livelihoods and migrate to urban areas in search of low-wage work, highlighting the growing impact of climate variability on rural communities ([Mongabay, 2024](#)). Poverty vulnerability, the risk of households falling into or staying in poverty due to shocks, is especially severe for smallholders, who face idiosyncratic shocks (e.g., illness, crop failure, livestock loss) and covariate shocks (e.g., floods, droughts, market disruptions/economic shocks) ([Gentle & Maraseni, 2012](#); [Günther & Harttgen, 2009](#)).

Despite research on climate variability's effects on livelihoods ([Aragie, 2013](#); [Nakamura et al., 2020](#); [Shiferaw et al., 2014](#)), its role in poverty vulnerability remains underexplored. Many studies rely on cross-sectional data, which fail to capture how vulnerability evolves over time ([Günther & Harttgen, 2009](#); [C. Herrera et al., 2018](#)). This study combines Ethiopian Socioeconomic Survey (ESS) short-panel data with National Meteorological Agency of Ethiopia (NMAE) climate data to analyze climate-

induced poverty risks, capturing temporal changes and unobserved heterogeneity ([Christiaensen & Boisvert, 2000](#); [Ligon & Schechter, 2003](#)).

This study examines climate variability's impact on poverty vulnerability at household and regional levels, focusing on per-unit consumption and the interaction between idiosyncratic and covariate shocks. It further assesses whether climate-related factors have a greater effect on poverty vulnerability than socioeconomic factors. The analysis tests two hypotheses:

1. Climate variability significantly increases poverty vulnerability by reducing per-unit consumption, with idiosyncratic and covariate shocks amplifying these effects.
2. Climate-related factors (e.g., temperature fluctuations, precipitation variability, and harsh agroecology) have a stronger impact on poverty vulnerability than socioeconomic factors.

Findings confirm that climate variability exacerbates poverty vulnerability at both household and regional levels. Regions facing greater climate risks have a vulnerability rate of 19.1%, compared to 13.2% for households. Climate factors surpass socioeconomic ones in driving poverty vulnerability. Specifically, a 1°C rise in temperature, a 100mm increase in precipitation variability, and a shift from highland to lowland agroecology reduce per-unit consumption by 1.3%, 3.8%, and 2.1%, emphasizing how idiosyncratic and covariate shocks amplify poverty vulnerability, thereby highlighting the need for targeted adaptation strategies to ensure consumption stability and long-term resilience for smallholder farmers.

This chapter is organized as follows: Section 4.2 reviews the literature and highlights research gaps. Section 4.3 provides the theoretical background, followed by Section 4.4, which outlines the empirical framework. Section 4.5 describes data sources and key variables, while Section 4.6 details the methods. Section 4.7 presents the results and discusses the findings. Finally, Section 4.8 concludes with potential policy recommendations.

4.2 Literature Review

4.2.1 Climate Variability, Poverty Vulnerability, and the Role of Shocks

Climate variability triggers extreme events such as floods and droughts, which disproportionately affect smallholder farmers reliant on rain-fed agriculture and with limited resources for mitigation ([Asfaw et al., 2021](#); [Debela et al., 2015](#); [Jamshidi et](#)

[al., 2019](#)). In SSA, recurrent droughts, floods, and erratic rainfall exacerbate existing vulnerabilities, heightening the risk of crop failures, livestock losses, and food insecurity ([Niang et al., 2014](#); [Thornton et al., 2014](#)). As [Barrett et al. \(2007\)](#) note, these short-term climatic shocks often lead to transient poverty, which can result in long-term economic setbacks, trapping rural households in cycles of deprivation.

These regional challenges are evident in countries like Ethiopia, where climate variability has disrupted agricultural productivity. For instance, the 2015–2016 El Niño drought severely affected rain-fed agriculture, disrupting output, food markets, and prices, and pushing millions into poverty ([Bayissa et al., 2017](#); [Funk et al., 2015](#); [Hirvonen & Headey, 2018](#)). Furthermore, limited financial and institutional support hindered recovery, reinforcing poverty traps for vulnerable households ([Wossen et al., 2018](#)).

In light of these impacts, different types of shocks affect households in distinct ways. Idiosyncratic shocks affect individuals, while covariate shocks disrupt entire communities, entrenching poverty vulnerability ([Dercon, 2004](#); [Füssel, 2012](#); [Günther & Harttgen, 2009](#)). Studies show that in rural Ethiopia, erratic rainfall and water scarcity represent more significant threats to food security than pests or disease ([Bryan et al., 2009](#); [Deressa et al., 2009](#); [Hill & Porter, 2017](#)). Such shocks destabilize incomes and lead to ineffective coping strategies, such as selling livestock or diversifying income sources, as indicated by [Brooks \(2003\)](#), [Carter et al. \(2007\)](#), and [Devereux \(2007\)](#).

To reduce this vulnerability, the literature emphasizes the need to strengthen institutions, expand access to microcredit and insurance, and invest in climate-smart agriculture ([Lipper et al., 2014](#); [Schlenker & Lobell, 2010](#)). However, socioeconomic constraints, such as limited access to technology, markets, and financial support, hinder the adoption of effective adaptation strategies ([Abate et al., 2015](#); [Bryan et al., 2009](#)). Given Ethiopia's limited adaptive capacity, enhancing resilience at both the community and individual levels is critical for mitigating climate-induced poverty, as highlighted by [Adger \(2000\)](#) and [Deressa et al. \(2008\)](#).

4.3 Theoretical Background: Household Vulnerability to Poverty and Economic Shocks

The concept of vulnerability has evolved since the 1970s, expanding to incorporate social, economic, political, and environmental factors that shape household

and regional poverty risks ([Chambers, 1989](#); [Cutter et al., 2000](#); [O'keefe et al., 1976](#)). The World Bank's interdisciplinary frameworks further link poverty, risk, and mitigation strategies, emphasizing the need for holistic policy responses ([Blaikie et al., 2014](#); [Moser, 1998](#)).

Household vulnerability is often examined through utility-based models, where consumption depends on income and exposure to idiosyncratic and covariate shocks ([Dercon & Krishnan, 2000](#); [Morduch, 1995](#)). These shocks deplete household assets and income, increasing poverty vulnerability ([Arrow, 1965](#); [Dercon, 2002](#); [Knight, 1921](#)). The consumption-smoothing hypothesis suggests households use savings, credit, or safety nets to stabilize consumption, but such mechanisms remain limited in LDCs ([Deaton, 1992](#); [Dercon, 2002](#)).

This study extends traditional vulnerability models by explicitly incorporating climate variability as a determinant of poverty vulnerability. While prior research recognizes the role of environmental shocks ([Niang et al., 2014](#); [Thornton et al., 2014](#)), few studies quantitatively compare the relative influence of climate-related factors with socioeconomic determinants ([Adger et al., 2003](#); [Deressa et al., 2009](#)). This study fills that gap by demonstrating that climate dynamics not only contribute to poverty vulnerability but amplify its effects beyond conventional economic risk factors, reinforcing the need for a broader theoretical perspective.

Alternative approaches highlight that asset-based approach to vulnerability suggests that households rely on physical, financial, and human capital as buffers against shocks ([Carter & Barrett, 2006](#)). However, in climate-sensitive regions, these assets may be insufficient to mitigate extreme weather fluctuations. Sen's Capability Approach shifts the focus to household access to essential resources such as food, education, and healthcare, elements that are disproportionately affected by climate-induced resource constraints ([Sen, 1981](#)). Similarly, Social Risk Management ([Holzmann & Jørgensen, 2001](#)) emphasizes the role of public policy in mitigating environmental risks.

This study contributes to these theoretical perspectives by examining the differential impact of climate-related and socioeconomic factors on poverty vulnerability. Specifically, it tests the hypothesis that climate variability (temperature fluctuations, precipitation patterns, harsh agroecological conditions) has a stronger impact on household poverty vulnerability than traditional socioeconomic determinants. While previous studies acknowledge the role of environmental factors,

this study empirically quantifies their relative influence, providing a refined framework for understanding poverty vulnerability in the context of climate variability.

Existing vulnerability theories primarily emphasize short-term shocks and household-level coping mechanisms (Carter & Barrett, 2006; Dercon, 2002; Morduch, 1995). However, this study shifts the focus to climate variability as a structural driver of poverty, rather than a transient shock. By demonstrating how climate-related factors contribute to chronic poverty, rather than episodic disruptions, the study proposes an extension of vulnerability theory that integrates long-term climate exposure into risk assessments.

This extension challenges the conventional assumption that poverty vulnerability is predominantly shaped by economic instability (Dercon, 2004; Sen, 1981). Instead, I argue that climate variability systematically weakens household resilience by reducing agricultural yields, destabilizing income streams, and limiting adaptation capacity (Adger, 2006). As a result, existing models of poverty vulnerability must evolve to account for persistent environmental stressors that reshape economic opportunities and social mobility, particularly in climate-sensitive developing economies like Ethiopia.

4.4 Empirical Framework

A robust empirical framework integrates household and community survey data on demographics, income, consumption, assets, and shocks to analyze poverty vulnerability (Chaudhuri et al., 2002). Specifically, using panel data, regression models estimate households' likelihood of falling below the poverty line, incorporating socioeconomic factors and shocks (Dercon & Krishnan, 2000). Furthermore, probit and logit models assess consumption risks, identifying key determinants of vulnerability (Pritchett et al., 2000). In addition, the framework also evaluates coping strategies and social protection programs, thereby offering policy insights (Hoddinott & Quisumbing, 2010).

To capture shock dynamics, the framework differentiates between idiosyncratic and covariate shocks (Dercon, 2002). Panel data differentiates household-specific from regional effects, ensuring targeted policy responses. Interventions for idiosyncratic shocks, such as health insurance or microfinance, differ from those addressing covariate shocks, which require infrastructure and climate adaptation programs (Skoufias, 2003).

Traditional poverty measures (ex-post) fail to capture future risks (ex-ante)([Calvo & Dercon, 2013](#); [Hill & Porter, 2017](#); [Hoddinott & Quisumbing, 2010](#)). To address this, the framework adopts a forward-looking approach, transitioning from static to dynamic poverty assessment. While the Foster–Greer–Thorbecke (FGT) index ([Foster et al., 1984](#)) measures current poverty, it is inadequate for predicting vulnerability. Instead, ex-ante methods estimate future poverty risks by incorporating household and community shocks ([Bellon et al., 2020](#); [Chaudhuri et al., 2002](#); [Günther & Harttgen, 2009](#); [Habib et al., 2010](#)).

4.5 Data and Variables

This study utilizes three rounds of the Ethiopian Socioeconomic Survey (ESS) panel (2011/12, 2013/14, 2015/16), conducted by Ethiopia’s Central Statistical Agency (CSA) and the World Bank’s LSMS-ISA. Tracking 3,313 rural and small-town households, the dataset retains 93.88% of the original sample, providing household, individual, and community-level data ([CSA & LSMS, 2017](#)). However, while nationally representative, regional coverage varies due to logistical and security constraints.

To incorporate climate variability, this study integrates daily temperature and precipitation data from the National Meteorology Agency of Ethiopia (NMAE), collected from 133 principal weather stations. These records were aggregated into monthly and annual averages to align with the ESS survey’s two-year intervals. Since temperature and precipitation are key drivers of agricultural productivity and livelihoods, they were selected as primary climate indicators. Furthermore, to assess household exposure, annual climate data were averaged over two consecutive years (e.g., 2011–2012) to smooth fluctuations over time. To ensure accuracy, geographic coordinates were used to link climate data with ESS households, allowing for precise regional exposure estimates.

Moreover, household proximity to weather stations was calculated using Euclidean distance ([Blanc & Strobl, 2016](#); [Michler et al., 2022](#)), enhancing the spatial alignment of climate and economic data, particularly in rural areas with sparse station coverage.

At the household level, variables include per-unit consumption, rural residence (1 = rural, 0 = small town), and household head gender (1 = male, 0 = female). Per adult-equivalent consumption was derived from total expenditures, adjusted for age-

and gender-weighted household composition. Additionally, other variables considered are literacy, landholding size (hectares), livestock holdings in TLU, household head illness, credit access, dependency ratio, household size, market distance (log-transformed), and participation in agricultural extension and casual labor markets.

At the community level, covariates encompass climate variability (temperature, precipitation, droughts, floods), spatial price fluctuations, weekly market access, irrigation, water services, microfinance, electrified schools, health facilities, and agroecological conditions. Although these variables offer valuable insights, simplified measurements may not fully capture the complex interactions between climate, socioeconomic conditions, and infrastructure.

4.6 Method

This study applies a two-level random coefficient modeling approach to examine determinants of per-unit consumption, leveraging hierarchically structured panel data to analyze household and regional variations ([Chaudhuri, 2003](#); [Chaudhuri et al., 2002](#)). The random coefficient model captures variations across groups while addressing regional influences on household economic conditions under climate variability ([Mina & Imai, 2017](#); [Rabe-Hesketh & Skrondal, 2008](#)). Though limited to three survey rounds, the model effectively accounts for within- and between-group variability ([Gelman & Hill, 2007](#); [Hox et al., 2017](#)).

Moreover, because households are nested within regions, this approach enables the estimation of the mean and variance of per-unit consumption, driven by regional climate factors ([Günther & Harttgen, 2009](#)). Thus, the two-level model is structured as follows:

$$lnc_{ijt} = \beta_{0j} + \beta_{1j}X_{ijt}^k + \varepsilon_{ijt} \quad (1)$$

where lnc_{ijt} represents log per-unit consumption of household i in region j at time t , with β_{0j} and β_{1j} as region-level intercept and slope coefficients. X_{ijt}^k denotes household characteristics, while ε_{ijt} captures the random error term.

At the regional level, factors (Z_{jt}) influence consumption variance through:

$$\beta_{0j} = \alpha_{00} + \alpha_{10}Z_{jt} + u_{0j} \quad (2)$$

$$\beta_{1j} = \alpha_{10} + \alpha_{11}Z_{jt} + u_{1j} \quad (3)$$

where u_{0j} and u_{1j} represent unobserved consumption variance at the regional level. Substituting these into Equation (1) gives the reduced form ([Günther & Harttgen, 2009](#); [Mina & Imai, 2017](#)):

$$\ln c_{ijt} = (\alpha_{00} + \alpha_{01}Z_{jt} + (\alpha_{10} + \alpha_{11}Z_{jt})X_{ijt}^k) + (u_{0j} + u_{1j}X_{ijt}^k + \varepsilon_{ijt}) \quad (4)$$

Here, the first component captures fixed effects, including household and regional covariates and their interactions, while the second represents random components, accounting for idiosyncratic shocks (ε_{ijt}) and covariate shocks ($u_{0j} + u_{1j}X_{ijt}^k$) ([Azam & Imai, 2012](#); [Goldstein, 1987](#)).

4.6.1 Measuring Poverty Vulnerability

To quantify the impact of household- and region-level shocks on poverty vulnerability, the analysis follows three steps: (1) estimating the impact of household- and region-level predictors on log per-unit consumption (Equation 4), (2) squaring residuals to calculate expected variances for household-level shocks (Equation 5) and regional-level shocks (Equation 6), and (3) combining these variances to determine total variance:

$$\sigma^2_{\varepsilon_{ijt}} = X_{ijt}^k + \lambda_2 Z_{jt} + \lambda_3 X_{ijt} Z_{jt} \quad (5)$$

$$\sigma^2_{u_{0ij}} = \zeta_0 + \zeta_1 Z_{jt} \quad (6)$$

The total variance is expressed as:

$$\sigma^2_{\varepsilon_{ijt}} + \sigma^2_{u_{0ij}} = \hat{\sigma}_{ijt}^2 = X_{ijt}^k + \lambda_2 Z_{jt} + \lambda_3 X_{ijt} Z_{jt} \quad (7)$$

Using Equation (8), poverty vulnerability is estimated based on the mean and variance of log per-unit consumption:

$$\hat{V}_{ijt} = \hat{P}(\ln c_{ijt} < \ln \bar{c} | X_{ijt}^k) = \Phi \left(\frac{\ln z - \ln \hat{c}_{ijt}}{\sqrt{\hat{\sigma}_{ijt}^2}} \right) \quad (8)$$

where \hat{V}_{ijt} represents the probability that household i in region j at time t falls below the poverty threshold ($\ln z$), with $\Phi(\cdot)$ denoting the cumulative standard normal distribution ([Chaudhuri et al., 2002](#)).

According to [Günther and Harttgen \(2009\)](#), the vulnerability threshold is:

$$V^*_{k,ij+t} = 1 - [P(\ln c_{ijt} > \ln z)]^k \quad (9)$$

This equation estimates the probability that a household will experience poverty at least once over k years due to economic shocks. Empirical studies commonly use a threshold of 0.5 ([Chaudhuri et al., 2002](#); [Suryahadi et al., 2000](#); [Tsehay & Bauer, 2012](#)).

Based on three-year panel data, this study sets the vulnerability threshold³⁸ at 20.63%, identifying households with a 0.2063 probability of falling into poverty within three years as vulnerable.

After estimating poverty vulnerability (Equation 8), a fixed-effects model is used to analyze how household and regional variables influence vulnerability while validating the two-level random coefficient model results:

$$V_{ijt} = \beta_0 + \beta_1 X_{ijt}^k + \beta_2 Z_{jt} + \mu_i + \nu_i + \epsilon_{ijt} \quad (10)$$

where V_{ijt} represents poverty vulnerability, μ_i accounts for household fixed effects, ν_i captures time-specific shocks, and ϵ_{ijt} is the residual error. By controlling for unobserved, time-invariant heterogeneity, this model ensures robust and reliable estimates (Wooldridge, 2010).

To enhance robustness, bootstrap techniques are used to reduce sample variability, while instrumental variable (IV) techniques address endogeneity by employing lagged climate indicators (e.g., temperature, precipitation) as instruments (Raudenbush, 2002).

4.7 Result and Discussion

4.7.1 Descriptive statistics

In rural Ethiopia, household-level (idiosyncratic) and regional-level (covariate) factors drive consumption volatility and poverty vulnerability. As shown in Table 4.3, these dynamics reflect both persistent challenges and gradual improvements.

At the household level, rising adult-equivalent family size and dependency ratios increased vulnerability. However, agricultural extension participation increased, and the share of households without credit access fell from 23.2% in 2011 to 14.4% in 2015. Meanwhile, landholding size, education, illness, livestock holdings, and casual labor participation fluctuated without clear trends. Despite these shifts, consumption volatility increased, peaking in the final year, while livestock holdings showed instability, declining initially before recovering, reflecting broader agricultural uncertainty.

At the regional level, climate variability remained highly unpredictable, with temperature fluctuating by 3.35°C and precipitation by 139.32 mm over the study

³⁸ 20.6% is the threshold vulnerability level of the households based on the threshold calculation formula. $V^t = 1 - \sqrt[n]{1 - V_n}$ where: V_n is threshold vulnerability of n year = 0.5, n is number of years $i \dots N$. V^t is the calculated threshold vulnerability for year n.

period. Improvements in market access, water services, and irrigation schemes helped mitigate some climate-related shocks, yet spatial price variations remained substantial, influenced by geographic disparities and infrastructure access. Furthermore, large-scale environmental changes, such as dam construction, may have altered local hydrological conditions, further complicating predictions.

Poverty trends remained relatively stable, averaging 23.6% with minor fluctuations (23.83% initially, 23.45% mid-study, and 23.54% in the final round, as shown in Table 4.1). Additionally, extreme poverty was recorded at 4.7%, with a 7.18% poverty gap and a 30.4% per-unit consumption gap, underscoring the persistent vulnerability of rural populations.

Table 4.1: Household Level Poverty decomposition (poverty line 3781ETB = 1.24USD)

Decomposed Poverty	Year			Total
	2011/12	2013/14	2015/16	
Poverty Ratio %	23.826	23.448	23.542	23.606
Extreme Poverty ratio %	4.929	4.745	4.64	4.772
Per unit poverty gap	0.089	0.088	0.089	0.089
Poverty gap ratio %	7.188	7.135	7.21	7.178
Consumption gap ratio %	30.169	30.427	30.626	30.406

Source: Author's computation based on *LSMS* data 2021

Building on these poverty trends, rural Ethiopian households fall into three categories, as shown in Table 4.2. The chronically poor, making up 22.05 percent, remained consistently below the poverty line, reflecting persistent deprivation. The transient poor, comprising 74.65 percent, fluctuated around the threshold due to external shocks such as climate variability and economic disruptions. The non-poor, representing 3.3 percent, maintained stable consumption, indicating relative economic security.

Table 4.2: Poverty Status of Households/category

Household Poverty Category	Year			Average
	2011/12	2013/14	2015/16	
Chronically Poor	22.17	21.91	22.08	22.05
Poor	74.92	74.60	74.42	74.65
Non-poor	2.91	3.50	3.50	3.30
Total	100.00	100.00	100.00	100.00

Source: Author's computation based on *LSMS* data 2021

Table 4.3: Summary statistics of the variables: mean and standard deviation by year: 2011/12 – 2015/16

Description of Variables	Overall		2011/12-2014		2013/14-2015		2014/15-2016	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Households' Annual Per unit consumption	6.6	0.662	6.598	0.661	6.604	0.662	6.597	0.663
Being in rural=1, otherwise=0	0.89	0.31	0.89	0.31	0.89	0.31	0.89	0.31
Household head gender (1=male, 0=female)	0.766	0.423	0.766	0.423	0.767	0.423	0.765	0.424
Household landholding size (hectare)	0.149	0.291	0.168	0.332	0.173	0.306	0.1125	0.232
Household head education (1=yes, 0=no)	0.41	0.492	0.407	0.491	0.412	0.492	0.411	0.492
Log of live stockholding in TLU	0.848	1.406	0.855	1.3	0.812	1.4	0.877	1.494
Adult equivalent household size	4.078	1.931	4.021	1.929	4.052	1.909	4.162	1.953
Agricultural extension participation (1=yes, 0=no)	0.325	0.468	0.284	0.451	0.333	0.471	0.35	0.477
Lack of access to credit (1=yes, 0=no)	0.186	0.389	0.232	0.422	0.191	0.393	0.144	0.351
HH illness or become sick in the last 12 months	0.317	0.466	0.287	0.452	0.337	0.473	0.332	0.471
Household head age	46.03	15.09	43.99	14.99	46.03	15.001	48.07	15.02
Household head age squared	2346.70	1537.22	2160.66	1472.50	2343.6	1526.78	2535.86	1587.70
Dependence ratio	7.143	5.997	6.329	4.866	7.135	4.916	7.827	7.524
Log of distance to the nearest local market in km	3.896	0.891	3.905	0.876	3.896	0.893	3.889	0.905
Agroecological conditions	321.57	3.53	321.56	3.54	321.59	3.517	321.57	3.52
Participation as a casual labourer	0.154	0.361	0.117	0.322	0.235	0.424	0.11	0.313
Availability of Regional/zonal large market (1=yes, 0=no)	0.535	0.499	0.472	0.499	0.564	0.496	0.568	0.495
Availability of Water services (1=yes, 0=no)	0.274	0.446	0.255	0.436	0.283	0.451	0.284	0.451
Availability of irrigation schemes (1=yes, 0=no)	0.588	0.492	0.498	0.5	0.631	0.483	0.634	0.482
Availability of microfinance institutions (1=yes, 0=no)	0.262	0.44	0.278	0.448	0.253	0.435	0.254	0.435
Availability of electrified schools	2.498	1.056	2.641	0.969	2.429	1.09	2.424	1.089
Availability of health facilities	3.378	1.704	3.537	1.665	3.304	1.724	3.285	1.715
Average Temperature in degree Celsius	19.93	3.356	19.755	3.479	19.741	3.337	20.297	3.218
Average annual precipitation	340.18	139.32	325.39	130.94	367.44	150.27	327.54	131.81
Floods	0.021	0.142	0.021	0.144	0.022	0.147	0.019	0.137
Drought derived from temperature	0.502	0.5	0.508	0.5	0.436	0.496	0.561	0.496
Spatial price change	0.231	0.492	0.231	0.492	0.231	0.492	0.231	0.492

Source: Derived from ESS and climate data from NMAE 2021

Table 4.4 presents a two-level random coefficient model examining the impact of idiosyncratic and covariate shocks on consumption volatility and poverty vulnerability. The model consists of fixed coefficients (household-level, regional-level, and interaction terms) and random coefficients (variance and covariance estimates at regional and household levels).

To analyze the random component, two covariance structures are used: independent, which assumes zero covariance for simplicity, and unstructured, which provides flexibility by estimating variances and covariances independently. Column 4 applies the unstructured structure, offering the most comprehensive insights into how household and regional factors interact to influence consumption and poverty vulnerability. Meanwhile, the independent structure serves as a robustness check, testing independence assumptions and simplifying the model when covariances are negligible.

Table 4.4: Estimation Results of Multilevel (two-level) Random Coefficient Model

VARIABLES	<i>Dependent variable is Per Adult Equivalent Unit Consumption (log)</i>			
	M1	M2	M3	M4
Fixed Part: Household Level Variables				
Panel 1				
Rural (1=rural, 0=small town)	-0.179** (0.090)	-0.180** (0.090)	-0.202** (0.090)	-0.205** (0.090)
Household head Gender (Male = 1, Female = 0)	0.084*** (0.027)	0.084*** (0.027)	0.082*** (0.027)	0.081*** (0.027)
Landholding size in hectare	0.012** (0.005)	0.012** (0.005)	0.011* (0.006)	0.010* (0.006)
Household head Education (Literate = 1 Illiterate=0)	0.070*** (0.018)	0.073*** (0.018)	0.068*** (0.018)	0.070*** (0.018)
Livestock holding in TLU	0.030*** (0.006)	0.030*** (0.006)	0.030*** (0.006)	0.029*** (0.006)
Adult equivalent family size	-0.181*** (0.021)	-0.183*** (0.021)	-0.186*** (0.021)	-0.187*** (0.021)
Agricultural Extension Participation (Yes = 1, No = 0)	0.021 (0.015)	0.022 (0.015)	0.021 (0.016)	0.021 (0.015)
Lack of Access to credit (Yes = 1, No = 0)	-0.037** (0.017)	-0.038** (0.017)	-0.039** (0.017)	-0.039** (0.017)
Household head Illness episode	-0.008 (0.014)	-0.007 (0.014)	-0.007 (0.014)	-0.007 (0.014)
Household Head Age (in years)	-0.146*** (0.033)	-0.151*** (0.033)	-0.157*** (0.033)	-0.164*** (0.033)
Dependence Ration	-0.078*** (0.015)	-0.078*** (0.015)	-0.079*** (0.015)	-0.080*** (0.015)
Distance to the nears local market (km)	-0.031** (0.013)	-0.034** (0.013)	-0.031** (0.013)	-0.034** (0.013)
Participation in Causal Labor (Seasonal Mig.)	-0.008 (0.018)	-0.008 (0.018)	-0.030 (0.023)	-0.029 (0.023)
Regional Variables				
Panel 2				
Weekly Regional Market (Yes = 1, No = 0)	0.043*** (0.015)	0.045*** (0.015)	0.044*** (0.015)	0.045*** (0.015)
Availability of Water Services (Yes = 1, No = 0)	0.002 (0.018)	0.002 (0.018)	0.003 (0.018)	0.002 (0.018)

CLIMATE VARIABILITY AND POVERTY VULNERABILITY AMONG ETHIOPIAN SMALLHOLDERS: A SHORT-PANEL ANALYSIS

VARIABLES	<i>Dependent variable is Per Adult Equivalent Unit Consumption (log)</i>			
	M1	M2	M3	M4
Irrigation Scheme (Yes = 1, No = 0)	0.023 (0.018)	0.021 (0.018)	0.027 (0.018)	0.024 (0.018)
Micro-finance insti. availability (Yes = 1, No = 0)	-0.018 (0.019)	-0.017 (0.019)	-0.018 (0.019)	-0.018 (0.019)
Availability of Electrified School				
2. Only primary electrified	-0.129*** (0.048)	-0.134*** (0.047)	-0.129*** (0.048)	-0.134*** (0.048)
3. Only secondary electrified	-0.065*** (0.020)	-0.067*** (0.020)	-0.069*** (0.020)	-0.072*** (0.020)
4. Neither electrified	-0.017 (0.027)	-0.019 (0.027)	-0.013 (0.027)	-0.016 (0.027)
Availability of Health Post (Yes = 1, No = 0)	-0.057** (0.025)	-0.060** (0.025)	-0.054** (0.026)	-0.057** (0.025)
Temperature	-0.013*** (0.004)	-0.013*** (0.004)	-0.014*** (0.005)	-0.013*** (0.005)
Precipitation	-0.038** (0.018)	-0.042** (0.018)	-0.028 (0.030)	-0.033 (0.029)
Spatial Price	-0.146 (0.195)	-0.280 (0.184)	-0.152 (0.192)	-0.259 (0.178)
Agroecological Condition (agroecology)	-0.019** (0.009)	-0.019** (0.009)	-0.020** (0.009)	-0.021** (0.009)
Interaction Terms			Panel 3	
Time × Temperature			-0.002 (0.004)	-0.002 (0.004)
Time × Precipitation			-0.319** (0.152)	-0.310** (0.151)
Flood × Inlandsize			-0.060*** (0.021)	-0.055*** (0.021)
Smallholder × Floods			-0.029 (0.027)	-0.040 (0.029)
Livestock × Precipitation			-0.054 (0.043)	-0.047 (0.043)
Livestock × Temperature			0.182 (0.030)	0.349 (0.030)
Causal Labor × Drought			0.057 (0.035)	0.055 (0.035)
Constant	8.471*** (0.238)	8.521*** (0.237)	8.604*** (0.275)	8.668*** (0.271)
Random Part: Region Level			Panel 4	
Variance (Random Slope)	-1.876*** (0.311)	-1.855*** (0.323)	-1.818*** (0.336)	-1.737*** (0.39)
Variance (Random Interc)	-1.684*** (0.277)	-1.628*** (0.293)	-1.701*** (0.276)	-1.665*** (0.283)
Cov(Random Slope & Interc)		-0.669 (0.457)		-0.665 (0.445)
Household Level			Panel 5	
Variance (Random Slope)	-1.107*** (0.046)	-0.677*** (0.055)	-1.102*** (0.046)	-0.675*** (0.055)
Variance (Random Interc)	-1.212*** (0.042)	-1.035*** (0.046)	-1.227*** (0.043)	-1.047*** (0.047)
Cov(Random Slope & Interc)		-0.604*** (0.073)		-0.607*** (0.073)
Variance (residual)	-0.947*** (0.013)	-0.967*** (0.013)	-0.945*** (0.013)	-0.966*** (0.013)
Observations	6,082	6,082	6,056	6,056

VARIABLES	<i>Dependent variable is Per Adult Equivalent Unit Consumption (log)</i>			
	M1	M2	M3	M4
Number of groups	10	10	10	10
HH-FE	Yes	Yes	Yes	Yes
Fixed Time-Effects	Yes	Yes	Yes	Yes

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Note: The estimation for the 1st and 3rd columns utilizes an independent covariance structure, whereas the 2nd and 4th columns use an unstructured covariance approach. Furthermore, the 1st and 2nd columns were estimated without incorporating interaction terms. In contrast, the 3rd and 4th columns included interaction terms between regional and household-level factors.

Source: Derived from ESS and climate data from NMAE 2021

4.7.2 Household and Regional Determinants of Per Adult-Equivalent Consumption

Climate variability significantly reduces household consumption and exacerbates poverty vulnerability. At the household level, landholding size, literacy, and livestock ownership improve per-unit consumption, with a 1% increase in landholding raising consumption by 1.1%, literacy by 7%, and each additional TLU by 3%. Conversely, household size, dependency ratio, older household heads, limited credit access, and greater market distance reduce consumption. Each additional household member lowers per-unit consumption by 18.7%, while a 1% increase in the head's age reduces it by 0.146%.

Rural households face heightened risks, particularly those with less than two hectares, experiencing 20.5% lower consumption due to low productivity, resource scarcity, and climate shocks. Smallholders are especially vulnerable, with floods and constrained resources further undermining resilience.

At the regional level, large weekly markets enhance consumption by 4.3% by improving access to goods and market efficiency. However, climate variability, poor infrastructure, and agroecological constraints negatively impact consumption. A 1°C rise in temperature reduces per-unit consumption by 1.3%, while precipitation variability leads to flooding, crop losses, and infrastructure damage. Households in lowland (arid) regions experience 2.1% lower consumption due to harsher environmental conditions. Floods disproportionately affect larger landholders, with losses increasing by 6% per additional hectare, highlighting the vulnerability of agriculture-dependent households.

4.7.3 Random-Effects and Total Impact Analysis

Random-effects analysis (Table 4.4, Column 4) reveals substantial variability in vulnerability. At the regional level, drought increases consumption variability by 3.1%, with arid regions facing greater risks due to climate instability. In contrast, regions with

less severe droughts exhibit higher consumption, indicating greater resilience. At the household level, variability in smallholder status (2.6%) and average consumption (1.2%) emphasizes how resource-poor households suffer disproportionately from climate-induced shocks.

The total effects analysis integrates fixed, random, and interaction terms, offering a comprehensive picture of consumption and poverty vulnerability. The average predicted per adult-equivalent consumption is 646.5 Ethiopian Birr, with most households clustering between 440.1 and 950.3 Birr, reflecting constrained resources and significant inequality. Consumption disparities range from 154.7 to 8,106.6 Birr, emphasizing widespread resource scarcity.

4.7.4 Poverty Vulnerability Estimates

Table 4.5 summarizes vulnerability estimates, with overall vulnerability at 23%, regional-level at 19.1%, and household-level at 13.2%. Poverty-induced vulnerability accounts for 35.2%, reflecting persistent poverty among chronically poor households, while risk-induced vulnerability stands at 14%, resulting from transient shocks pushing households into poverty.

Table 4.5: Decomposition of Estimated Vulnerability: A Summary

Vulnerability	Year			
	Overall	2011/12	2013/14	2015/16
Overall Vulnerability	0.229	0.226	0.229	0.232
Regional Vulnerability	0.191	0.185	0.191	0.196
Household Vulnerability	0.132	0.127	0.131	0.137
Poverty Induced Vulnerability	0.352	0.349	0.352	0.355
Risk Induced Vulnerability	0.14	0.123	0.144	0.153

Source: Derived from ESS and climate data from NMAE 2021

Expanding on these regional disparities' sheds light on household and regional vulnerability over time, uncovering enduring inequalities. Amhara, Beneshangul-Gumuz, SNNPR, and Gambella exhibit higher poverty risks, often surpassing the 23% national vulnerability rate, Table 4.5, except Gambella (18.2%). Beneshangul-Gumuz records the highest vulnerability (38.7%), while Dire Dawa has the lowest (3.7%), highlighting significant regional contrasts in poverty exposure (Table 4.6).

Table 4.6 Regional mean household vulnerability by year

List of Region	Regional Household level Vulnerability by Year			Region-level mean Vulnerability
	2011/12	2013/14	2015/16	
Tigray	0.037	0.044	0.050	0.108
Afar	0.015	0.039	0.035	0.095
Amhara	0.147	0.170	0.169	0.348
Oromia	0.048	0.046	0.049	0.111
Somali	0.021	0.021	0.017	0.086
Beneshangul Gumuz	0.266	0.307	0.325	0.387
SNNPR	0.244	0.249	0.281	0.354
Gambelie	0.070	0.074	0.085	0.182
Harari	0.013	0.011	0.011	0.043
Dire Dawa	0.008	0.009	0.010	0.037

Source: Derived from ESS and climate data from NMAE 2021

Figure 4.1 compares poverty-induced and risk-induced vulnerability. The left graph shows poverty-induced vulnerability, where socioeconomic barriers such as inadequate education, healthcare, credit, and agricultural support drive persistent poverty vulnerability. Climate variability intensifies these challenges, resulting in moderate to high vulnerability. The histogram peaks at higher vulnerability levels, with the red curve sharply spiking, highlighting the intensified impact of deprivation and climate shocks.

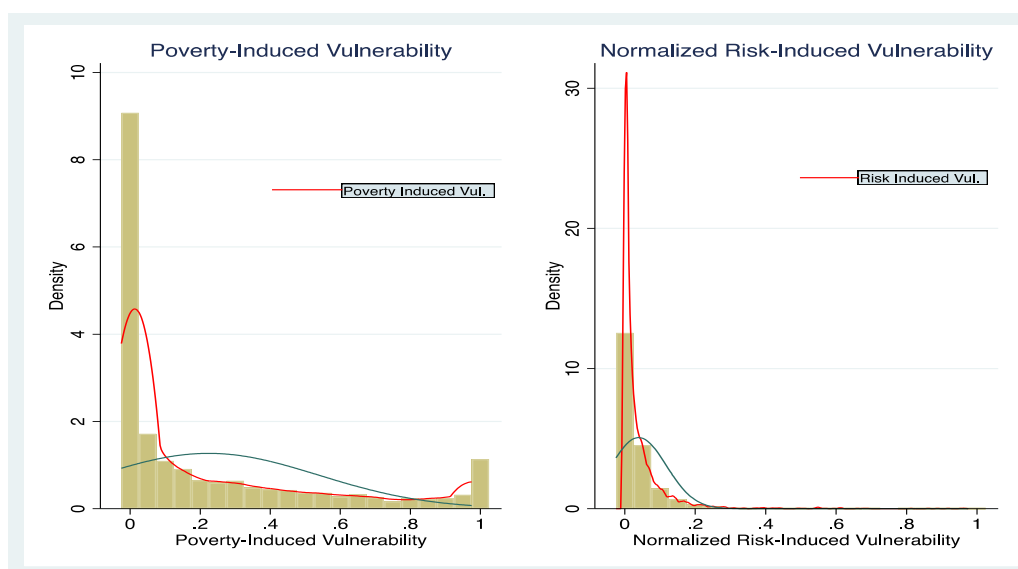


Figure 4.1: Poverty and Risk-induced Vulnerability

The right graph illustrates risk-induced vulnerability, averaging 0.14, significantly lower than poverty-induced vulnerability (0.352). The left-skewed histogram shows most households face low to moderate risk, though sharp spikes indicate disproportionate impacts from climate extremes and market disruptions. Unlike poverty-induced vulnerability, this measure reflects short-term shocks rather than chronic deprivation.

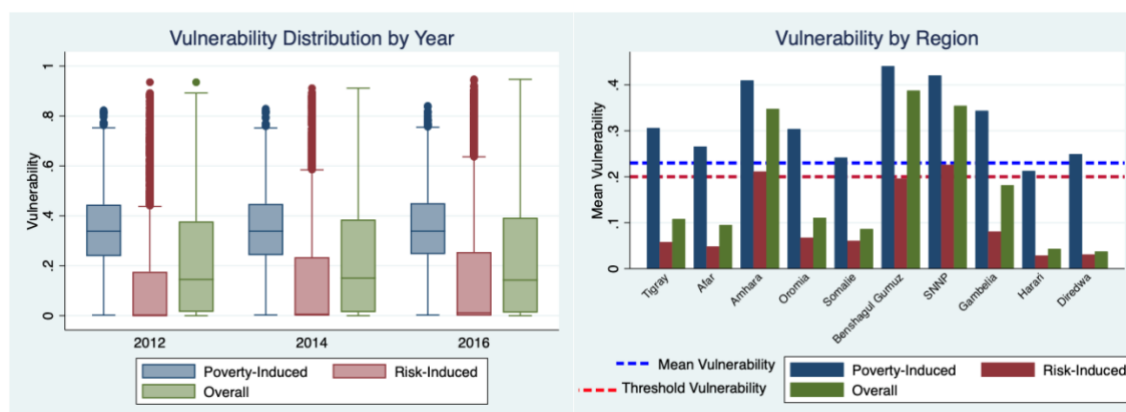


Figure 4.2: Vulnerability distribution by year (on the left) and by region (on the right)

In Figure 4.2 the box plot (left) shows that poverty-induced vulnerability consistently has the highest median, reflecting its long-term impact on consumption, while risk-induced vulnerability trends upward over time, increasing consumption volatility. The bar graph (right) highlights regional disparities, with Amhara, Beneshangul-Gumuz, and SNNPR exhibiting the highest vulnerability, surpassing the 20.63% threshold and the 23% national average. In contrast, Dire Dawa and Harari show lower vulnerability, illustrating geographic variations in poverty vulnerability.

To assess climate variability’s impact on poverty vulnerability, Table 4.7 presents fixed-effects model results across four specifications. This model integrates climatic factors (temperature, precipitation) and non-climatic control variables to determine their influence on vulnerability. By comparing these results with the two-level random-coefficient model Table 4.4, the fixed-effects approach validates the robustness of earlier findings, offering additional insights.

Table 4.7: Estimation Results on Climate Variability's Impact on Poverty Vulnerability

Independent Variables	Dependent variable is Estimated Vulnerability to Poverty			
	M1	M2	M3	M4
Average Temperature	0.092*** (0.027)	0.093*** (0.027)	0.096*** (0.027)	0.114*** (0.024)
Average Precipitation		-0.004 (0.004)	-0.008** (0.004)	-0.000 (0.004)
Temperature x Precipitation			0.000 (0.000)	0.000 (0.000)
Livestock Holding in TLU				-0.015*** (0.001)
Land size in hectare				-0.007*** (0.001)
Adult equivalent Household Size				0.078*** (0.005)
Agroecology				0.053** (0.022)
Extension Participation				-0.013*** (0.003)
Lack of access to credit				0.025*** (0.003)
Dependency Ratio				0.026*** (0.003)
Constant	-0.048 (0.078)	-0.022 (0.074)	-0.010 (0.073)	-0.366*** (0.080)
Observations	6,082	6,082	6,082	6,082
R-squared	0.012	0.012	0.013	0.182
Number of Households	2,590	2,590	2,590	2,590
HH-FE	Yes	Yes	Yes	Yes
Fixed Time-Effects	Yes	Yes	Yes	Yes

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Source: Derived from ESS and climate data from NMAE 2021

Findings confirm temperature as the primary driver of climate-induced poverty vulnerability, with each 1°C increase raising vulnerability by 0.114 units. This suggests a significant impact on household consumption stability, as higher temperatures exacerbate deviations from expected consumption levels. Precipitation variability, except in Model 3, shows no significant relationship with vulnerability, reinforcing that temperature fluctuations have the strongest impact on household welfare.

4.7.5 Robustness Check

Bootstrap and Instrumental Variable (IV) techniques, as presented in Table 4.8 confirm the reliability of findings. Bootstrap results show temperature, precipitation variability, and regional price changes remain statistically significant, underscoring the impact of climate variability on poverty vulnerability. IV diagnostics validate instrument strength and exogeneity, addressing endogeneity concerns. These methods

reaffirm that climate shocks, particularly temperature fluctuations, are major determinants of poverty vulnerability in Ethiopia.

Table 4.8: 2SLS-IV in a Two-Level Model Estimation

VARIABLES	2SLS-IV Log-Consumption	FE-IV Log-Consumption
Temperature	-0.035** (0.017)	-0.0782*** (0.00738)
Lag. Temperature	0.012 (0.008)	
Precipitation	-0.239*** (0.091)	-0.619*** (0.0346)
Lag. Precipitation	0.062 (0.090)	
Household age	-0.213*** (0.024)	
Adult equivalent Household size	-0.245*** (0.013)	
Constant	8.452*** (0.324)	12.62*** (0.361)
Observations	6,368	
Number of groups	10	
HH-FE	Yes	
Time Fixed-Effect	Yes	

Source: Author's computation based on *LSMS* data 2021

4.7.6 Discussion

In Ethiopia, persistent poverty vulnerability stems from both household-level (idiosyncratic) and regional (covariate) shocks, with climate variability playing a key role, as shown in the estimation. This aligns with [C. Herrera et al. \(2018\)](#), who highlight the impact of climate variability on poverty vulnerability. While landholding size, education, and livestock ownership enhance consumption ([Bezu et al., 2012](#)), factors such as rural residence, large households, limited credit, and market distance exacerbate vulnerability in Ethiopia.

The two-level random coefficient model shows that higher consumption reduces poverty vulnerability, aligning with [Christiaensen and Subbarao \(2005\)](#), who found it helps households absorb economic shocks. Conversely, the fixed-effects model confirms that lower consumption increases vulnerability, reinforcing [Jalan and Ravallion \(2000\)](#) argument that persistent low consumption creates a poverty trap.

At the regional level, temperature and precipitation variability, combined with harsh agroecological conditions, significantly suppress household consumption.

Among these factors, temperature fluctuations have a more pronounced impact than precipitation variability, aligning with previous studies ([Deressa et al., 2009](#); [Hertel & Rosch, 2010](#)). Moreover, statistical tests confirm that climate shocks exert a stronger negative influence on consumption than socioeconomic factors. Furthermore, variance analysis reveals that household-level factors account for 44.9% of consumption variability, whereas regional shocks contribute 12.7%, thereby exacerbating poverty risks across communities.

Consequently, poverty-induced vulnerability outweighs risk-induced factors, with 23% of households facing a 20.6% probability of falling below the poverty line within three years. Households' dependent on climate-sensitive activities are particularly exposed, as regional shocks (e.g., temperature, agroecological stress, and price fluctuations) further reduce agricultural output, livestock productivity, and purchasing power.

4.8 Conclusion and Policy Implications

4.8.1 Conclusion

This study provides empirical evidence that climate variability is a structural driver of poverty vulnerability, exerting a greater influence than socioeconomic factors in agriculture-dependent regions. Temperature and precipitation fluctuations worsen consumption volatility, with two-level random coefficient and fixed-effects models confirming that climate-induced shocks significantly impact household welfare.

These findings challenge traditional poverty frameworks centered on economic instability, demonstrating that climate variability is not merely an external shock but a fundamental determinant of long-term economic opportunities and social mobility.

4.8.1 Policy Implications

This study highlights the need for a climate-responsive approach to poverty vulnerability mitigation, as climate variability exerts a greater influence on poverty vulnerability than socioeconomic factors. Conventional frameworks focused on economic instability must be reconsidered.

To address this, development strategies must integrate climate-smart infrastructure, early warning systems, and adaptive safety nets ([Alderman & Haque, 2007](#); [Dercon, 2004](#); [Grosh et al., 2008](#)). Aligned with Social Risk Management ([Holzmann & Jørgensen, 2001](#)), this approach emphasizes institutional interventions to mitigate climate-induced poverty vulnerability. This perspective expands the

theoretical discussion, advocating a shift from reactive economic measures to proactive, climate-adaptive policies.

A targeted approach should strengthen education, vocational training, and financial access, while rural infrastructure and market linkages reduce geographic disadvantages. Given the increasing impact of climate shocks, climate-smart agriculture, adaptive cash transfers, and disaster preparedness should be prioritized, with policies tailored to arid and marginalized regions to ensure equitable resource distribution.

Reference:

- Abate, G. T., de Brauw, A., Minot, N., & Bernard, T. (2015). *The Impact of the Use of New Technologies on Farmer's Wheat Yield in Ethiopia*.
- Adger, W. N. (2000). Social and ecological resilience: are they related? *Progress in human geography*, 24(3), 347-364. <https://doi.org/10.1191/030913200701540465>
- Adger, W. N. (2006). Vulnerability. *Global environmental change*, 16(3), 268-281. <https://doi.org/10.1016/j.gloenvcha.2006.02.006>
- Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. (2003). Adaptation to climate change in the developing world. *Progress in development studies*, 3(3), 179-195. <https://doi.org/10.1191/1464993403ps06>
- Ainembabazi, J. (2018). The 2015-16 El Niño-induced drought crisis in Southern Africa: What do we learn from historical data? 2018 Conference, July 28-August 2, 2018, Vancouver, British Columbia,
- Alderman, H., & Haque, T. (2007). *Insurance against covariate shocks: The role of index-based insurance in social protection in low-income countries of Africa*. World Bank Publications. <https://doi.org/10.1596/978-08213-7036-0>
- Anderson, W., Cook, B. I., Slinski, K., Schwarzwald, K., McNally, A., & Funk, C. (2023). Multiyear La Niña events and multiseason drought in the Horn of Africa. *Journal of Hydrometeorology*, 24(1), 119-131. <https://doi.org/10.1175/JHM-D-22-0043.1>
- Aragie, E. A. (2013). *Climate change, growth, and poverty in Ethiopia*.
- Arrow, K. J. (1965). Aspects of the Theory of Risk-Bearing. *Yrjö Jahnsson Foundation, Helsinki*.
- Asfaw, A., Bantider, A., Simane, B., & Hassen, A. (2021). Smallholder farmers' livelihood vulnerability to climate change-induced hazards: agroecology-based comparative analysis in Northcentral Ethiopia (Woleka Sub-basin). *Heliyon*, 7(4), e06761. <https://doi.org/10.1016/j.heliyon.2021.e06761>
- Azam, M. S., & Imai, K. S. (2012). Measuring households' vulnerability to idiosyncratic and covariate shocks—The case of Bangladesh. *Research Institute for Economics and Business Administration, Kobe University, Japan. (Discussion Paper Series)*. <https://www.rieb.kobe-u.ac.jp/academic/ra/dp/English/DP2012-02.pdf>
- Barrett, C. B., Barnett, B. J., Carter, M. R., Chantarat, S., Hansen, J. W., Mude, A. G., Osgood, D., Skees, J. R., Turvey, C. G., & Ward, M. N. (2007). Poverty traps and climate risk: limitations and opportunities of index-based risk financing. *IRI Technical Report No. 07-02, Available at SSRN: https://ssrn.com/abstract=1141933* or. <https://doi.org/10.2139/ssrn.1141933>
- Bayissa, Y., Tadesse, T., Demisse, G., & Shiferaw, A. (2017). Evaluation of satellite-based rainfall estimates and application to monitor meteorological drought for the Upper Blue

- Nile Basin, Ethiopia. *Remote Sensing*, 9(7), 669. <https://doi.org/10.3390/rs9070669>
- Bellon, M. M., Pizzinelli, C., & Perrelli, M. R. (2020). *Household consumption volatility and poverty risk: case studies from South Africa and Tanzania*. International Monetary Fund.
- Bezu, S., Barrett, C. B., & Holden, S. T. (2012). Does the nonfarm economy offer pathways for upward mobility? Evidence from a panel data study in Ethiopia. *World development*, 40(8), 1634-1646. <https://doi.org/10.1016/j.worlddev.2012.04.019>
- Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (2014). *At risk: natural hazards, people's vulnerability and disasters*. Routledge.
- Blanc, E., & Strobl, E. (2016). Assessing the impact of typhoons on rice production in the Philippines. *Journal of Applied Meteorology and Climatology*, 55(4), 993-1007. <https://doi.org/10.1175/JAMC-D-15-0214.1>
- Brooks, N. (2003). Vulnerability, risk and adaptation: A conceptual framework.
- Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science & Policy*, 12(4), 413-426. <https://doi.org/10.1016/j.envsci.2008.11.002>
- Carter, R. M., Little, D. P., Mogues, Tewodaj, Negatu, & Workneh. (2007). Poverty traps and natural disasters in Ethiopia and Honduras. *World development*, 35(5), 835-856.
- Carter, M. R., & Barrett, C. B. (2006). The economics of poverty traps and persistent poverty: An asset-based approach. *The journal of development studies*, 42(2), 178-199. <https://doi.org/10.1080/00220380500405261>
- Chambers, R. (1989). Editorial introduction: vulnerability, coping and policy. *IDS bulletin*, 20(2), 1-7. <https://doi.org/10.1111/j.1759-5436.1989.mp20002001.x>
- Chaudhuri, S. (2003). Assessing vulnerability to poverty: concepts, empirical methods and illustrative examples. *Department of Economics, Columbia University, New York*, 56.
- Chaudhuri, S., Jalan, J., & Suryahadi, A. (2002). Assessing household vulnerability to poverty from cross-sectional data: A methodology and estimates from Indonesia.
- Christiaensen, L. J., & Boisvert, R. N. (2000). On measuring household food vulnerability: Case evidence from Northern Mali. <https://hdl.handle.net/1813/57699>
- Christiaensen, L. J., & Subbarao, K. (2005). Towards an understanding of household vulnerability in rural Kenya. *Journal of African economies*, 14(4), 520-558.
- CSA & LSMS, C. S. A. L. S. M. S. L., World Bank. (2017). Ethiopia Socioeconomic Survey (ESS) Wave Three (2015/2016), Addis Ababa, Ethiopia.
- Cutter, S. L., Mitchell, J. T., & Scott, M. S. (2000). Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina. *Annals of the association of American Geographers*, 90(4), 713-737. <https://doi.org/10.1111/0004-5608.00219>
- Deaton, A. (1992). *Understanding consumption*. Oxford University Press.
- Debela, N., Mohammed, C., Bridle, K., Corkrey, R., & McNeil, D. (2015). Perception of climate change and its impact by smallholders in pastoral/agropastoral systems of Borana, South Ethiopia. *SpringerPlus*, 4, 236. <https://doi.org/10.1186/s40064-015-1012-9>
- Dercon, S. (2002). Income risk, coping strategies, and safety nets. *The World Bank Research Observer*, 17(2), 141-166.
- Dercon, S. (2004). Growth and shocks: evidence from rural Ethiopia. In *Macroeconomic Policies and Poverty* (1st ed., pp. 308-329). Routledge.

- Dercon, S., & Krishnan, P. (2000). Vulnerability, seasonality and poverty in Ethiopia. *The journal of development studies*, 36(6), 25-53. <https://doi.org/10.1080/00220380008422653>
- Deressa, Hassan, R., & Ringler, C. (2009). Assessing household vulnerability to climate change: The case of farmers in the Nile basin of Ethiopia. *IFPRI-Discussion Papers*(935).
- Deressa, T., Hassan, R. M., & Ringler, C. (2008). *Measuring Ethiopian farmers' vulnerability to climate change across regional states*. Intl Food Policy Res Inst.
- Devereux, S. (2007). The impact of droughts and floods on food security and policy options to alleviate negative effects. *Agricultural Economics*, 37, 47-58.
- Foster, J., Greer, J., & Thorbecke, E. (1984). A class of decomposable poverty measures. *Econometrica: journal of the Econometric Society*, 761-766.
- Funk, C., Shukla, S., Hoell, A., & Livneh, B. (2015). 16. Assessing The Contributions Of East African And West Pacific Warming To The 2014 Boreal Spring East African Drought. *Bulletin of the American Meteorological Society*, 96(12), S77-S82. JSTOR, <http://www.jstor.org/stable/26233145>. Accessed 10 Aug. 2024.
- Füssel, H.-M. (2012). Vulnerability to climate change and poverty. *Climate Change, Justice and Sustainability: Linking climate and development policy*, 9-17. Springer. https://doi.org/10.1007/978-94-007-4540-7_2
- Gelman, A., & Hill, J. (2007). *Data analysis using regression and multilevel/hierarchical models*. Cambridge university press.
- Gentle, P., & Maraseni, T. N. (2012). Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal. *Environmental science policy*, 21, 24-34.
- Grosh, M., Del Ninno, C., Tesliuc, E., & Ouerghi, A. (2008). *For protection and promotion: The design and implementation of effective safety nets*. World Bank Publications. <https://doi.org/10.1596/978-0-8213/7581-5>
- Günther, I., & Harttgen, K. (2009). Estimating households vulnerability to idiosyncratic and covariate shocks: A novel method applied in Madagascar. *World development*, 37(7), 1222-1234. <https://doi.org/10.1016/j.worlddev.2008.11.006>
- Habib, B., Narayan, A., Olivieri, S., & Sanchez-Paramo, C. (2010). Assessing ex ante the poverty and distributional impact of the global crisis in a developing country: A micro-simulation approach with application to Bangladesh. *World Bank Policy Research Working Paper*(5238). <https://ssrn.com/abstract=1574735>
- Herrera, Carlos, Ruben, Ruerd, Dijkstra, & Geske. (2018). Climate variability and vulnerability to poverty in Nicaragua. *Journal of Environmental Economics Policy*, 7(3), 324-344.
- Herrera, C., Ruben, R., & Dijkstra, G. (2018). Climate variability and vulnerability to poverty in Nicaragua. *Journal of Environmental Economics and Policy*, 7(3), 324-344. <https://doi.org/10.1080/21606544.2018.1433070>
- Hertel, T. W., & Rosch, S. D. (2010). Climate change, agriculture, and poverty. *Applied economic perspectives and policy*, 32(3), 355-385. <https://doi.org/10.1093/aep/ppq016>
- Hill, R. V., & Porter, C. (2017). Vulnerability to drought and food price shocks: evidence from Ethiopia. *World development*, 96, 65-77. <https://doi.org/10.1016/j.worlddev.2017.02.025>
- Hirvonen, K., & Headey, D. (2018). Can governments promote homestead gardening at scale? Evidence from Ethiopia. *Global food security*, 19, 40-47. <https://doi.org/10.1016/j.gfs.2018.09.001>

- Hoddinott, J., & Quisumbing, A. (2010). Methods for microeconometric risk and vulnerability assessment. In *Risk, shocks, and human development: On the brink* (pp. 62-100). Springer. https://doi.org/10.1057/9780230274129_4
- Holzmann, R., & Jørgensen, S. (2001). Social risk management: A new conceptual framework for social protection, and beyond. *International Tax and Public Finance*, 8, 529-556. <https://doi.org/10.1023/A:1011247814590>
- Hox, J., Moerbeek, M., & Van de Schoot, R. (2017). *Multilevel analysis: Techniques and applications*. Routledge.
- Jalan, J., & Ravallion, M. (2000). Is transient poverty different? Evidence for rural China. *The journal of development studies*, 36(6), 82-99. <https://doi.org/10.1080/00220380008422655>
- Jamshidi, O., Asadi, A., Kalantari, K., Azadi, H., & Scheffran, J. (2019). Vulnerability to climate change of smallholder farmers in the Hamadan province, Iran. *Climate Risk Management*, 23, 146-159.
- Knight, F. H. (1921). Risk, uncertainty and profit. *Hart, Schaffner and Marx*.
- Ligon, E., & Schechter, L. (2003). Measuring vulnerability. *The Economic Journal*, 113(486), C95-C102.
- Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., & Henry, K. (2014). Climate-smart agriculture for food security. *Nature Climate Change*, 4(12), 1068-1072. <https://doi.org/10.1038/NCLIMATE2437>
- Markova, G., Baas, S., Conforti, P., & Ahmed, S. (2018). 2017: the impact of disasters and crises on agriculture and food security. *FAO, Rome (Italy)*, Chapter III. pp, 45-50.
- Michler, J. D., Josephson, A., Kilic, T., & Murray, S. (2022). Privacy protection, measurement error, and the integration of remote sensing and socioeconomic survey data. *Journal of Development Economics*, 158, 102927. <https://doi.org/10.1016/j.jdeveco.2022.102927>
- Mina, C. D., & Imai, K. S. (2017). Estimation of vulnerability to poverty using a multilevel longitudinal model: Evidence from the Philippines. *The journal of development studies*, 53(12), 2118-2144.
- Morduch, J. (1995). Income smoothing and consumption smoothing. *Journal of economic perspectives*, 9(3), 103-114.
- Moser, C. O. (1998). The asset vulnerability framework: reassessing urban poverty reduction strategies. *World development*, 26(1), 1-19.
- Nakamura, Shohei, Bundervoet, Tom, Nuru, & Mohammed. (2019). *Rural roads, poverty, and resilience: evidence from Ethiopia*. The World Bank.
- Nakamura, S., Bundervoet, T., & Nuru, M. (2020). Rural roads, poverty, and resilience: Evidence from Ethiopia. *The journal of development studies*, 56(10), 1838-1855. <https://doi.org/10.1080/00220388.2020.1736282>
- Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, A., Lennard, C., Padgham, J., & Urquhart, P. (2014). Climate Change 2014: Impacts, Adaptation and Vulnerability: Part B: Regional Aspects: Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 1199-1266.
- O'keefe, P., Westgate, K., & Wisner, B. (1976). Taking the naturalness out of natural disasters. *Nature*, 260(5552), 566-567. <https://doi.org/10.1038/260566a0>
- Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., & Dasgupta, P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151)*. *Ipcc*.
- Parry, M., Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P., & Hanson, C. (2007). *Climate change 2007-impacts, adaptation and vulnerability: Working group II*

- contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge University Press.
- Pritchett, L., Suryahadi, A., & Sumarto, S. (2000). *Quantifying vulnerability to poverty: A proposed measure, applied to Indonesia*. World Bank Publications.
- Rabe-Hesketh, S., & Skrondal, A. (2008). *Multilevel and longitudinal modeling using Stata*. STATA press.
- Raudenbush, S. W. (2002). Hierarchical linear models: Applications and data analysis methods. *Advanced Quantitative Techniques in the Social Sciences Series/SAGE*.
- Sazib, N., Mladenova, L. E., & Bolten, J. D. (2020). Assessing the impact of ENSO on agriculture over Africa using earth observation data. *Frontiers in Sustainable Food Systems*, 4, 509914. <https://doi.org/10.3389/fsufs.2020.509914>
- Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, 5(1), 014010. <https://doi.org/10.1088/1748-9326/5/1/014010>
- Sen, A. (1981). *Poverty and famines: an essay on entitlement and deprivation*. Oxford university press.
- Shiferaw, Bekele, Tessema, Tesfaye, Kindie, Kassie, Menale, Abate, Tsedeke, Prasanna, BM, Menkir, & Abebe. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes*, 3, 67-79.
- Skoufias, E. (2003). Economic crises and natural disasters: Coping strategies and policy implications. *World development*, 31(7), 1087-1102. [https://doi.org/10.1016/S0305-750X\(03\)00069-X](https://doi.org/10.1016/S0305-750X(03)00069-X)
- Suryahadi, A., Sumarto, S., & Pritchett, L. (2000). Quantifying vulnerability to poverty: a proposed measure, applied to Indonesia. *Applied to Indonesia (September 2000)*.
- Thomson, M., Abayomi, K., Barnston, A. G., Levy, M., & Dilley, M. (2003). El Niño and drought in southern Africa. *The Lancet*, 361(9355), 437-438. [https://doi.org/10.1016/s0140-6736\(03\)12421-x](https://doi.org/10.1016/s0140-6736(03)12421-x)
- Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2014). Climate variability and vulnerability to climate change: a review. *Global change biology*, 20(11), 3313-3328. <https://doi.org/10.1111/gcb.12581>
- Tsehay, A. S., & Bauer, S. (2012). Poverty and vulnerability dynamics: Empirical evidence from smallholders in northern highlands of Ethiopia. *Quarterly Journal of International Agriculture*, 51(892-2016-65173), 301-332.
- Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press. Chapter 20 pp. 703-706.
- Wossen, T., Berger, T., Haile, M. G., & Troost, C. (2018). Impacts of climate variability and food price volatility on household income and food security of farm households in East and West Africa. *Agricultural systems*, 163, 7-15. <https://doi.org/10.1016/j.agsy.2017.02.006>

Chapter 5: General Discussion, Conclusion, and Policy Implication

5.1 General Discussion

The findings align with the growing body of research indicating that climate change significantly impacts economic growth in SSA, both at the aggregate level and within specific sectors ([Dell et al., 2012](#); [Fosu, 2015](#); [Kurukulasuriya & Mendelsohn, 2007](#)). Higher temperatures and irregular precipitation patterns negatively affect GDP per capita, with the agricultural sector, being highly sensitive to climate, disproportionately impacted. This aligns with the findings of [Schlenker and Roberts \(2009\)](#), which show that temperatures exceeding a critical threshold significantly reduce agricultural productivity. These disruptions extend to other sectors, such as industry, manufacturing, and services, through spillover effects, as declines in agricultural productivity reduce inputs available to these sectors.

Increased temperature and precipitation variability reduce agricultural productivity, which in turn undermines aggregate economic growth. This is consistent with findings by [Lobell et al. \(2008\)](#), who highlight that changes in climate significantly reduce crop yields, especially in regions heavily dependent on agriculture, such as Sub-Saharan Africa. Notably, sub-Saharan African countries with high-risk agricultural economies face severe consequences, as climate change disrupts land productivity, increases health costs, and raises living expenses. [Connolly-Boutin and Smit \(2016\)](#) emphasize that climate-induced disruptions in livestock and crop production further strain economic stability in these regions. This creates a cycle where agricultural losses exacerbate poverty vulnerability, especially for rural households dependent on climate-sensitive sectors. As [Kurukulasuriya and Mendelsohn \(2007\)](#) suggest, rural households are particularly vulnerable to these changes, as they rely heavily on agriculture for income and sustenance. Climate-induced shocks such as floods and droughts also lead to significant negative deviations in growth, hindering long-term economic resilience in the region, as indicated by [Emediegwu et al. \(2022\)](#), who discuss how such events can lead to persistent economic setbacks.

Another significant finding of this study is the role of institutional quality, particularly political stability, in shaping economic growth and the effectiveness of climate adaptation strategies. The persistence of corruption and political instability across SSA exacerbates the region's vulnerability to climate change, while also hindering efforts to reduce CO₂ emissions and improve environmental governance. This

is consistent with [Acemoglu et al. \(2001\)](#), who argue that poor governance and political instability often hinder economic development and climate change adaptation efforts. Although economic growth can improve governance quality over time, this improvement is slow, and structural challenges such as corruption and political volatility continue to undermine sustainable development. [Alesina et al. \(1996\)](#) further highlight how political instability negatively impacts governance capacity, making it more difficult to implement effective policies. Political instability is a key driver of corruption, which weakens governance and makes it more difficult to implement long-term anti-corruption measures or to adopt policies needed to address the adverse effects of climate change. This further highlights the critical importance of fostering political stability and strengthening governance frameworks to ensure that climate policies are not only designed but also effectively implemented, as suggested by [Kaufmann et al. \(2011\)](#), who emphasize that political stability and governance are key to successful climate policy implementation.

This dissertation further examines the impact of climate variability on poverty vulnerability, with a particular focus on Ethiopia. The analysis reveals that climate variability, especially changes in temperature and precipitation, has a more significant effect on poverty vulnerability than socio-economic factors. This is consistent with [Deressa et al. \(2011\)](#), who found that climate change plays a more substantial role in shaping vulnerability than socio-economic factors such as income and education, especially in regions highly dependent on agriculture. In particular, while socio-economic factors such as gender, education, landholding size, and access to credit influence poverty vulnerability, they are less effective in mitigating the broader regional challenges posed by climate change. [Hertel and Rosch \(2010\)](#) similarly emphasize that while socio-economic factors can offer some protection, they are insufficient when compared to the large-scale disruptions caused by climate variability.

Consequently, rural households, especially those with larger families and higher dependency ratios, are disproportionately affected by climate-induced shocks. [Kurukulasuriya and Mendelsohn \(2007\)](#) argue that rural households, particularly in Sub-Saharan Africa, are more vulnerable to climate-induced shocks because their livelihoods depend heavily on agriculture. Although land ownership and livestock holdings can provide some protection against climate shocks, vulnerability remains high due to exposure to regional stresses, such as droughts, and limited access to public services or infrastructure. [Dercon \(2004\)](#) highlights how rural households in these

regions often lack the resources to adequately cope with climate variability, which exacerbates their vulnerability. Furthermore, households in areas with harsh agroecological conditions and poor market access face compounded risks, as climate variability disrupts agricultural output, reduces livestock productivity, and increases living costs. This aligns with [Rosenzweig and Hillel \(1998\)](#), who show that areas with poor soil quality and erratic weather patterns experience the most severe impacts on agriculture, further entrenching poverty.

Thus, at the micro-level, climate variability directly affects agricultural productivity, which in turn impacts household consumption and welfare. While socio-economic factors are still relevant, they play a secondary role compared to the immediate effects of climate change on rural livelihoods. This is supported by [Deressa et al. \(2009\)](#), who find that climate variability, particularly changes in temperature and precipitation, directly impacts agricultural productivity in rural areas, overwhelming the protective capacity of socio-economic factors.

5.2 General Conclusion

Climate change significantly affects economic growth in SSA, particularly in climate-sensitive sectors like agriculture, which also supports industry and manufacturing. Rising temperatures and precipitation variability disrupt agricultural productivity, making it the most vulnerable sector. While non-agricultural sectors also experience negative effects, they are less severe. Moreover, precipitation variability exacerbates economic instability, affecting both sector-specific and aggregate growth, with high-risk countries being particularly susceptible to temperature shocks.

Beyond climate-related challenges, corruption and political instability further constrain economic growth, with weak institutions amplifying these effects. SSA economies remain highly vulnerable to external shocks, including CO₂ emissions associated with industrial expansion, which drive both environmental and economic instability. Although economic growth contributes to governance improvements by reducing corruption and political instability over time, environmental degradation weakens long-term institutional stability, limiting the effectiveness of institutions in mitigating climate-related disruptions.

Similarly, climate variability plays a dominant role in shaping poverty vulnerability in Ethiopia, particularly among rural, agriculture-dependent households. Both household (idiosyncratic) and regional (covariate) shocks reduce consumption,

with climate-related factors, such as temperature fluctuations, precipitation variability, and harsh agroecological conditions, having a more significant impact than socioeconomic factors. Structural challenges, combined with limited access to credit and markets, intensify poverty risks by restricting household resilience and increasing consumption volatility.

Furthermore, rising temperatures and erratic precipitation patterns disrupt agricultural productivity, increase living costs, and strain economic activities, further exacerbating rural poverty. Empirical findings confirm that temperature fluctuations have a more pronounced effect on poverty vulnerability than precipitation changes, with adverse agroecological conditions compounding these risks. Ultimately, climate variability remains the primary driver of household consumption instability and poverty risk, outweighing the influence of socioeconomic conditions.

5.3 General Policy Implication

To effectively address climate-induced economic instability in SSA, a strategic focus is needed to enhance the resilience of agriculture, the most affected sector. In particular, policies should prioritize climate adaptation strategies, such as investing in climate-resilient crops, efficient water management, and sustainable land-use practices. Moreover, strengthening infrastructure, particularly irrigation and storage facilities, can mitigate the adverse effects of temperature fluctuations and precipitation variability, thereby reducing economic volatility across all sectors.

At the same time, institutional reforms play a crucial role in mitigating the interconnected impacts of corruption, political instability, and climate change on economic growth. To achieve this, strengthening governance structures, ensuring transparency, and enhancing regulatory frameworks are essential for stabilizing economic performance while reducing emissions-related vulnerabilities. Furthermore, integrating environmental policies with economic planning will enable SSA countries to transition toward a more sustainable growth trajectory, thus minimizing long-term institutional fragility and climate-related risks.

More broadly, reducing poverty vulnerability in SSA, as exemplified by rural Ethiopia, requires policies that expand financial inclusion, improve access to credit, and strengthen market linkages for smallholder farmers, thereby enhancing household welfare through improved consumption. Building on this, targeted investments in social protection programs and climate-smart agricultural techniques can further strengthen

household resilience to both idiosyncratic and covariate shocks. Moreover, bridging spatial disparities in infrastructure and essential services is crucial for overcoming structural barriers, ultimately reducing long-term poverty vulnerabilities linked to climate variability across the region.

Reference:

- Abate, G. T., de Brauw, A., Minot, N., & Bernard, T. (2015). *The Impact of the Use of New Technologies on Farmer's Wheat Yield in Ethiopia*.
- Abdel-Latif, H., Elgohari, H., & Mohamed, A. (2018). Corruption, political instability, and growth: Evidence from the Arab Spring. *Available at SSRN 3240211*.
- Abeyasinghe, R. (2004). Democracy, political stability, and developing country growth: Theory and evidence.
- Abidoye, B. O., & Odusola, A. F. (2015). Climate change and economic growth in Africa: an econometric analysis. *Journal of African economies*, 24(2), 277-301. <https://doi.org/10.1093/jae/eju033>
- Abram, N. J., McGregor, H. V., Tierney, J. E., Evans, M. N., McKay, N. P., Kaufman, D. S., & Consortium, P. k. (2016). Early onset of industrial-era warming across the oceans and continents. *Nature*, 536(7617), 411-418. <https://doi.org/10.1038/nature19082>
- Abreha, K. G., Kassa, W., Lartey, E. K., Mengistae, T. A., Owusu, S., & Zeufack, A. G. (2021). *Industrialization in Sub-Saharan Africa: seizing opportunities in global value chains*. World Bank Publications.
- Acemoglu, D. (2005). Institutions as the Fundamental Cause of Long-Run Growth. *Handbook of Economics Growth*.
- Acemoglu, D., Johnson, S., & Robinson, J. A. (2001). The Colonial Origins of Comparative Development: An Empirical Investigation. *American Economic Review*, 91(5), 1369-1401. <https://doi.org/10.1257/aer.91.5.1369>
- Acemoglu, D., Johnson, S., & Robinson, J. A. (2004). Institutions as the Fundamental Cause of Long-Run Growth. *Available at SSRN 571052*.
- Acemoglu, D., Naidu, S., Restrepo, P., & Robinson, J. A. (2019). Democracy does cause growth. *Journal of political economy*, 127(1), 47-100. <https://doi.org/10.1086/700936>
- Acemoglu, D., & Robinson, J. A. (2013). *Why nations fail: The origins of power, prosperity, and poverty*. Crown Currency.
- ADB, A. D. B. (2021). From debt resolution to growth: The road ahead for Africa. *Africa Development Bank Group Publications*.
- Adger, W. N. (2000). Social and ecological resilience: are they related? *Progress in human geography*, 24(3), 347-364. <https://doi.org/10.1191/030913200701540465>
- Adger, W. N. (2006). Vulnerability. *Global environmental change*, 16(3), 268-281. <https://doi.org/10.1016/j.gloenvcha.2006.02.006>
- Adger, W. N., Huq, S., Brown, K., Conway, D., & Hulme, M. (2003). Adaptation to climate change in the developing world. *Progress in development studies*, 3(3), 179-195. <https://doi.org/10.1191/1464993403ps06>
- Ahmad, E., Ullah, M. A., & Arfeen, M. I. (2012). Does corruption affect economic growth? *Latin american journal of economics*, 49(2), 277-305.
- Aidt, T., Dutta, J., & Sena, V. (2008). Governance regimes, corruption and growth: Theory and evidence. *Journal of comparative economics*, 36(2), 195-220. <https://doi.org/10.1016/j.jce.2007.11.004>

- Ainembabazi, J. (2018). The 2015-16 El Niño-induced drought crisis in Southern Africa: What do we learn from historical data? 2018 Conference, July 28-August 2, 2018, Vancouver, British Columbia,
- Aisen, A., & Veiga, F. J. (2013). How does political instability affect economic growth? *European Journal of Political Economy*, 29, 151-167. <https://doi.org/10.1016/j.ejpoleco.2012.11.001>
- Alagidede, P., & Adu, G. (2014). Climate change and economic growth in sub-Saharan Africa: nonparametric evidence. *Economic Research Southern Africa (ERSA), South Africa.*, 1(1), 1-20. https://econrsa.org/wp-content/uploads/2022/06/working_paper_460.pdf
- Alagidede, P., Adu, G., & Frimpong, P. B. (2015). The effect of climate change on economic growth: evidence from Sub-Saharan Africa. *Environmental Economics and Policy Studies*, 18(3), 417-436. <https://doi.org/10.1007/s10018-015-0116-3>
- Alderman, H., & Haque, T. (2007). *Insurance against covariate shocks: The role of index-based insurance in social protection in low-income countries of Africa*. World Bank Publications. <https://doi.org/10.1596/978-08213-7036-0>
- Alesina, A., Özler, S., Roubini, N., & Swagel, P. (1996). Political instability and economic growth. *Journal of Economic Growth*, 1(2), 189-211.
- Ali, H. S., Zeqiraj, V., Lin, W. L., Law, S. H., Yusop, Z., Bare, U. A. A., & Chin, L. (2019). Does quality institutions promote environmental quality? *Environmental Science and Pollution Research*, 26(11), 10446-10456.
- Ali, S., Ying, L., Nazir, A., Ishaq, M., Shah, T., Ilyas, A., Khan, A. A., Din, I. U., & Tariq, A. (2019). The effect of climate change on economic growth: evidence from Pakistan. *Pacific International Journal*, 2(2), 21-30. <https://doi.org/10.55014/pij.v2i2.70>
- Althor, G., Watson, J. E., & Fuller, R. A. (2016). Global mismatch between greenhouse gas emissions and the burden of climate change. *Scientific reports*, 6(1), 20281. <https://doi.org/10.1038/srep20281>
- Alvarado, R., & Toledo, E. (2017). Environmental degradation and economic growth: evidence for a developing country. *Environment, Development and Sustainability*, 19(4), 1205-1218. <https://doi.org/10.1007/s10668-016-9790-y>
- Anderson, W., Cook, B. I., Slinski, K., Schwarzwald, K., McNally, A., & Funk, C. (2023). Multiyear La Niña events and multiseason drought in the Horn of Africa. *Journal of Hydrometeorology*, 24(1), 119-131. <https://doi.org/10.1175/JHM-D-22-0043.1>
- Antonakis, J., Bendahan, S., Jacquart, P., & Lalive, R. (2010). On making causal claims: A review and recommendations. *The leadership quarterly*, 21(6), 1086-1120. <https://doi.org/10.1016/j.leaqua.2010.10.010>
- Aragie, E. A. (2013). *Climate change, growth, and poverty in Ethiopia*.
- Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies*, 58(2), 277-297. <https://doi.org/10.2307/2297968>
- Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of econometrics*, 68(1), 29-51.
- Arminen, H., & Menegaki, A. N. (2019). Corruption, climate and the energy-environment-growth nexus. *Energy Economics*, 80, 621-634.
- Arrhenius, S. (1896). XXXI. On the influence of carbonic acid in the air upon the temperature of the ground. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 41(251), 237-276. <https://doi.org/10.1080/14786449608620846>
- Arrow, K. J. (1965). Aspects of the Theory of Risk-Bearing. *Yrjö Jahnsson Foundation, Helsinki*.

- Asfaw, A., Bantider, A., Simane, B., & Hassen, A. (2021). Smallholder farmers' livelihood vulnerability to climate change-induced hazards: agroecology-based comparative analysis in Northcentral Ethiopia (Woleka Sub-basin). *Heliyon*, 7(4), e06761. <https://doi.org/10.1016/j.heliyon.2021.e06761>
- Aye, G. C., & Edoja, P. E. (2017). Effect of economic growth on CO2 emission in developing countries: Evidence from a dynamic panel threshold model. *Cogent Economics & Finance*, 5(1), 1379239.
- Azam, M., Khan, A. Q., Bin Abdullah, H., & Qureshi, M. E. (2016). The impact of CO2 emissions on economic growth: evidence from selected higher CO2 emissions economies. *Environ Sci Pollut Res Int*, 23(7), 6376-6389. <https://doi.org/10.1007/s11356-015-5817-4>
- Azam, M. S., & Imai, K. S. (2012). Measuring households' vulnerability to idiosyncratic and covariate shocks—The case of Bangladesh. *Research Institute for Economics and Business Administration, Kobe University, Japan.(Discussion Paper Series)*. <https://www.rieb.kobe-u.ac.jp/academic/ra/dp/English/DP2012-02.pdf>
- Baltagi, B. H. (2008). *Econometric analysis of panel data* (Vol. 4). Springer.
- Bardhan, P. (2017). Corruption and development: a review of issues. *Political corruption*, 321-338.
- Barrett, C. B., Barnett, B. J., Carter, M. R., Chantarat, S., Hansen, J. W., Mude, A. G., Osgood, D., Skees, J. R., Turvey, C. G., & Ward, M. N. (2007). Poverty traps and climate risk: limitations and opportunities of index-based risk financing. *IRI Technical Report No. 07-02, Available at SSRN: https://ssrn.com/abstract=1141933* or <https://doi.org/10.2139/ssrn.1141933>
- Barrios, Salvador, Bertinelli, Luisito, Strobl, & Eric. (2010). Trends in rainfall and economic growth in Africa: A neglected cause of the African growth tragedy. *The Review of Economics Statistics*, 92(2), 350-366.
- Barro, R., & Sala-i-Martin, X. (2004). *Economic growth* second edition. In: The MIT Press, Cambridge, Massachusetts; London, England. Chapter 12, pp. 535-542.
- Barro, R. J. (1991). Economic growth in a cross section of countries. *The quarterly journal of economics*, 106(2), 407-443.
- Barro, R. J. (1996). Determinants of economic growth: A cross-country empirical study. In: National Bureau of Economic Research Cambridge, Mass., USA.
- Barro, R. J. (2003). Determinants of economic growth in a panel of countries. *Annals of economics and finance*, 4, 231-274.
- Barro, R. J., & McCleary, R. (2003). *Religion and economic growth*. *American sociological review*, 68(5), 760-781.
- Bayissa, Y., Tadesse, T., Demisse, G., & Shiferaw, A. (2017). Evaluation of satellite-based rainfall estimates and application to monitor meteorological drought for the Upper Blue Nile Basin, Ethiopia. *Remote Sensing*, 9(7), 669. <https://doi.org/10.3390/rs9070669>
- Bello-Schünemann, J., & Moyer, J. D. (2018). Structural pressures and political instability: Trajectories for sub-Saharan Africa.
- Bellon, M. M., Pizzinelli, C., & Perrelli, M. R. (2020). *Household consumption volatility and poverty risk: case studies from South Africa and Tanzania*. International Monetary Fund.
- Benson, C., & Clay, E. (1994). The Impact of Drought on Sub-Saharan African Economies. *IDS bulletin*, 25(4), 24-32. <https://doi.org/10.1111/j.1759-5436.1994.mp25004004.x>

- Berrang-Ford, L., Ford, J. D., & Paterson, J. (2011). Are we adapting to climate change? *Global environmental change*, 21(1), 25-33. <https://doi.org/10.1016/j.gloenvcha.2010.09.012>
- Bezu, S., Barrett, C. B., & Holden, S. T. (2012). Does the nonfarm economy offer pathways for upward mobility? Evidence from a panel data study in Ethiopia. *World development*, 40(8), 1634-1646. <https://doi.org/10.1016/j.worlddev.2012.04.019>
- Bicaba, Z., Brixiová, Z., & Ncube, M. (2017). Can extreme poverty in Sub-Saharan Africa be eliminated by 2030? *Journal of African Development*, 19(2), 93-110. <https://doi.org/10.5325/jafrideve.19.2.0093>
- Black, R., Adger, W. N., Arnell, N. W., Dercon, S., Geddes, A., & Thomas, D. (2011). The effect of environmental change on human migration. *Global environmental change*, 21, S3-S11. <https://doi.org/10.1016/j.gloenvcha.2011.10.001>
- Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (2014). *At risk: natural hazards, people's vulnerability and disasters*. Routledge.
- Blanc, E., & Strobl, E. (2016). Assessing the impact of typhoons on rice production in the Philippines. *Journal of Applied Meteorology and Climatology*, 55(4), 993-1007. <https://doi.org/10.1175/JAMC-D-15-0214.1>
- Bloom, D. E., Canning, D., & Sevilla, J. (2004). The effect of health on economic growth: a production function approach. *World development*, 32(1), 1-13. <https://doi.org/10.1016/j.worlddev.2003.07.002>
- Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of econometrics*, 87(1), 115-143. [https://doi.org/10.1016/S0304-4076\(98\)00009-8](https://doi.org/10.1016/S0304-4076(98)00009-8)
- Bollen, K. A. (2014). *Structural equations with latent variables*. John Wiley & Sons.
- Bond, S., Leblebicioğlu, A., & Schiantarelli, F. (2010). Capital accumulation and growth: a new look at the empirical evidence. *Journal of applied econometrics*, 25(7), 1073-1099. <https://doi.org/10.1002/jae.1163>
- Bosello, F., & Parrado, R. (2022). Climate Change Impacts and Market-Driven Adaptation: The Costs of Inaction Including Market Rigidities. In *Climate and Development* (pp. 137-175). World Scientific Publishing. https://doi.org/10.1142/9789811240553_0006
- Bowen, A., Cochrane, S., & Fankhauser, S. (2012). Climate change, adaptation and economic growth. *Climatic change*, 113(2), 95-106.
- Brock, W. A., & Taylor, M. S. (2005). Economic growth and the environment: a review of theory and empirics. *Handbook of economic growth*, 1, 1749-1821. [https://doi.org/10.1016/S1574-0684\(05\)01028-2](https://doi.org/10.1016/S1574-0684(05)01028-2)
- Brooks, N. (2003). Vulnerability, risk and adaptation: A conceptual framework.
- Bruce, J., Lee, H., & Haites, E. (1996). Climatic change 1995: economic and social dimensions of climate change. Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change, 13-14. United Kingdom.
- Bruinshoofd, A. (2016). Institutional quality and economic performance. *Rabobank Research Economic Report*, Utrecht.
- Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science & Policy*, 12(4), 413-426. <https://doi.org/10.1016/j.envsci.2008.11.002>
- Bughin, J., Chironga, M., & Desvaux, G. (2016). *Lions on the move II: Realizing the potential of Africa's economies*.
- Buhaug, H., & Urdal, H. (2013). An urbanization bomb? Population growth and social disorder in cities. *Global environmental change*, 23(1), 1-10.

- Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, 527(7577), 235-239.
- Calvo, C., & Dercon, S. (2013). Vulnerability to individual and aggregate poverty. *Social Choice and Welfare*, 41(4), 721-740. <https://doi.org/10.1007/s00355-012-0706-y>
- Carter, R. M., Little, D. P., Mogues, Tewodaj, Negatu, & Workneh. (2007). Poverty traps and natural disasters in Ethiopia and Honduras. *World development*, 35(5), 835-856.
- Carter, M. R., & Barrett, C. B. (2006). The economics of poverty traps and persistent poverty: An asset-based approach. *The journal of development studies*, 42(2), 178-199. <https://doi.org/10.1080/00220380500405261>
- Chambers, R. (1989). Editorial introduction: vulnerability, coping and policy. *IDS bulletin*, 20(2), 1-7. <https://doi.org/10.1111/j.1759-5436.1989.mp20002001.x>
- Chamma, D. D. (2024). Climate change and economic growth in sub-Saharan Africa: an empirical analysis of aggregate-and sector-level growth. *Journal of Social and Economic Development*, 1-33. <https://doi.org/10.1007/s40847-024-00377-x>
- Chaudhuri, S. (2003). Assessing vulnerability to poverty: concepts, empirical methods and illustrative examples. *Department of Economics, Columbia University, New York*, 56.
- Chaudhuri, S., Jalan, J., & Suryahadi, A. (2002). Assessing household vulnerability to poverty from cross-sectional data: A methodology and estimates from Indonesia.
- Chersich, M. F., & Wright, C. Y. (2019). Climate change adaptation in South Africa: a case study on the role of the health sector. *Global Health*, 15(1), 22. <https://doi.org/10.1186/s12992-019-0466-x>
- Christiaensen, L. J., & Boisvert, R. N. (2000). On measuring household food vulnerability: Case evidence from Northern Mali. <https://hdl.handle.net/1813/57699>
- Christiaensen, L. J., & Subbarao, K. (2005). Towards an understanding of household vulnerability in rural Kenya. *Journal of African economies*, 14(4), 520-558.
- Cobb, C. W., & Douglas, P. H. (1928). A Theory of Production. *The American Economic Review*, 18(1), 139-165.
- Conceição, P. (2020). Human development report 2020: The next frontier – Human development and the Anthropocene. United Nations Development Programme, New York, NY. <https://hdr.undp.org/en/2020-report>.
- Conforti, P., Ahmed, S., & Markova, G. (2018). Impact of disasters and crises on agriculture and food security, 2017 (pp. 136-143). Rome, Italy: FAO. <http://www.fao.org/3/i8656en/i8656EN.pdf>
- Connolly-Boutin, L., & Smit, B. (2016). Climate change, food security, and livelihoods in sub-Saharan Africa. *Regional Environmental Change*, 16, 385-399. <https://doi.org/10.1007/s10113-015-0761-x>
- CSA & LSMS, C. S. A. L. S. M. S. L., World Bank. (2017). Ethiopia Socioeconomic Survey (ESS) Wave Three (2015/2016), Addis Ababa, Ethiopia.
- Cutter, S. L., Mitchell, J. T., & Scott, M. S. (2000). Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina. *Annals of the association of American Geographers*, 90(4), 713-737. <https://doi.org/10.1111/0004-5608.00219>
- d'Agostino, G., Dunne, J. P., & Pieroni, L. (2016). Corruption and growth in Africa. *European Journal of Political Economy*, 43, 71-88. <https://doi.org/10.1016/j.ejpoleco.2016.03.002>
- David, E., Vera, K., & Laura, S. (2017). Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2016 and 1997 to 2016. In Germany:: Germanwatch. Retrieved from <https://policycommons.net/artifacts/1555064/risk-index-2018/2244873/> on 10 Jan 2024. CID: 20.500.12592/vmwj4p.

- De Hoyos, R. E., & Sarafidis, V. (2006). Testing for cross-sectional dependence in panel-data models. *The stata journal*, 6(4), 482-496. <https://doi.org/10.1177/1536867X06006004>
- Deaton, A. (1992). *Understanding consumption*. Oxford University Press.
- Debela, N., Mohammed, C., Bridle, K., Corkrey, R., & McNeil, D. (2015). Perception of climate change and its impact by smallholders in pastoral/agropastoral systems of Borana, South Ethiopia. *SpringerPlus*, 4, 236. <https://doi.org/10.1186/s40064-015-1012-9>
- Del Monte, A., & Pennacchio, L. (2020). Corruption, government expenditure and public debt in OECD countries. *Comparative economic studies*, 62(4), 739-771.
- Dell, Melissa, Jones, F. B., Olken, & A. B. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3), 66-95. <https://doi.org/10.1257/mac.4.3.66>
- Dell, Melissa, Jones, F. B., Olken, & A. B. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature*, 52(3), 740-798. <https://doi.org/10.1257/jel.52.3.740>
- Dercon, S. (2002). Income risk, coping strategies, and safety nets. *The World Bank Research Observer*, 17(2), 141-166.
- Dercon, S. (2004). Growth and shocks: evidence from rural Ethiopia. In *Macroeconomic Policies and Poverty* (1st ed., pp. 308-329). Routledge.
- Dercon, S., & Krishnan, P. (2000). Vulnerability, seasonality and poverty in Ethiopia. *The journal of development studies*, 36(6), 25-53. <https://doi.org/10.1080/00220380008422653>
- Deressa, Hassan, R., & Ringler, C. (2009). Assessing household vulnerability to climate change: The case of farmers in the Nile basin of Ethiopia. *IFPRI-Discussion Papers*(935).
- Deressa, T., Hassan, R. M., & Ringler, C. (2008). *Measuring Ethiopian farmers' vulnerability to climate change across regional states*. Intl Food Policy Res Inst.
- Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *The Journal of Agricultural Science*, 149(1), 23-31. <https://doi.org/10.1017/S0021859610000687>
- Devereux, S. (2007). The impact of droughts and floods on food security and policy options to alleviate negative effects. *Agricultural Economics*, 37, 47-58.
- Devlina, Rao, R. R., & Sahu, S. K. (2022). Corruption and carbon emission: an empirical investigation. *International Journal of Green Economics*, 16(4), 355-388.
- Diao, X., Hazell, P. B., Resnick, D., & Thurlow, J. (2007). *The role of agriculture in development: Implications for Sub-Saharan Africa* (Vol. 153). Intl Food Policy Res Inst.
- Dietz, S., & Stern, N. (2015). Endogenous growth, convexity of damage and climate risk: how Nordhaus' framework supports deep cuts in carbon emissions. *The Economic Journal*, 125(583), 574-620. <https://doi.org/10.1111/eoj.12188>
- Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics*, 80(4), 549-560. <https://doi.org/10.1162/003465398557825>
- Durlauf, S. (1999). The New Empirics of Economic Growth. *Handbook of Macroeconomics/North-Holland*.
- Eboli, F., Parrado, R., & Roson, R. (2010). Climate-change feedback on economic growth: explorations with a dynamic general equilibrium model. *Environment and Development Economics*, 15(5), 515-533. <https://doi.org/10.1017/S1355770X10000252>

- Eckstein, D., Künzel, V., & Schäfer, L. (2017). Global climate risk index 2018. Who Suffers Most From Extreme Weather Events? Weather-related Loss Events in 2016 and 1997 to 2016, Germanwatch. Bonn, Germany. Retrieved from <https://policycommons.net/artifacts/1555064/risk-index-2018/2244873/> on 08 Aug 2021. CID: 20.500.12592/vmwj4p.
- Eckstein, D., Künzel, V., & Schäfer, L. (2021). The global climate risk index 2021. In: Bonn, Germany: Germanwatch. Retrived from <https://bvearmb.do/handle/123456789/1306> on 10 Jan 2022.
- Edoun, E., & Mbohwa, C. (2016). Correlation between political instability and the rise of poverty in Africa. 3rd International Multidisciplinary Scientific Conference on Social Sciences and Arts SGEM 2016,
- Egbetokun, S., Osabuohien, E., Akinbobola, T., Onanuga, O. T., Gershon, O., & Okafor, V. (2019). Environmental pollution, economic growth and institutional quality: exploring the nexus in Nigeria. *Management of Environmental Quality: An International Journal*, 31(1), 18-31.
- Emediegwu, L. E., Wossink, A., & Hall, A. (2022). The impacts of climate change on agriculture in sub-Saharan Africa: a spatial panel data approach. *World development*, 158, 105967. <https://doi.org/10.1016/j.worlddev.2022.105967>
- Estrada, F., Tol, R. S., & Botzen, W. W. (2019). Extending integrated assessment models' damage functions to include adaptation and dynamic sensitivity. *Environmental Modelling & Software*, 121, 104504. <https://doi.org/10.1016/j.envsoft.2019.104504>
- Fankhauser, S., & Tol, R. S. (2005). On climate change and economic growth. *Resource and Energy Economics*, 27(1), 1-17. <https://doi.org/10.1016/j.reseneeco.2004.03.003>
- FAO. (2016). Agriculture in Sub-Saharan Africa: Prospects and challenges for the next decade. In: Author Rome.
- FAO, F. a. A. O. (2021). Strengthening resilience to safeguard agricultural livelihoods. Retrieved from *SimplyEducate. Me*: <http://simplyeducate.me/2015/01/05/conceptual-framework-guide>.
- Farrag, N. A., & Ezzat, A. M. (2016). The Impact of Corruption on Economic Growth: A Comparative Analysis between Europe and MENA Countries. In *Handbook of Research on Comparative Economic Development Perspectives on Europe and the MENA Region* (pp. 74-97). IGI Global.
- Feenstra, R. C., Inklaar, R., & Timmer, M. P. (2015). The next generation of the Penn World Table. *American Economic Review*, 105(10), 3150-3182. <https://doi.org/10.1257/aer.20130954>
- Ferrini, L. (2012). The importance of institutions to economic development. *E-International Relations*, 30(8), 142.
- Foster, J., Greer, J., & Thorbecke, E. (1984). A class of decomposable poverty measures. *Econometrica: journal of the Econometric Society*, 761-766.
- Fosu, A. K. (1992). Political instability and economic growth: evidence from Sub-Saharan Africa. *Economic Development and cultural change*, 40(4), 829-841.
- Fosu, A. K. (2002). Political instability and economic growth: Implications of coup events in Sub-Saharan Africa. *American Journal of Economics and Sociology*, 61(1), 329-348. <https://doi.org/10.1111/1536-7150.00162>
- Fosu, A. K. (2015). Growth, inequality and poverty in Sub-Saharan Africa: recent progress in a global context. *Oxford Development Studies*, 43(1), 44-59. <https://doi.org/10.1080/13600818.2014.964195>

- Fourier, J. (1827). General remarks on the temperatures of the Earth's globe and planetary spaces. *Memoirs of the Royal Academy of Sciences of the Institute of France*, 7, 569-604.
- Fredriksson, P. G., & Neumayer, E. (2016). Corruption and climate change policies: do the bad old days matter? *Environmental and Resource Economics*, 63, 451-469. <https://doi.org/10.1007/s10640-014-9869-6>
- Fredriksson, P. G., & Svensson, J. (2003). Political instability, corruption and policy formation: the case of environmental policy. *Journal of public economics*, 87(7-8), 1383-1405. [https://doi.org/10.1016/S0047-2727\(02\)00036-1](https://doi.org/10.1016/S0047-2727(02)00036-1)
- Freeman, L. (2017). Environmental change, migration, and conflict in Africa: a critical examination of the interconnections. *The Journal of Environment & Development*, 26(4), 351-374.
- Funk, C., Shukla, S., Hoell, A., & Livneh, B. (2015). 16. Assessing The Contributions Of East African And West Pacific Warming To The 2014 Boreal Spring East African Drought. *Bulletin of the American Meteorological Society*, 96(12), S77-S82. JSTOR, <http://www.jstor.org/stable/26233145>. Accessed 10 Aug. 2024.
- Füssel, H.-M. (2012). Vulnerability to climate change and poverty. *Climate Change, Justice and Sustainability: Linking climate and development policy*, 9-17. Springer. https://doi.org/10.1007/978-94-007-4540-7_2
- Gakpa, L. L. (2020). *Political instability, FDI and economic growth in Sub-Saharan African Countries: evidence from modelling dynamic simultaneous equations*. AERC.
- Galinato, G. I., & Galinato, S. P. (2012). The effects of corruption control, political stability and economic growth on deforestation-induced carbon dioxide emissions. *Environment and Development Economics*, 17(1), 67-90. <https://doi.org/10.1017/S1355770X11000222>
- Gani, A. (2012). The relationship between good governance and carbon dioxide emissions: evidence from developing economies. *Journal of Economic Development*, 37(1), 77. <https://doi.org/10.35866/caujed.2012.37.1.004>
- Gazdar, K., & Cherif, M. (2015). Institutions and the finance–growth nexus: Empirical evidence from MENA countries. *Borsa Istanbul Review*, 15(3), 137-160.
- Gelman, A., & Hill, J. (2007). *Data analysis using regression and multilevel/hierarchical models*. Cambridge university press.
- Gentle, P., & Maraseni, T. N. (2012). Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal. *Environmental science policy*, 21, 24-34.
- Gillingham, K., Newell, R. G., & Pizer, W. A. (2008). Modeling endogenous technological change for climate policy analysis. *Energy Economics*, 30(6), 2734-2753. <https://doi.org/10.1016/j.eneco.2008.03.001>
- Goldstein, H. (1987). *Multilevel models in education and social research*. Oxford University Press.
- Greene, W. H. (2012). *Econometric Analysis. 7th Edition, Prentice Hall, Upper Saddle River*. (Chap-14), 351-361.
- Greenough, G., McGeehin, M., Bernard, S. M., Trtanj, J., Riad, J., & Engelberg, D. (2001). The potential impacts of climate variability and change on health impacts of extreme weather events in the United States. *Environ Health Perspect*, 109 Suppl 2(Suppl 2), 191-198. <https://doi.org/10.1289/ehp.109-1240666>
- Greenstone, M., & Deschenes, O. (2006). The economic impacts of climate change: Evidence from agricultural profits and random fluctuations in weather. *American Economic Review*, 97(1), 354-385. <https://doi.org/10.2139/ssrn.876929>

- Grosh, M., Del Ninno, C., Tesliuc, E., & Ouerghi, A. (2008). *For protection and promotion: The design and implementation of effective safety nets*. World Bank Publications. <https://doi.org/10.1596/978-0-8213/7581-5>
- Günther, I., & Harttgen, K. (2009). Estimating households vulnerability to idiosyncratic and covariate shocks: A novel method applied in Madagascar. *World development*, 37(7), 1222-1234. <https://doi.org/10.1016/j.worlddev.2008.11.006>
- Gyimah-Brempong, K. (2002). Corruption, economic growth, and income inequality in Africa. *Economics of governance*, 3(3), 183-209.
- Gylfason, T. (2001). Natural resources, education, and economic development. *European economic review*, 45(4-6), 847-859. [https://doi.org/10.1016/S0014-2921\(01\)00127-1](https://doi.org/10.1016/S0014-2921(01)00127-1)
- Habib, B., Narayan, A., Olivieri, S., & Sanchez-Paramo, C. (2010). Assessing ex ante the poverty and distributional impact of the global crisis in a developing country: A micro-simulation approach with application to Bangladesh. *World Bank Policy Research Working Paper*(5238). <https://ssrn.com/abstract=1574735>
- Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., & Vogt-Schilb, A. (2016). Shock Waves: Managing the Impacts of Climate Change on Poverty In (pp. 31-68). Washington, DC: The World Bank.
- Hallegatte, S., & Rozenberg, J. (2017). Climate change through a poverty lens. *Nature Climate Change*, 7(4), 250-256. <https://doi.org/10.1038/nclimate3253>
- Hanck, C., Arnold, M., Gerber, A., & Schmelzer, M. (2021). *Introduction to Econometrics with R*. Universität Duisburg-Essen; 225-243.
- Hansen, L. P. (1982). Large sample properties of generalized method of moments estimators. *Econometrica: journal of the Econometric Society*, 1029-1054.
- Harris, I., Jones, P. D., Osborn, T. J., & Lister, D. H. (2014). Updated high-resolution grids of monthly climatic observations—the CRU TS3. 10 Dataset. *International journal of climatology*, 34(3), 623-642. <https://doi.org/10.1002/joc.3711>
- Harris, J. M., Roach, B., & Anne-Marie, C. (2007). The economics of global climate change: Global Development And Environment Institute Tufts University Medford, MA 02155 <http://ase.tufts.edu/gdae>.
- Haydaroglu, C. (2016). Corruption, Institutions and Economic Growth in Sub-Saharan Africa. *International Journal of Economics and Research*, 7, 14-26.
- Herrera, Carlos, Ruben, Rued, Dijkstra, & Geske. (2018). Climate variability and vulnerability to poverty in Nicaragua. *Journal of Environmental Economics Policy*, 7(3), 324-344.
- Herrera, C., Ruben, R., & Dijkstra, G. (2018). Climate variability and vulnerability to poverty in Nicaragua. *Journal of Environmental Economics and Policy*, 7(3), 324-344. <https://doi.org/10.1080/21606544.2018.1433070>
- Hertel, T. W., & Rosch, S. D. (2010). Climate change, agriculture, and poverty. *Applied economic perspectives and policy*, 32(3), 355-385. <https://doi.org/10.1093/aep/32.3.355>
- Hill, R. C., Griffiths, W. E., & Lim, G. C. (2018). *Principles of econometrics*. pp. 531-549. John Wiley & Sons.
- Hill, R. V., & Porter, C. (2017). Vulnerability to drought and food price shocks: evidence from Ethiopia. *World development*, 96, 65-77. <https://doi.org/10.1016/j.worlddev.2017.02.025>
- Hirvonen, K., & Headey, D. (2018). Can governments promote homestead gardening at scale? Evidence from Ethiopia. *Global food security*, 19, 40-47. <https://doi.org/10.1016/j.gfs.2018.09.001>

- Hoddinott, J., & Quisumbing, A. (2010). Methods for microeconomic risk and vulnerability assessment. In *Risk, shocks, and human development: On the brink* (pp. 62-100). Springer. https://doi.org/10.1057/9780230274129_4
- Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. *The stata journal*, 7(3), 281-312. <https://doi.org/10.1177/1536867X0700070>
- Holzmann, R., & Jørgensen, S. (2001). Social risk management: A new conceptual framework for social protection, and beyond. *International Tax and Public Finance*, 8, 529-556. <https://doi.org/10.1023/A:1011247814590>
- Hope Sr, K. R. (2009). Climate change and poverty in Africa. *International Journal of Sustainable Development & World Ecology*, 16(6), 451-461. <https://doi.org/10.1080/13504500903354424>
- Hox, J., Moerbeek, M., & Van de Schoot, R. (2017). *Multilevel analysis: Techniques and applications*. Routledge.
- Hsiang, S. M., Burke, M., & Miguel, E. (2015). Climate and conflict. *Annual Review of Economics*, 7(1), 577-617.
- Hsiao, C. (2022). *Analysis of panel data*. Cambridge university press. pp. 291-310.
- Huddleston, P., Smith, T., White, I., & Elrick-Barr, C. (2022). Adapting critical infrastructure to climate change: A scoping review. *Environmental Science & Policy*, 135, 67-76. <https://doi.org/10.1016/j.envsci.2022.04.015>
- Hussein, K., & Suttie, D. (2016). FAD Research Series 5-Rural-urban linkages and food systems in sub-Saharan Africa: The rural dimension. IFAD Research series. ISBN 978-92-9072-676-0 , Available at SSRN: <https://ssrn.com/abstract=3284460>
- Iheonu, C., Ihedimma, G., & Onwuanaku, C. (2017). Institutional Quality and Economic Performance in West Africa. University Library of Munich, Germany.
- Ikefuji, M., Magnus, J. R., & Sakamoto, H. (2010). Climate change, economic growth, and health. ISER Discussion Paper, No. 785, Osaka University, Institute of Social and Economic Research (ISER), Osaka. (Paper No.: 785). <https://doi.org/10.2139/ssrn.1665102>
- IPCC. (1996). Economic and social dimensions of climate change. *Contribution of Working Group3 to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, 13-14.
- IPCC. (2014a). 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*, 1132.
- IPCC. (2014b). *Mitigation of Climate Change*. In Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., ... & Minx, J.C. (Eds.), *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1454, 147). . Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- J, R. A., & Anaba, M. I. (2022). The effects of economic growth on carbon dioxide emissions in selected Sub-Saharan African (SSA) countries. *Heliyon*, 8(11), e11193. <https://doi.org/10.1016/j.heliyon.2022.e11193>
- Jalan, J., & Ravallion, M. (2000). Is transient poverty different? Evidence for rural China. *The journal of development studies*, 36(6), 82-99. <https://doi.org/10.1080/00220380008422655>
- Jamshidi, O., Asadi, A., Kalantari, K., Azadi, H., & Scheffran, J. (2019). Vulnerability to climate change of smallholder farmers in the Hamadan province, Iran. *Climate Risk Management*, 23, 146-159.

- Jaramillo, L., Cebotari, A., Diallo, Y., Gupta, R., Koshima, Y., Kularatne, C., Lee, J. D., Rehman, S., Tintchev, K., & Tintchev, M. K. I. (2023). *Climate challenges in fragile and conflict-affected states*. International Monetary Fund.
- Jayne, T. S., Chamberlin, J., & Benfica, R. (2018). Africa's unfolding economic transformation. In (Vol. 54, pp. 777-787): Taylor & Francis.
- Jones, R. L., Kharb, A., & Tubeuf, S. (2023). The untold story of missing data in disaster research: a systematic review of the empirical literature utilising the Emergency Events Database (EM-DAT). *Environmental Research Letters*, 8(10), 103006. <https://doi.org/10.1088/1748-9326/acfd42>
- Kailash Chandra, P., & Shrabani, M. (2018). Covariate and idiosyncratic shocks and coping strategies for poor and non-poor rural households in India. *Journal of Quantitative Economics*, 16(1), 101-127.
- Kaufmann, D., Kraay, A., & Mastruzzi, M. (2011). The worldwide governance indicators: methodology and analytical issues1. *Hague journal on the rule of law*, 3(2), 220-246.
- Keefer, P., & Knack, S. (2002). Polarization, politics and property rights: Links between inequality and growth. *Public choice*, 111(1), 127-154.
- Keenan, R. J. (2015). Climate change impacts and adaptation in forest management: a review. *Annals of Forest Science*, 72(2), 145-167. <https://doi.org/10.1007/s13595-014-0446-5>
- Kessides, C. (2006). *The urban transition in Sub-Saharan Africa: Implications for economic growth and poverty reduction*. Citeseer.
- Kimball, B., & Idso, S. (1983). Increasing atmospheric CO₂: effects on crop yield, water use and climate. *Agricultural water management*, 7(1-3), 55-72. [https://doi.org/10.1016/0378-3774\(83\)90075-6](https://doi.org/10.1016/0378-3774(83)90075-6)
- Kimuli, I., Lubwama, M., Sebbit, A., & Kirabira, J. B. (2022). Macroeconomic effects of a low carbon electrification of greater Kampala Metropolitan area energy policy: A computable general equilibrium analysis. *Energy Strategy Reviews*, 43, 100909. <https://doi.org/10.1016/j.esr.2022.100909>
- Kjellstrom, T., Kovats, R. S., Lloyd, S. J., Holt, T., & Tol, R. S. (2009). The direct impact of climate change on regional labor productivity. *Arch Environ Occup Health*, 64(4), 217-227. <https://doi.org/10.1080/19338240903352776>
- Knight, F. H. (1921). Risk, uncertainty and profit. *Hart, Schaffner and Marx*.
- Kotchen, M. J. (2020). On the scope of climate finance to facilitate international agreement on climate change. *Economics Letters*, 190, 109070.
- Kreft, S., Eckstein, D., & Melchior, I. (2016). *Global climate risk index 2017: Who suffers most from extreme weather events? weather-related loss events in 2015 and 1996 to 2015*. Germanwatch, Bonn, Germany. Retrieved from <https://policycommons.net/artifacts/1555054/global-climate-risk-index-2017/2244863/> on 08 Aug 2021. CID: 20.500.12592/1cp03c.
- Kumar, S., Kumar, N., & Vivekadhish, S. (2016). Millennium development goals (MDGS) to sustainable development goals (SDGS): Addressing unfinished agenda and strengthening sustainable development and partnership. *Indian journal of community medicine: official publication of Indian Association of Preventive & Social Medicine*, 41(1), 1. <https://doi.org/10.4103/0970-0218.170955>
- Kurukulasuriya, P., & Mendelsohn, R. O. (2007). A Ricardian analysis of the impact of climate change on African cropland. *World Bank Policy Research Working Paper*(4305).
- Lecocq, F., & Shalizi, Z. (2007). How might climate change affect economic growth in developing countries? The World Bank Development Research Group: WPS4315. Washington D.C., USA. .

- Lemoine, D. M., & Traeger, C. P. (2012). *Tipping points and ambiguity in the economics of climate change. National Bureau of Economic Research (No.W18230): Working Paper 18230, 25-34. Cambridge Massachusetts, USA.* <http://www.nber.org/papers/w18230>
- Lepot, M., Aubin, J.-B., & Clemens, F. H. (2017). Interpolation in time series: An introductory overview of existing methods, their performance criteria and uncertainty assessment. *Water*, 9(10), 796.
- Letta, M., & Tol, R. S. (2019). Weather, climate and total factor productivity. *Environmental and Resource Economics*, 73(1), 283-305. <https://doi.org/10.1007/s10640-018-0262-8>
- Li, M., Li, J., Haq, S. u., & Nadeem, M. (2024). Agriculture land use transformation: A threat to sustainable food production systems, rural food security, and farmer well-being? *PloS one*, 19(1), e0296332. <https://doi.org/10.1371/journal.pone.0296332>
- Ligon, E., & Schechter, L. (2003). Measuring vulnerability. *The Economic Journal*, 113(486), C95-C102.
- Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., & Henry, K. (2014). Climate-smart agriculture for food security. *Nature Climate Change*, 4(12), 1068-1072. <https://doi.org/10.1038/NCLIMATE2437>
- Lipset, S. M. (1959). Some social requisites of democracy: Economic development and political legitimacy. *American political science review*, 53(1), 69-105.
- Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science*, 319(5863), 607-610. <https://doi.org/10.1126/science.1152339>
- Lucas Jr, R. E. (1988). On the mechanics of economic development. *Journal of monetary economics*, 22(1), 3-42. [https://doi.org/10.1016/0304-3932\(88\)90168-7](https://doi.org/10.1016/0304-3932(88)90168-7)
- Lutz, W., Sanderson, W., & Andruchowitz, S. (2017). Moving Frontiers in Population Forecasting and Aging: Sergei Scherbov 65. Annotated Reprints of Key Publications. In: International Institute for Applied Systems Analysis, Laxenburg, Austria.
- Maduka, A. C., Ogwu, S. O., & Ekesiobi, C. S. (2022). Assessing the moderating effect of institutional quality on economic growth—carbon emission nexus in Nigeria. *Environmental Science and Pollution Research*, 1-15.
- Maino, R., & Emrullahu, D. (2022). *Climate change in Sub-Saharan Africa fragile states: Evidence from panel estimations. International Monetary Fund.* <https://doi.org/10.5089/9798400204869.001>.
- Mann, M. E., Schurer, A. P., Hawkins, E., Tett, S., & Hegerl, G. C. (2017). Importance of the Pre-Industrial Baseline in Determining the Likelihood of Exceeding the Paris Limits. In AGU Fall Meeting Abstracts (Vol. 2017, pp. GC51H-03).
- Markova, G., Baas, S., Conforti, P., & Ahmed, S. (2018). 2017: the impact of disasters and crises on agriculture and food security. *FAO, Rome (Italy)*, Chapter III. pp, 45-50.
- Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., & Gomis, M. (2021). Climate change 2021: the physical science basis. *Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change*, 2(1), 2391. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. <https://doi.org/10.1017/9781009157896>
- Mauro, P. (1995). Corruption and growth. *The quarterly journal of economics*, 110(3), 681-712. <https://doi.org/10.2307/2946696>
- Mazhin, S. A., Farrokhi, M., Noroozi, M., Roudini, J., Hosseini, S. A., Motlagh, M. E., Kolivand, P., & Khankeh, H. (2021). Worldwide disaster loss and damage databases: A

- systematic review. *J Educ Health Promot*, 10(1), 329. https://doi.org/10.4103/jehp.jehp_1525_20
- McCarthy, J. J., Canziani, F. O., Leary, A. N., Dokken, J. D., White, & S. K. (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2). Cambridge University Press.
- McCleary, R. M., & Barro, R. J. (2006). Religion and economy. *Journal of economic perspectives*, 20(2), 49-72. <https://doi.org/10.1257/jep.20.2.49>
- McMichael, A. J., Woodruff, R. E., & Hales, S. (2006). Climate change and human health: present and future risks. *The Lancet*, 367(9513), 859-869. [https://doi.org/10.1016/S0140-6736\(06\)68079-3](https://doi.org/10.1016/S0140-6736(06)68079-3)
- Michler, J. D., Josephson, A., Kilic, T., & Murray, S. (2022). Privacy protection, measurement error, and the integration of remote sensing and socioeconomic survey data. *Journal of Development Economics*, 158, 102927. <https://doi.org/10.1016/j.jdeveco.2022.102927>
- Mina, C. D., & Imai, K. S. (2017). Estimation of vulnerability to poverty using a multilevel longitudinal model: Evidence from the Philippines. *The journal of development studies*, 53(12), 2118-2144. <https://doi.org/10.1080/00220388.2016.1265942>
- Mishra, K. A., Singh, P. V., Jain, & K. S. (2010). Impact of global warming and climate change on social development. *Journal of Comparative Social Welfare*, 26(2-3), 239-260. <https://doi.org/10.1080/17486831003687626>
- Mongabay. (2024). Drought, climate change force Ethiopia pastoralists to go job hunting. Retrieved April 6, 2025, from <https://news.mongabay.com/2024/10/drought-climate-change-force-ethiopia-pastoralists-to-go-job-hunting/>
- Mongioli, G. (2011). Demand, structural interdependence, and economic provisioning. *American Journal of Economics and Sociology*, 70(5), 1147-1174. <https://doi.org/10.1111/j.1536-7150.2011.00812.x>
- Moon, H., & Perron, B. (2008). Seemingly Unrelated Regressions. *The new Palgrave dictionary of economics*, 1(9), 19.
- Moore, F. C., & Diaz, D. B. (2015). Temperature impacts on economic growth warrant stringent mitigation policy. *Nature Climate Change*, 5(2), 127. <https://doi.org/10.1038/nclimate2481>
- Moral-Benito, E. (2012). Determinants of economic growth: A Bayesian panel data approach. *Review of Economics and Statistics*, 94(2), 566-579.
- Morduch, J. (1995). Income smoothing and consumption smoothing. *Journal of economic perspectives*, 9(3), 103-114.
- Moser, C. O. (1998). The asset vulnerability framework: reassessing urban poverty reduction strategies. *World development*, 26(1), 1-19.
- Nakamura, Shohei, Bundervoet, Tom, Nuru, & Mohammed. (2019). *Rural roads, poverty, and resilience: evidence from Ethiopia*. The World Bank.
- Nakamura, S., Bundervoet, T., & Nuru, M. (2020). Rural roads, poverty, and resilience: Evidence from Ethiopia. *The journal of development studies*, 56(10), 1838-1855. <https://doi.org/10.1080/00220388.2020.1736282>
- Nastis, S. A., Michailidis, A., & Chatzitheodoridis, F. (2012). Climate change and agricultural productivity. *African Journal of Agricultural Research*, 7(35), 4885-4893. <https://doi.org/10.5897/AJAR11.2395>
- Nautiyal, S., Schaldah, R., Raju, K., Kaechele, H., Pritchard, B., & Rao, K. S. (2016). *Climate change challenge (3C) and social-economic-ecological interface-building—exploring potential adaptation strategies for bio-resource conservation and livelihood*

- development: Epilogue* (pp. 631-639). Springer International Publishing. https://doi.org/10.1007/978-3-319-31014-5_37
- Nest, M., & Mullard, S. (2021). Lobbying, corruption and climate finance: The stakes for international development. *U4 Issue*.
- Nest, M., Mullard, S., & Wathne, C. (2020). Corruption and climate finance.
- Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, A., Lennard, C., Padgham, J., & Urquhart, P. (2014). Climate Change 2014: Impacts, Adaptation and Vulnerability: Part B: Regional Aspects: Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 1199-1266.
- Njoh, A. J. (2003). Urbanization and development in sub-Saharan Africa. *Cities*, 20(3), 167-174. [https://doi.org/10.1016/S0264-2751\(03\)00010-6](https://doi.org/10.1016/S0264-2751(03)00010-6)
- Nordås, R., & Gleditsch, N. P. (2007). Climate change and conflict. *Political geography*, 26(6), 627-638. https://doi.org/10.1007/978-3-319-10954-1_3
- Nordhaus, W. (2019). Climate change: The ultimate challenge for economics. *American Economic Review*, 109(6), 1991-2014.
- Nordhaus, W. D. (1977). Economic growth and climate: the carbon dioxide problem. *The American Economic Review*, 341-346. <https://www.jstor.org/stable/1815926>
- Nordhaus, W. D. (1993). Optimal greenhouse-gas reductions and tax policy in the "DICE" model. *The American Economic Review*, 83(2), 313-317. <https://www.jstor.org/stable/2117683>
- North, D. C. (1990). *Institutions, institutional change and economic performance* (Vol. 4). Cambridge university press. [https://doi.org/10.1016/0167-2681\(92\)90062-G](https://doi.org/10.1016/0167-2681(92)90062-G)
- Nwani, S. E., Kelikume, I., & Osuji, E. (2020). Does service sector growth cause agricultural and industrial development? A dynamic econometric approach. *International Journal of Management, Economics and Social Sciences (IJMESS)*, 9(2), 58-75. <https://doi.org/10.32327/IJMESS/9.2.2020.4>
- O'keefe, P., Westgate, K., & Wisner, B. (1976). Taking the naturalness out of natural disasters. *Nature*, 260(5552), 566-567. <https://doi.org/10.1038/260566a0>
- O'Loughlin, J., Witmer, F. D., Linke, A. M., Laing, A., Gettelman, A., & Dudhia, J. (2012). Climate variability and conflict risk in East Africa, 1990–2009. *Proceedings of the National Academy of Sciences*, 109(45), 18344-18349.
- Okonjo-Iweala, N. (2020). Africa can play a leading role in the fight against climate change. *Brookings Institution, United States of America*. Retrieved from <https://policycommons.net/artifacts/4140371/africa-can-play-a-leading-role-in-the-fight-against-climate-change/4948897/> on 10 Jan 2024. CID: 20.500.12592/bmr4q1.
- Osuagwu, E. S. (2018). Evidence of long-run relationship between agriculture and manufacturing industry output in Nigeria (May 29, 2018). Available at SSRN: <https://ssrn.com/abstract=3186381> or <http://dx.doi.org/10.2139/ssrn.3186381>
- Osuagwu, E. S. (2020). Empirical evidence of a long-run relationship between agriculture and manufacturing industry output in Nigeria. *SAGE Open*, 10(1), 2158244019899045. <https://doi.org/10.1177/2158244019899045>
- Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., & Dasgupta, P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change* (p. 151). *Ipcc*.
- Pachauri, R. K., & Meyer, L. (2014). IPCC, 2014: climate change 2014: synthesis report. Contribution of Working Groups I. *II and III to the Fifth Assessment Report of the intergovernmental panel on Climate Change*. IPCC, Geneva, Switzerland, 151.

- Parry, M., Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P., & Hanson, C. (2007). *Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge University Press.
- Patterson, J. J. (2020). *Remaking Political Institutions: Climate Change and Beyond*. Cambridge University Press. <https://doi.org/10.1017/9781108769341>
- Payne, J. E. (2010). A survey of the electricity consumption-growth literature. *Applied energy*, 87(3), 723-731.
- Peterson, E. W. F. (2017). The role of population in economic growth. *SAGE Open*, 7(4), 2158244017736094. <https://doi.org/10.1177/2158244017736>
- Pindyck, R. S. (2012). Uncertain outcomes and climate change policy. *Journal of environmental economics management*, 63(3), 289-303.
- Piontek, F., Kalkuhl, M., Kriegler, E., Schultes, A., Leimbach, M., Edenhofer, O., & Bauer, N. (2019). Economic growth effects of alternative climate change impact channels in economic modeling. *Environmental and Resource Economics*, 73, 1357-1385. <https://doi.org/10.1007/s10640-018-00306-7>
- Pring, C. (2015). People and corruption: Africa survey. In.
- Pritchett, L., Suryahadi, A., & Sumarto, S. (2000). *Quantifying vulnerability to poverty: A proposed measure, applied to Indonesia*. World Bank Publications.
- Rabe-Hesketh, S., & Skrondal, A. (2008). *Multilevel and longitudinal modeling using Stata*. STATA press.
- Raihan, A., Muhtasim, D. A., Farhana, S., Hasan, M. A. U., Pavel, M. I., Faruk, O., Rahman, M., & Mahmood, A. (2022). Nexus between economic growth, energy use, urbanization, agricultural productivity, and carbon dioxide emissions: New insights from Bangladesh. *Energy Nexus*, 8, 100144. <https://doi.org/10.1016/j.nexus.2022.100144>
- Ramin, B. M., & McMichael, A. J. (2009). Climate change and health in sub-Saharan Africa: a case-based perspective. *EcoHealth*, 6(1), 52-57. <https://doi.org/10.1007/s10393-009-0222-4>
- Ramsey, J. B. (1969). Tests for specification errors in classical linear least-squares regression analysis. *Journal of the Royal Statistical Society Series B: Statistical Methodology*, 31(2), 350-371. <https://doi.org/10.1111/j.2517-6161.1969.tb00796.x>
- Raudenbush, S. W. (2002). Hierarchical linear models: Applications and data analysis methods. *Advanced Quantitative Techniques in the Social Sciences Series/SAGE*.
- Regan, J. M., & Young, S. K. (2022). Climate change in the Horn of Africa: causations for violent extremism. *Behavioral Sciences of Terrorism and Political Aggression*, 1-27.
- Reidmiller, D. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Lewis, K. L., Maycock, T. K., & Stewart, B. C. (2017). Impacts, risks, and adaptation in the United States: Fourth national climate assessment, volume II. *U.S. Global Change Research Program*. <https://nca2018.globalchange.gov/>. <https://doi.org/10.7930/NCA4.2018>
- Rezai, A., Taylor, L., & Foley, D. (2018). Economic growth, income distribution, and climate change. *Ecological Economics*, 146, 164-172. <https://doi.org/10.1016/j.ecolecon.2017.10.020>
- Rhein, S., & Jansesberger, V. (2024). Does drought exposure erode trust in the political system in Sub-Saharan Africa? *Climatic change*, 177(7), 114. <https://doi.org/10.1007/s10584-024-03768-5>
- Rigas, N., & Kounetas, K. E. (2024). The impact of CO2 emissions and climate on economic growth and productivity: International evidence. *Review of Development Economics*, 28(2), 719-740. <https://doi.org/10.1111/rode.13075>

- Rigaud, S., Manen, C., & Garcia-Martinez de Lagran, I. (2018). Symbols in motion: Flexible cultural boundaries and the fast spread of the Neolithic in the western Mediterranean. *PloS one*, 13(5), e0196488. <https://doi.org/10.1371/journal.pone.0196488>.
- Ritchie, H., Roser, M., & Rosado, P. (2020). CO₂ and Greenhouse Gas Emissions. *Our World in Data*. <https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions>.
- Rockström, J., Lannerstad, M., & Falkenmark, M. (2007). Assessing the water challenge of a new green revolution in developing countries. *Proceedings of the National Academy of Sciences*, 104(15), 6253-6260. <https://doi.org/10.1073/pnas.060573910>
- Rodrik, D. (2003). Institutions, integration, and geography: In search of the deep determinants of economic growth. In *Search of Prosperity: Analytic Country Studies on Growth, 1-30*. Princeton, NJ Princeton University Press.
- Romer, P. M. (1990). Endogenous technological change. *Journal of political economy*, 98(5, Part 2), S71-S102. https://www.nber.org/system/files/working_papers/w3210/w3210.pdf
- Roodman, D. (2009). How to do xtabond2: An introduction to difference and system GMM in Stata. *The stata journal*, 9(1), 86-136.
- Rosen, R. A., & Guenther, E. (2015). The economics of mitigating climate change: What can we know? *Technological Forecasting and Social Change*, 91, 93-106. <https://doi.org/10.1016/j.techfore.2014.01.013>
- Rosenzweig, C., & Hillel, D. (1998). *Climate change and the global harvest: potential impacts of the greenhouse effect on agriculture*.
- Sabir, S., Rafique, A., & Abbas, K. (2019). Institutions and FDI: evidence from developed and developing countries. *Financial Innovation*, 5(1), 1-20. <https://doi.org/10.1186/s40854-019-0123-7>
- Sabola, G. A. (2024). Climate change impacts on agricultural trade and food security in emerging economies: case of Southern Africa. *Discover Agriculture*, 2(1), 12. <https://doi.org/10.1007/s44279-024-00026-1>
- Sachs, J. D., & Warner, A. (1995). Natural resource abundance and economic growth. In: National bureau of economic research Cambridge, Mass., USA.
- Salgado, C. M., Azevedo, C., Proença, H., & Vieira, S. M. (2016). Missing data. *Secondary analysis of electronic health records*, 143-162.
- Sathaye, J., Makundi, W., Dale, L., Chan, P., & Andrasko, K. (2006). GHG mitigation potential, costs and benefits in global forests: a dynamic partial equilibrium approach. *The Energy Journal*, 127-162. <https://doi.org/10.5547/ISSN0195-6574-EJ-VolSI2006-NoSI3-7>
- Sazib, N., Mladenova, L. E., & Bolten, J. D. (2020). Assessing the impact of ENSO on agriculture over Africa using earth observation data. *Frontiers in Sustainable Food Systems*, 4, 509914. <https://doi.org/10.3389/fsufs.2020.509914>
- Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, 5(1), 014010. <https://doi.org/10.1088/1748-9326/5/1/014010>
- Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *Proceedings of the National Academy of Sciences*, 106(37), 15594-15598. <https://doi.org/10.1073/pnas.0906865106>
- Sekrafi, H., & Sghaier, A. (2018). The effect of corruption on carbon dioxide emissions and energy consumption in Tunisia. *PSU Research Review*, 2(1), 81-95. <https://doi.org/10.1108/PRR-11-2016-0008>
- Sen, A. (1981). *Poverty and famines: an essay on entitlement and deprivation*. Oxford university press.

- Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., & Reinhardt, J. (2017a). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*, 17(6), 1585-1600. <https://doi.org/10.1007/s10113-015-0910-2>
- Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., & Reinhardt, J. (2017b). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*, 17, 1585-1600. <https://doi.org/10.1007/s10113-015-0910-2>
- Shabbir, G., Anwar, M., & Adil, S. (2016). Corruption, political stability and economic growth. *The Pakistan development review*, 689-702.
- Shehata, E., & Mickael, S. (2015). RESETXT: Stata Module to Compute Panel Data REgression Specification Error Tests (RESET). <https://ideas.repec.org/c/boc/bocode/s457954.html>.
- Shiferaw, Bekele, Tessema, Tesfaye, Kindie, Kassie, Menale, Abate, Tsedeke, Prasanna, BM, Menkir, & Abebe. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes*, 3, 67-79.
- Shleifer, A., & Vishny, R. W. (1993). Corruption. *The quarterly journal of economics*, 108(3), 599-617.
- Singh, A. K., Kumar, S., & Jyoti, B. (2022). Influence of climate change on agricultural sustainability in India: A state-wise panel data analysis. *Asian Journal of Agriculture*, 6(1), 15-27. <https://doi.org/10.13057/asianjagric/g060103>
- Skoufias, E. (2003). Economic crises and natural disasters: Coping strategies and policy implications. *World development*, 31(7), 1087-1102. [https://doi.org/10.1016/S0305-750X\(03\)00069-X](https://doi.org/10.1016/S0305-750X(03)00069-X)
- Skoufias, E., & Vinha, K. (2013). The impacts of climate variability on household welfare in rural Mexico. *Population and Environment*, 34, 370-399.
- Smallwood, J.-M. (2018). Investigating The Relationship Between Corruption and Climate Change: Is Corruption Bad For Climate Change? *Political Science Research Journal*, 2018. Accessed at socialsciences.uoregon.edu.
- Smit, B., & Pilifosova, O. (2003). Adaptation to climate change in the context of sustainable development and equity. *Sustainable Development*, 8(9), 9.
- Solow, R. M. (1956). A contribution to the theory of economic growth. *The quarterly journal of economics*, 70(1), 65-94.
- Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics*, 39(3), 312-320. <https://doi.org/10.2307/1926047>
- Sono, D., Wei, Y., & Jin, Y. (2021). Assessing the Climate Resilience of Sub-Saharan Africa (SSA): A Metric-Based Approach. *Land*, 10(11), 1205. <https://doi.org/10.3390/land10111205>
- Sovacool, B. K., Linnér, B.-O., & Goodsite, M. E. (2015). The political economy of climate adaptation. *Nature Climate Change*, 5(7), 616-618. <https://doi.org/10.1038/nclimate2665>
- Sparks, D. (2021). *Economic transformation in sub-Saharan Africa: The way forward*. Routledge.
- Sridhar, K. S. (2016). Economic impacts of climate change in India's cities. *Climate Change Challenge (3C) and Social-Economic-Ecological Interface-Building: Exploring Potential Adaptation Strategies for Bio-resource Conservation and Livelihood Development*, 279-295.
- Statista. (2022). Share of agriculture, forestry, and fishing in GDP in Sub-Saharan Africa in 2022. Retrieved December 27, 2024, from

- <https://www.statista.com/statistics/1454175/share-of-agriculture-value-added-to-gdp-in-sub-saharan-africa/>.
- Stern, D. I. (2004). The rise and fall of the environmental Kuznets curve. *World development*, 32(8), 1419-1439. <https://doi.org/10.1016/j.worlddev.2004.03.004>
- Stern, N. (2006). The economics of climate change. *UNITED KINGDOM*.
- Stern, N. (2008). The economics of climate change. *American Economic Review*, 98(2), 1-37. <https://doi.org/10.1257/aer.98.2.1>
- Stern, N. (2013). The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models. *Journal of Economic Literature*, 51(3), 838-859. <https://doi.org/10.1257/jel.51.3.838>
- Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S., & Edmonson, N. (2006). *Stern Review: The economics of climate change* (Vol. 30). London: HM treasury.
- Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P. M. (2013). Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change (pp. 33-115). *Climate change: Cambridge university press*.
- Suryahadi, A., Sumarto, S., & Pritchett, L. (2000). Quantifying vulnerability to poverty: a proposed measure, applied to Indonesia. *Applied to Indonesia (September 2000)*.
- Thomson, M., Abayomi, K., Barnston, A. G., Levy, M., & Dilley, M. (2003). El Niño and drought in southern Africa. *The Lancet*, 361(9355), 437-438. [https://doi.org/10.1016/s0140-6736\(03\)12421-x](https://doi.org/10.1016/s0140-6736(03)12421-x)
- Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2014). Climate variability and vulnerability to climate change: a review. *Global change biology*, 20(11), 3313-3328. <https://doi.org/10.1111/gcb.12581>
- TI-CPI, T. I. C. P. I. (2021). Corruption Perception Index, CPI (cpi2021). https://images.transparencycdn.org/images/CPI2021_Report_EN-web.pdf
- Tol, R. S. (2009). The economic effects of climate change. *Journal of economic perspectives*, 23(2), 29-51.
- Treisman, D. (2000). The causes of corruption: a cross-national study. *Journal of public economics*, 76(3), 399-457. [https://doi.org/10.1016/S0047-2727\(99\)00092-4](https://doi.org/10.1016/S0047-2727(99)00092-4)
- Tsehay, A. S., & Bauer, S. (2012). Poverty and vulnerability dynamics: Empirical evidence from smallholders in northern highlands of Ethiopia. *Quarterly Journal of International Agriculture*, 51(892-2016-65173), 301-332.
- Tsigaris, P., & Wood, J. (2016). A simple climate-Solow model for introducing the economics of climate change to undergraduate students. *International Review of Economics Education*, 23, 65-81. <https://doi.org/10.1016/j.iree.2016.06.002>
- Uddin, M. A., Ali, M. H., & Masih, M. (2017). Political stability and growth: An application of dynamic GMM and quantile regression. *Economic Modelling*, 64, 610-625. <https://doi.org/10.1016/j.econmod.2017.04.028>
- Ulusoy, M. K., & Pirgaip, B. (2019). The Causal Relationship between Economic Policy Uncertainty and Stock Market Returns. *Atatürk Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, 23(4), 2239-2251.
- UNFCCC. (2007). Impacts, Vulnerabilities and Adaptation in Developing Countries. UNFCCC-United Nations Framework Convention on Climate Change. Bonn, Germany.
- UNFCCC, U. (2009). *UNFCCC, UN Framework Convention on Climate Change, (2009), Kyoto Protocol Reference Manual on Accounting of Emissions and Assigned Amount*,

- (Working Papers, eSocialSciences, <https://EconPapers.repec.org/RePEc:ess:wpaper:id:2296>., Issue.
- Vanderheiden, S. (2008). *Atmospheric justice: A political theory of climate change*. OUP USA pp. 9-15.
- Vinod, H. D., & Kaushik, S. K. (2007). Human capital and economic growth: evidence from developing countries. *The American Economist*, 51(1), 29-39. <https://doi.org/10.1177/056943450705100>
- Wakweya, R. B. (2023). Challenges and prospects of adopting climate-smart agricultural practices and technologies: Implications for food security. *Journal of Agriculture and Food Research*, 100698. <https://doi.org/10.1016/j.jafr.2023.100698>
- Walter, M., & Luebke, M. (2013). The impact of corruption on climate change: threatening emissions trading mechanisms? *UNEP Global Environmental Alert System*, March.
- Wang, S., Yuan, Y., & Wang, H. (2019). Corruption, hidden economy and environmental pollution: A spatial econometric analysis based on China's provincial panel data. *International journal of environmental research and public health*, 16(16), 2871.
- Wang, Y., & Chang, C.-P. (2023). The effect of policy stability on clean energy investment. *Economic Change and Restructuring*, 56(1), 327-344. <https://doi.org/10.1007/s10644-022-09422-3>
- Warren, R., Hope, C., Mastrandrea, M., Tol, R., Adger, N., & Lorenzoni, I. (2006). Spotlighting impacts functions in integrated assessment. (*Working paper; No. 91*). Tyndall Centre on Climate Change.
- Warsame, A. A., Sheik-Ali, I. A., Jama, O. M., Hassan, A. A., & Barre, G. M. (2022). Assessing the effects of climate change and political instability on sorghum production: Empirical evidence from Somalia. *Journal of Cleaner Production*, 360, 131893.
- Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A., Cox, P. M., Depledge, J., Drummond, P., Ekins, P., Galaz, V., Grace, D., Graham, H., Grubb, M., Haines, A., . . . Costello, A. (2015). Health and climate change: policy responses to protect public health. *Lancet*, 386(10006), 1861-1914. [https://doi.org/10.1016/S0140-6736\(15\)60854-6](https://doi.org/10.1016/S0140-6736(15)60854-6)
- WB, W. B. (2020). *World Development Indicators*, Washington DC: The World Bank Group. <https://databank.worldbank.org/source/world-development-indicators> : Accessed 28 October 2021.
- Webster, M., Ginnetti, J., Walker, P., Coppard, D., & Kent, R. (2008). The humanitarian costs of climate change. *Strengthening the Humanity and Dignity of People in Crisis through Knowledge and Practice*. Medford, MA: Feinstein International Center, Tufts University.
- Weitzman, M. L. (2010). What Is The " Damages Function" For Global Warming—And What Difference Might It Make? *Climate Change Economics*, 1(01), 57-69. <https://doi.org/10.1142/S2010007810000042>
- Welborn, L. (2018). Africa and climate change-projecting vulnerability and adaptive capacity: ISS Africa Report, 2018(14), 1-24. <https://hdl.handle.net/10520/EJC-1486f763e1>
- Welsch, H. (2004). Corruption, growth, and the environment: a cross-country analysis. *Environment and Development Economics*, 9(5), 663-693.
- Wenz, L., & Willner, S. N. (2022). Climate impacts and global supply chains: an overview. *Handbook on trade policy and climate change*, 290-316.
- Wilkinson, E., & Peters, K. (2015). Climate extremes and resilient poverty reduction: development designed with uncertainty in mind. London: Overseas Development Institute.

- Winsemius, H. C., Jongman, B., Veldkamp, T. I., Hallegatte, S., Bangalore, M., & Ward, P. J. (2018). Disaster risk, climate change, and poverty: assessing the global exposure of poor people to floods and droughts. *Environment and Development Economics*, 23(3), 328-348. <https://doi.org/10.1017/S1355770X17000444>
- Winter, M., & Shearer's, B. (2013). *Climate change and landslide hazard and risk-a Scottish perspective*. (No. PPR650).
- Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press. Chapter 20 pp. 703-706.
- Wossen, T., Berger, T., Haile, M. G., & Troost, C. (2018). Impacts of climate variability and food price volatility on household income and food security of farm households in East and West Africa. *Agricultural systems*, 163, 7-15. <https://doi.org/10.1016/j.agry.2017.02.006>
- Wu, F., & Yan, X. (2018). Institutional quality and sustainable development of industries' exports: Evidence from China. *Sustainability*, 10(11), 4173.
- Xepapadeas, A. (2005). Economic growth and the environment. *Handbook of environmental economics*, 3, 1219-1271. [https://doi.org/10.1016/S1574-0099\(05\)03023-8](https://doi.org/10.1016/S1574-0099(05)03023-8)
- Yang, X. C. a. L. (2018). Temperature and Economic Performance of Chinese Manufacturing Firms. *Environment for Development: Discussion Paper Series, Efd DP 18-04*. <https://www.jstor.org/stable/resrep17123.3>
- Zahonogo, P. (2016). Trade and economic growth in developing countries: Evidence from sub-Saharan Africa. *Journal of African Trade*, 3(1-2), 41-56. <https://doi.org/10.1016/j.joat.2017.02.001>
- Zellner, A. (1962). An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *Journal of the American statistical association*, 57(298), 348-368. <https://doi.org/10.1080/01621459.1962.10480664>
- Zellner, A., & Huang, D. S. (1962). Further properties of efficient estimators for seemingly unrelated regression equations. *International Economic Review*, 3(3), 300-313. <https://doi.org/10.2307/2525396>
- Zhang, Peng, Deschenes, Olivier, Meng, Kyle, Zhang, & Junjie. (2018). Temperature effects on productivity and factor reallocation: Evidence from a half million Chinese manufacturing plants. *Journal of Environmental Economics and Management*, 88, 1-17. <https://doi.org/10.1016/j.jeem.2017.11.001>
- Zhang, D., Ozturk, I., & Ullah, S. (2022). Institutional factors-environmental quality nexus in BRICS: a strategic pillar of governmental performance. *Economic Research-Ekonomska Istraživanja*, 1-13.
- Zhang, M., Zhang, H., Zhang, L., Peng, X., Zhu, J., Liu, D., & You, S. (2023). Corruption, anti-corruption, and economic development. *Humanities and Social Sciences Communications*, 10(1), 1-13. <https://doi.org/10.1057/s41599-023-01930-5>
- Zhang, P., Zhang, J., & Chen, M. (2017). Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. *Journal of Environmental Economics and Management*, 83, 8-31. <https://doi.org/10.1016/j.jeem.2016.12.001>
- Zhang, Y., & Ayyub, B. M. (2021). Temperature extremes in a changing climate. *Climate Change and Extreme Events*, 9-23. <https://doi.org/10.1016/B978-0-12-822700-8.00001-9>
- Zhang, Y., Liang, A., Wang, Y., Chen, X., Zhang, S., Jia, S., Zhang, X., Yang, X., & McLaughlin, N. (2022). Climate change impacts on soil fertility in Chinese Mollisols. In *Sustainable Crop Productivity and Quality Under Climate Change* (pp. 275-293). Elsevier. <https://doi.org/10.1016/B978-0-323-85449-8.00010-5>

Reference:
