The Impacts of Climate Change on Economic Growth, Agricultural Production, and Income Inequality: An Empirical Analysis of Developed and Developing Economies

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APPROVAL SHEET

THE IMPACTS OF CLIMATE CHANGE ON ECONOMIC GROWTH, AGRICULTURAL PRODUCTION, AND INCOME INEQUALITY: AN EMPIRICAL ANALYSIS OF DEVELOPED AND DEVELOPING ECONOMIES

By

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ABSTRACT

This study examines the (a)symmetric effects of climate changes on economic growth and agricultural production for a panel of 179 countries over the period 1980-2020 and income inequality for the period 1991-2020. It also examines the (a)symmetric effects of climate changes on food and crop production in Pakistan over the period 1960-2020. This study employed the ARDL approach with a mean group (MG) and pooled mean group (PMG) estimators, fixed effects, and random effects models for estimation. The objectives of this study are: to investigate the (a) symmetric effects of climate changes on (i) economic growth, (ii) agricultural production, and (iii) income inequality. This study also aimed to investigate (a) the symmetric impacts of climate changes on agricultural production in Pakistan. The findings of the linear ARDL model reveal that average changes in most of the climate indicators have detrimental effects on economic growth, whereas, mean sea level pressure contributes positively to economic growth during the examined period. Similarly, the influence of extreme values of climatic indicators in the form of minimum temperature, maximum precipitation, and natural disasters dummy used for the flood, drought, storm, and sea-level rise on economic growth is detrimental. Yet, the findings reveal that minimum precipitation significantly enhances economic growth. We also show that both positive and negative mean deviations of temperature and precipitation cause significant reductions in economic growth. Finally, asymmetric effects of climate change were also found for 6 continents and three regions of 3 major continents i.e., Asia, Europe, and Africa. The findings in the case of climate and agricultural production relationship reveal that climate changes in the form of average changes in temperature and sunshine duration, extreme changes like maximum temperature and minimum precipitation, and also negative and positive changes in precipitation below and above their historical mean damage food and crop production. Besides, the findings in the case of Pakistan reveal that although temperature negatively affects food production, precipitation enhances the total production of food in Pakistan. The findings of the nonlinear approach indicate that the impacts of temperature are quite asymmetric as both positive and negative changes to temperature damage food production with different intensities. Further, asymmetric effects are found in changes in precipitation on food production. Similarly, maximum temperature poses adverse effects on food production, whereas, maximum precipitation enhances it. The average change as well as the positive temperature change, adversely affects crop production, whereas, average precipitation and minimum precipitation assert favorable effects on crop production. The results also indicate that natural disasters have detrimental effects on food and crop production. Contrary to this, the duration of sunshine boosts both food and crop production during the examined period. The findings of the linear ARDL model revealed that most of the climate change indicators exacerbate income inequality except sunshine duration which insignificantly reduces it. The findings of the non-linear model show that the effects of climate change are quite asymmetric. Extreme climate changes in the form of rising minimum temperature and maximum precipitation increase income inequality, whereas, other changes do not exert significant effects on income inequality. Further, the effects of carbon emissions on income inequality are asymmetric. We suggested some important policy measures for mitigation and adaptation to combat surging climate hazards.

Key Words: Economic Growth; Temperature; Precipitation; Agricultural Production; Inequality

JEL Codes: O44; O47; O57; Q50; Q51; Q54; Q55; Q56; Q57; Q59; D63

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APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of Southeast Asian Nations
C-D-C	Cobb-Douglas-Climate
CO_2	Carbon Dioxide
DICE	Dynamic Integrated Ckimate-Economy
ECM	Error Correction Mechanism
EKC	Environmental Kuznets Curve
FAFD	Foreign Aid and Financial Development
FAO	Food and Agriculture Organization
FDS	Flood, Draught, and Storm
GFCF	Gross Fixed Capital Formation
GHGs	Green House Gases
GMM	GMM=Generalized Method of Moments
HAC	Heteroskedasticity and Autocorrelation Consistent
IAM	Integrated Assessment Model
IPCC	Inter-governmental Panel on Climate Change
LM	Lagrange Multiplier
MENA	Middle East and North Africa
MG	Pooled Mean
MREX	Merchandise Exports
MSLP	Mean Sea Level Pressure
ND	Natural Disasters
OECD	Organization for Economic Co-operation and Development
PMG	Pooled Mean Group
SSA	Sub-Saharan Africa
TFP	Total Factor Productivity
TMPA	Trademark and Patent Applications
UNDP	United Nations Development Program
WB	World Bank
WDI	World Development Indicators
WTO	World Metrological Organization

Chapter 1

Introduction

Global warming due to greenhouse gases emissions since industrialization has been the major cause of anthropogenic changes to climate (IPCC, 2013)[1]. The economics of climate change has emerged as an area of contention and concern over the last few decades. The issue of climate change and its substantial economic impacts can be found in the writing of ancient Greeks and Ibn Khaldun's Muqaddimah (Gate, 1967) in the 14th century. The climate-growth relationship is a closely related human affair that is found in the book of Huntington (1915), who wrote on the issue of "the effects of temperature and humidity". He has discussed the dominant effect of climate on human affairs. He argued that racial differences arise through natural selection propelled by disparities in climate and climate change. Montesquieu's Climate Theory given in his book "The Spirit of Laws (1748)" adds more worth to this study. This theory says that a climate of colder nature makes men more courageous, vigorous, and strong in response to a physical cause while a hotter climate makes them indolent, slothful, and feeble.

Solow (1956), under the umbrella of classical growth theorists, assumes GDP as output, which is produced by using 'production factors' i.e., technology, human capital, and physical capital. This model is extended by the inclusion of 'natural capital' as an additional factor of production. Natural capital consists of natural resources, ecosystems, environmental resources, and land. It is acknowledged and accepted that nature (ecosystem) plays a vital role in the functioning of an economy and its well-being creation (Daily, 1997). Integration of nature into economics is the pioneering work started by Nobel Laureate William Nordhaus in the 1970s. The

[1] IPCC (inter-governmental panel for climate change) was established in 1988 for the scientific assessment of climate change. It assesses the potential socioeconomic and environmental impacts. It is cited by thousands of researchers in peer-reviewed research studies across the globe.

co-evolution of fossil fuels and global warming has inspired and provoked William Nordhaus to stimulate his research work in this field. The findings of the study by Nordhaus (2005) reveal that geography is an important source of difference in incomes in regions with high incomes.[2] Temperature and greenhouse gases (GHG) emissions have a close relationship.[3] For instance, CO_2 emissions increased by about 1.9% per year whereas overall GHG emissions increased up by 1.6% per year (IPCC, 2007a). Nordhaus (2018) used the dynamic integrated climate change model (DICE) to assess the relationship of GDP growth with rising CO_2 levels and also the effect of CO_2 increase on the global average temperature. This rise in global temperature may result in a loss of around $15 trillion in 2150.

The dire changes in the climate are creating concerns among stakeholders and the world community (Tebaldi *et al.*, 2006). According to the report of UNDP (1998), climate change is one of the major threats that emerged over the years in the way to achieving the goal of hunger and poverty reduction aimed at millennium development goals (MDGs). It is a fact that extreme weather events are responsible for the damages related to climate (Meehl *et al.*, 2000). It is reported that 216 million people could migrate around the globe within the territories of their own countries by 2050 because of climate change (World Bank, 2021). According to a World Bank report (2002), nearly 0.165 million people fall below the poverty line due to environmental hazards in the form of Hurricane Mitch in 1998 in Honduras. There is also empirical evidence that climate changes exert detrimental effects on food production, water resources, health, and the environment which may decline GDP (Stern, 2006). However, few other studies find a

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[2] William Nordhaus is a renowned Nobel Laureate who integrated knowledge and nature into economics. Nordhaus and Paul. M Romer broadened the scope of economic analysis through the designing of tools to show how the market economy affects nature and knowledge in the long run. The work of these two laureates is built upon a growth model developed by Solow who also won the Nobel Prize in 1987.

[3] Emissions mainly consist of carbon, nitrogen, and sulphar emissions.

positive as well as a negative association between per capita income growth, air, and water pollution (Shafik, 1994; Kuznets, 1955). Some of the empirical studies show an inverted U-shaped relationship between GDP per capita and carbon dioxide emission (Angelis *et al.*, 2019). The simulation results using the climate-economy model reveal that the effects of capital accumulation on economic well-being are higher than the direct effects of climate change in the presence of technological change (Fankhauser & Tol, 2005).

Several scholars and researchers have shown serious concerns over the issue that how temperature, rainfall, and storms have influenced societies and thereby the economic performance of different economies (Carleton & Hsiang, 2016; Dell *et al.*, 2012; Colacito 2019). Changes in temperature exert adverse effects on the economic performance of 42 countries while it enhances the economic growth of 52 economies (Berg *et al.*, 2021). A rise in mean global temperature would reduce the world output by 7 to 14% (Kalkuhl & Wenz, 2020), 23% (Burke *et al.*, 2015), 1.9% (Berg *et al.*, 2021), and remain in the range from 2% to 10% or more of global GDP (Harris *et al.*, 2017) at the end of 21^{st} century while damages may range from 1% to 3.3% by 2060 (Dellink *et al.*, 2017). Similarly, recently, a study by Magazzino *et al.* (2021) reveals that a 1 percent rise in temperature reduces income by 0.39% while a 1% rise in the level of emission stimulates income by 0.22%. The global average temperature is expected to increase by $2^{\circ}C$ by 2100 which will assert significant economic losses throughout the world (Kaur & Kaushik, 2021).

Recently, a study by Newell (2020) investigates the relationship between temperature and GDP and finds no significant effect of temperature on GDP growth, whereas, hot temperature significantly affects both GDP and agricultural production. The temperature rise has wide-ranging effects on economic growth as it reduces industrial output, agricultural output, and political stability (Dell *et al.*, 2012). Some other studies have concluded that temperature is a significant and influential indicator of climate change which has damaging effects on income. The findings of these studies exhibit that climate change significantly reduces economic growth and productivity growth. Temperature rise above a threshold exerts negative effects on productivity. Precipitation asserts adverse impacts on annual growth rate (Adom & Amoani, 2021; Hoang & Huynh, 2020; Du *et al.*, 2017; Dell *et al.*, 2012; Lanzafame, 2014; Sequeira *et al.*, 2018; Deryugina and Hsiang, 2014; Colacito 2019). However, temperature, in the long run, significantly boosts economic growth in SSA (Alagidede *et al.*, 2015). Nevertheless, some other studies have documented that it only affects the GDP growth of poor countries (Leta & Tol, 2019; Henseler & Schumacher, 2019). The hazard of climate also exerts damaging effects on the economy as temperature and CO_2 emissions significantly reduce, whereas, precipitation marginally enhances the economic performance of different countries (Ali *et al.*, 2019).

GDP growth significantly declines due to rainfall as it damages the production of agriculture and services sectors, whereas, for the industrial sector, its effects are not detrimental (Sangkhaphan & Shu, 2019). Few studies have used rainfall as an important indicator of climate change which has both negative (Tebaldi & Beaudin, 2016; Dell *et al.*, 2012; Alagidede *et al.*, 2014) and positive effects on economic growth (Odusola & Abidoye, 2015). Another study by Barrios *et al.* (2010) finds that rainfall is one of the important determinants of poor economic performance in Africa which can considerably reduce the economic growth of African economies relative to the world. Energy consumption boosts while CO_2 emissions damage economic growth (Bozkurt & Akan, 2014). The findings based on the projections made by Pretis *et al.* (2017) reveal that rainfall is positively associated with both agricultural output and overall GDP.

Variations in temperature above and below its historical norms affect economic growth significantly, whereas, precipitation does not significantly reduce economic performance (Kahn *et al.*, 2019). Minimum and maximum values of both temperature and precipitation are considered very important that assert both positive and negative effects on major crops of the agriculture sector (Pretis *et al.*, 2017; Ali *et al.*, 2017; Lobell 2017). Natural disasters exert adverse effects on economic growth worldwide (Atsalakis *et al.*, 2020). Climate change significantly reduces economic output which requires revising the mitigation policies and implementing them without any further delay (Klenert 2020; Islam *et al.*, 2021; Dietz & Stern 2020; Millner & Dietz 2012).

The climate-agriculture nexus has become a very important area of future research worldwide (Unganai, 2009; Torquebian, 2013). The agriculture sector is the major sector of the economy which is more vulnerable and faces the adversity of climate change. Food and Agricultural Organization (2015) report that over 500 million people in southern Asia and Africa are facing the issue of food insecurity and more importantly, this bulk of the population directly or indirectly depends on agriculture. The estimates of FAO (2008) indicate that due to a lack of access to food and insufficient food availability, the number of malnourished and hungry people increased from 90 million in 1970 to 225 million in 2008, which may reach 325 million people by 2015. Climate change hampers the agriculture sector which results in losses of inland water ecosystems, rural livelihoods, marine ecosystems, and breakdown of food systems which in turn threatens food security (IPCC, 2014).

The effects stem from climate change threaten the population of the tropical region the most where it faces greater food insecurity. This effect also becomes more detrimental considering the aspect that the agriculture sector of the tropical region employs 30-80% of the population (FAO, 2015). The fourth report of IPCC (2007) also indicates that due to prolonged floods and draughts, the area in the form of fertile land and the productivity of fisheries decline. It is also evident that draught elevates temperature which adversely affects the agriculture sector in most African regions (FAO, 2017). The IPCC in 2007 and 2014 further revealed that climate change affects global agriculture significantly in the 21st century as the majority of the world economies will face a rise in mean temperature, changing patterns of heavy precipitation, more heat stresses, shortage of water resources, and desertification. Specifically, empirical evidence shows that rising temperatures, changing patterns of rainfall, droughts, and floods have damaging effects on agricultural production (Mendelsohn, 2014; Kurukulasuriya *et al.*, 2006).

The IPCC and FAO consider the agriculture sector as the most vulnerable that is exposed to climate hazards, especially in developing countries in the world (Melkonyan & Asadoorian, 2013). The total factor productivity pertinent to the agriculture sector has gone down to 0.7% over the period 1950-1996 which is less than half of its historical growth of 2.3% per year (Sheng *et al.*, 2017). Tanure *et al.* (2020) use the Computable General Equilibrium (CGE) model for the assessment of the effect of climate variability on agriculture production, GDP, land use, and job creation following the scenarios proposed by IPCC. Anthropogenic climate change exerts detrimental effects on the TFP of the agriculture sector (Ortiz-Bobea *et al.*, 2021). The effect of rainfall is damaging, whereas, the temperature does not affect the TFP growth of the agriculture sector (Ogundari & Onyeaghala, 2021).

There is greater urgency to analyze the effects of changes in climate on grain production as the researchers have recognized those natural factors as well as social and economic factors, are posing serious threats to grain production (Shang *et al.*, 2017; Challinor *et al.*, 2010; Arshad *et al.*, 2017). The changes in climate increase the issues and problems of the agriculture sector which reduces the yield (Murphy *et al.*, 2004; Murphy 2009). Climate change hurts crop production as an increase in temperature has damaging effects on crop production both in the short run and in the long run. The impact of rainfall is positive on the production of crops in the long run, however; its impact is detrimental in the short run (Warsame *et al.*, 2021).

The assessment report of IPCC (2007) indicates that during the past century, global temperature has increased by 0.6°C to 0.8°C which is an unusual rise in temperature during the past 1000 years (Liu *et al.*, 2012). These changes also have consequences for cereal production and yield. The findings reveal a positive effect of temperature on cereal yield, whereas, the effect of precipitation on cereal production and yield was found negative (Sossou *et al.* 2020). The temperature change enhances the growth and yield of cotton, rice, and cereal (Arshad *et al.* 2021; He *et al.* 2020). Climate hazard negatively affects the production of olives in the form of minimum, and maximum temperature and precipitation (Orlandi *et al.* 2020), crop yield of food and non-food crops (Guntukula, 2020), and grain production (Bai *et al.*, 2019).

Few researchers found detrimental effects of maximum and minimum temperature on crop production, cropping area of all crops, wheat yield, grain production, barley yield, and food production, whereas, precipitation enhances the cropping area of all crops, crop yield, and barley yield (Ali *et al.*, 2017; Amin *et al.*, 2015; Ha *et al.*, 2021; Al-Bakri *et al.*, 2019; Jemmali *et al.*, 2021; Tonkaz *et al.*, 2010) and minimum temperature increases crop production (Ali *et al.*, 2017). Precipitation exerts adverse effects on rice production, grain production, food production, and food crop prices (Wang *et al.*, 2018; Ha *et al.*, 2021; Nsabimana and Habimana, 2017), whereas, it does not significantly affect agriculture production (Krimly *et al.*, 2016).

Nature and manmade disasters such as floods, landslides, earthquakes, droughts, and conflicts hit Pakistan from time to time and affect millions of the population (FAO, 2021). Climate change damages agriculture production in Pakistan (Rehman *et al.*, 2021; Ahmed *et al.*, 2020; Rehman *et al.*, 2021). The agriculture sector is an important and primary source that ensures food availability and provides livelihoods to residents in Pakistan. It also provides raw materials to the industrial sector and enables the economy to enhance exports of finished goods and thereby earn foreign exchange (GoP, 2018). The agriculture sector of Pakistan experienced growth of 2.77%, whereas, crop growth remained at 4.65% during 2020-21. This sector employs 38.5% of the labor force and its share of GDP is 19.2%. The contribution of major crops towards agriculture value addition is 22.49% which is 4.32% of GDP, whereas, the share of other crops in GDP is 2.24% which is 19.69% of the agriculture value addition (GoP, 2021). The contribution of other sub-sectors to the GDP of Pakistan is also meaningful (Chandio *et al.*, 2018). The growth of the overall economy significantly depends on the growth of the agriculture sector. Therefore, it is worthwhile to examine how climate changes affect the production and productivity of different crops in Pakistan.

Indeed, few studies have already shown the negative impacts of the average, maximum, and minimum temperature on crop yield, crop production, wheat, and rice production (Chandio *et al.*, 2021; Abbas, 2021; Gul *et al.*, 2021). Similarly, average minimum temperature enhances the production of all crops and precipitation asserts negative effects on the production of all crops except wheat production (Ali *et al.*, 2017). Contrary to this, precipitation exerts positive effects on the yield of food crops (Gul *et al.*, 2021). Dudu and Cakmak (2018) find that agriculture and food production may face detrimental effects due to the surging changes in climate in the second half of this century. One of the studies finds a U-shaped relationship between wheat productivity and temperature, as well as between rainfall and wheat production (Rehman *et al.*, 2021).

Positive and negative shocks in CO_2 emissions negatively influence cereal production (Koondhar *et al.*, 2021), and cultivated areas (Abbas, 2021: Rehman *et al.*, 2021). However, CO_2 emissions exert mixed effects on fruit production (Hussain *et al.*, 2021), and positive effects on crop yields (Chandio *et al.*, 2021). Michieka *et al.* (2021), very recently, also authenticate the existence of asymmetric Effects of temperature on agriculture output. Specifically, maximum temperature exerts negative effects on the yield of all crops, cropping areas, and crop yield, similarly, precipitation negatively affects the yield of all crops and positively affects the yield of maize (Khan *et al.*, 2019; Amin *et al.*, 2015). Another study by Maharjan and Joshi (2013) find mixed effects of maximum temperature and rainfall on crop yield.

Climate change, poverty, and income inequality are important defining issues of the current era. The climate-poverty nexus emerged as a new area of research (Howe *et al.*, 2013). Climate change and income inequality are closely and positively associated (Cevik and Jalles 2022). Poverty is a key factor that increases climate change vulnerability (Adger *et al.* 2003; IPCC, 2007; Ribot, 2010; Fussel, 2012; IPCC, 2012). According to a World Bank report, climate change is an ongoing surging threat to poverty reduction that can become more threatening in the future. The estimates of WB say that climate hazards will drive 68-135 million people into poverty by 2030. It can cause about 200 million population to mitigate with their own countries by 2050. Climate changes acerbate existing inequality (Hundenborn *et al.*, 2018) and poverty (Finn & Leibbrandt, 2017). Few researchers have established different outcomes when analyzing income inequality by assigning greater weightage to damages at lower levels of income (Denning *et al.* 2015; Anthoff and Tol, 2010; Adler *et al.* 2017). According to the policy research working paper of the World Bank, by 2030, climate change will be one of the major factors exerting serious implications for the increase in poverty through higher food prices and a decrease in agricultural production in the regions like Asia and Africa.

The 3rd IPCC (2001) inspection shows that poor segments of the world are most likely to be affected by climate change. Some studies show that poor populations either belonging to divided regions or the world are more likely to be affected by climate change hazards including sea-level rise than other segments of the population (Kim, 2011; Marlinich *et al.*, 2013). It has increased inequality not only within but also between communities (Hsiang *et al.*, 2019). A study by Diffenbaugh and Burke (2019) indicates that studies of climate change and economic inequality exaggerate between-country inequalities. An important contribution from the existing literature as a theoretical framework is the model developed by Blackburn and Chivers (2015) to assess the nexus between income inequality and pollution. According to the study, pollution has detrimental effects on output. It increases the losses of agents as the return on investment in human capital is reduced. Thus, more damage caused by pollution leads to greater inequality in incomes as agents' investments are reduced.

Few studies showed that climate change can affect poverty through the channels like consumption, livelihood, health, assets, and productivity (De Cian *et al.* 2016; Mendelsohn *et al.* 2006; Tol, 2004). Climate changes adversely affect agriculture productivity, industrial productivity, income inequality, profitability, employment, investment, health, government subsidy policy, regional conflict on resources, labor productivity, and annual income (Kunawotor *et al.*, 2021; Alam *et al.*, 2017; Lee *et al.*, 2016; Dell *et al.*, 2014), distribution of incomes (Marx, 2018), income growth (Letta *et al.*, 2018), and welfare (Donadelli *et al.*, 2017). There is no consistent effect of climate change on inequality as the effects of such changes differ in their implications for the different sectors of the economy (Lindelow, 2020).

Income inequality tends to remain low in the temperature range of 11°C to 17°C (Dasgupta *et al.*, 2014). Temperature rise reduces income within and across (Dell *et al.*, 2009). Climate change, on the one hand, increased temperature due to GHG emissions that affect the population of low-income countries. On the other hand, if resources are employed to reduce GHG emissions as a mitigation cost, it slows down the economic growth of poor economies (Taconet *et al.*, 2021). Climatic change in the form of temperature shocks leads to multidimensional energy poverty (Feeny, 2021). Temperature rise above 9°C may exert negative effects on economic performance which in turn may cause global income inequality. An increase in temperature affects annual income (Deryugina & Hsiang, 2014), the productivity of labor and its supply (Antonella *et al.*, 2019; Graff Zivin & Neidell, 2014), migration (Shayegh, 2017; Callaneo *et al.*, 2019), human capital (Graff Zivin *et al.*, 2018).

More rainfall results in the decline of economic performance in high-income countries where manufacturing and services sectors are strongly hindered by rainfall changes (Kotz *et al.*, 2022). The effects of precipitation are adverse for developing countries compared to developed countries where agriculture is the most vulnerable sector of the economy (Damania *et al.*, 2019). Temperature and precipitation changes bring a significant rise in spatial inequality by affecting the income and agriculture sectors (Mveyange, 2018). More rains cause more poverty, whereas, fewer showers of rain lead to a decline in poverty (Cabral, 2014). Extreme changes in precipitation and temperature affect both economic activity and income distribution with different intensities (Otrachshenko & Popova, 2021).

The trade-off between CO_2 emissions and income inequality depends on the income level (Gruewald & Klasen, 2015). One of the studies showed that when carbon emissions reduction efficiency rise, the income inequality gap increases (Cui *et al.*, 2021). In low and middle-income economies, lower emissions are closely related to higher income inequality while high and upper-middle-income economies experience higher income inequality with the increased level of emissions per capita. Emissions and income share of the top 10% are positively associated, whereas, income inequality does not significantly affect emissions (Jorgenson *et al.*, 2016). The bottom household decile emits 2.7% while the top decile emits 26.8% of the total carbon emissions (Vera *et al.*, 2020). The occurrence of natural disasters increased income inequality in the short run, whereas, natural disasters do not affect income inequality in the long run (Yamamura, 2015). Climate changes increase poverty and inequality which exert favorable impacts on urbanization and migration from low to high-latitude countries (Burzynski *et al.*, 2019). Extreme weather reduces regional per capita GDP but does not affect the distribution of income (Otrachshenko & Popova 2022). One of the studies considers climate change as one of the significant drivers of inequality in Sub-Saharan Africa (SSA) that requires an early intervention for climate change reversal (Ujunwa *et al.*, 2021).

Although the existing empirical literature discusses several issues about climate change and income inequality, few gaps still exist. To the best of our knowledge, none of the studies highlighted the different dimensions of climate change, the way our study does. The existing studies ignored the possibility of asymmetric effects of climate change on economic growth, agricultural production, and income inequality. This study focuses on these effects by investigating the asymmetric effects of climate changes in the form of positive and negative changes from their mean deviations of major climate indicators (temperature and precipitation) on economic growth, agricultural production, and income inequality. To the best of our understanding, there is no specific study that focused on extreme climate changes (minimum and maximum precipitation and temperature) to assess their effects on economic growth, agricultural production, and income inequality. To our understanding, there is limited empirical literature that captures not only the effect of climate change on global economic performance but also assesses the impacts of climate change on the economic growth of continents and regions. Empirical evidence on such issues will enhance our understanding of how climate change is related to economic growth.

The existing studies also ignored the importance of sunshine duration for economic activities, food production, crop production, and income inequality. This study highlights the importance of sunshine as an indicator by investigating its relationship to economic growth, agricultural production, and income inequality. Carbon emissions are one of the major causes of the exacerbation of climate change. To the best of our understanding, the existing literature ignored the symmetry and asymmetric effects of carbon emissions on income inequality which are the focus of this study.

1.1 Gaps in the Existing Literature

The existing research work depicts that most of the studies conducted in past took either one country as a case study or used regional blocks while ignoring the global level analysis (Bozkurt and Akav 2014; Alagidede *et al.*, 2015; Arndt *et al.*, 2012; Ozturk and Acaravci 2010; Akram 2012; Barrios *et al.*, 2003; Huong *et al.*, 2018; Sangkhaphan and Shu, 2019). The study has stressed conducting further research, not at the country level but also at subnational levels (Akram 2012; Sheng and Xu 2019). The existing studies do not provide comprehensive knowledge about the relationship between climate change and economic growth, especially keeping in view the extreme and asymmetric effects of climate change on economic growth. Although Kahn *et al.* (2019) attempted to analyze the asymmetric effects of climate change, their approach was too limited. The main issue of the study was the inclusion of only climate change indicators i.e., temperature and precipitation which raised the issue of omitted variable bias.

While different studies have discussed the nexus between climate change and agriculture production, a few critical gaps still exist. First, to the best of our understanding, most of the existing literature uses only temperature and precipitation as climate change factors and ignored other variables like mean sea level pressure, sunshine, and natural disasters (Alagidede *et al.*, 2015; Arndt *et al.*, 2012; Akram 2012; Barrios *et al.*, 2003; Du *et al.*, 2017; Deressa and Hassan 2009; Lu *et al.*, 2019; Mariara and Karanja 2007; Gbetibouo and Hassan 2004; Potgieter *et al.*, 2013). There is a need to reassess and rethink the harmful impacts likely to emerge in the future for better policy formulation to mitigate those (Ochieng *et al.*, 2016). This study uses sunshine duration as an explanatory variable. Sunshine duration is important for the growth of crops as crop leaves absorb sunlight and use it as a source of energy for photosynthesis, whereas, it may also exert negative effects on the growth of crops. Natural disasters in the form of floods, droughts, storms, and sea-level rise can prove devastating for economic activities. To investigate the effects of natural calamities, this study uses a dummy variable that shows how much an economy is vulnerable to floods, droughts, storms, and sea level rise.

Second, to our knowledge, besides the average changes in climate indicators affecting economic growth, the extreme values of major climate factors can also influence economic growth, agricultural production, and income inequality which were ignored by the existing literature. This paper aims to assess the effect of these extreme values on economic growth, food production, crop production, and income inequality. Third, to the best of our understanding, no study has so far assessed the asymmetric effects of major climate change indicators (temperature and precipitation) on economic growth, food production, crop production, and income inequality worldwide. Hence, it bridges this gap too.

Fourth, to the best of our knowledge, no study assessed asymmetric effects and extreme effects of climate change indicators (temperature and precipitation) on food and crop production in Pakistan. The existing studies mainly focused on the symmetric effects of climate change in Pakistan. Hence, this paper aims to bridge this gap. Further, to our understanding, existing studies have not focused on the effects of natural disasters in the form of floods, droughts, storms, and sea-level rise on food and crop production in Pakistan. Continuous torrential monsoon rainfall and resultant flooding in general and urban flooding, in particular, has wreaked havoc in different cities of Pakistan. The agriculture sector absorbs 22% of the economic effects caused by natural disasters (FAO, 2015). This study investigates the effects exerted by hazardous climate factors on food and crop production by using natural disasters dummy.

Fifth, none of the studies focus on the symmetry and asymmetric effects of carbon emissions on income inequality before this study. Although carbon emissions are not a direct indicator of climate change, they can affect economic growth and thereby income inequality. The existing literature provides the justification that carbon emissions can affect economic growth. However, the existing literature lacks in providing ample justification empirically that how asymmetric effects can affect economic growth as well as income inequality in developed and developing economies. On the basis of this evidence, we think that it may affect income inequality. This aspect of the analysis is the newish way to investigate the emissions-inequality nexus. This gap in literature molds our intention to highlight the differential effects of climate change on agriculture production and income inequality. The existing previous studies also ignored the effects of the sunshine hours and natural disasters on global inequality which we consider in our study as indicators of climate change.

Finally, the existing literature has mainly focused on the average effects of climate change and its consequences on the economy. However, no study raised this issue at the global level by splitting the sample into continents and their selected regions using panel data. This study tries to bridge this gap.

1.2 Problem Statement

Climate change is considered the mother of all externalities. Greenhouse gas emissions are on an ever-increasing path due to the burning of fossil fuels and deforestation. This increase in emissions consequently results in the rise of temperature, variations in patterns of precipitation, rise in mean sea level, changes in average hours of sunshine, floods, drought, storm, relative humidity, etc. These factors of climate change are asserting serious threats to the world ecosystem and thereby affecting global economic activities.

Climate change has hazardous implications for economic growth. It exerts detrimental effects on different sectors of an economy which hampers overall economic growth. The agriculture sector is considered one of the major sectors influenced and affected by the hazard of climatic change. The effects of surging climate change are not restricted to the agriculture sector only. It can also affect the industrial and services sectors. Heat and cold weather can exert significant influences on human health and labor productivity. Are the climate changes either in the form of average changes, asymmetric changes, or extreme changes affecting the real GDP and also the GDP per capita or not one of the issues of concern addressed in this desertion?

Climate change has its effects on the direct physical production of the agriculture sector as well as on the revenue generated by this sector. It can influence crop and food production and thereby increase the issue of food security.

Environmental degradation, on one hand, can affect economic activities, whereas, on the other hand, it may assert serious implications for the distribution of incomes. It may hamper and can cause a decline in global human development and thereby increasing gaps between the income of the poor and the rich. Future generations may face dire consequences of this menace if not tackled and treated properly and the time before it could be too late.

The differential impacts of climate change especially asymmetric effects and extreme effects will bring interesting insights that could be used to recommend policies for the international climate regime as well as for Pakistan and can serve to make an addition in defining equitable burden sharing for climate responsibility. Existing literature postulates that climate change can affect the world economic system differently. Its consequences and implications for world economies can also differ. It is a paramount problem that requires the attention of researchers and policymakers to save the future of our generations.

1.3 Objectives of the Study

The objectives of the study are as follows.

1- To investigate the impacts of climate change on economic growth by
    a) assessing the impacts of the average change in temperature, precipitation, and other climate indicators on real GDP and GDP per capita.

b) investigating the impacts of extreme changes (maximum and minimum) in major climate indicators (temperature and precipitation) on GDP per capita and GDP per capita.

c) examining the influence of asymmetric effects of major climate change indicators (temperature and precipitation) on real GDP and GDP per capita.

d) investigating the effect of climate changes on the economic growth of 6 continents e.g., Asia, Europe, Africa, North and Central America, South America, and Australia, and 3 selected regions e.g., South Asia, Central Europe, and Western Africa.

2- To investigate the nexus between climate change and agricultural production and to achieve this objective, this study focuses on the following

a) to examine whether average climate changes affect agricultural production by affecting food and crop production or not.

b) to investigate the effects of extreme changes (maximum and minimum) in major climate indicators (temperature and precipitation) on food and crop production.

c) to assess the asymmetric effects of climate changes on food and crop production.

d) to examine empirically which food and crop production of which division is more vulnerable to climate changes e.g., developed economies or developing economies.

3- To investigate the impacts of average changes, asymmetry changes, and extreme changes (maximum and minimum) in major climate indicators (temperature and precipitation) on food and crop production in Pakistan.

4- To investigate the impact of climate change on income inequality by followings.

a) to assess the impacts of average changes, asymmetry changes, and extreme changes (maximum and minimum) in major climate indicators (temperature and precipitation) on income inequality.

b) to examine the impacts of average changes and asymmetric effects of carbon emissions on income inequality.

1.4 Research Questions and Hypotheses

This study has the following research question.

1. How the average change in temperature precipitation and other climate change indicators are impacting the real GDP and GDP per capita?
2. Does sunshine duration influence economic growth, agricultural production, and income inequality?
3. Do climate change indicators i.e., temperature and precipitation have differential impacts on real GDP and GDP per capita?
4. Are developing economies more vulnerable to and face the economic consequences of natural disasters compared to developed economies?
5. Are natural disasters assert damaging impacts on the economic growth of developed and developing countries?
6. What are the impacts of maximum and minimum temperatures on economic growth, agricultural production, and income inequality?
7. Does precipitation being an input in agricultural production influence food and crop production?

8. Do natural disasters affect food production in Pakistan? Are natural disasters influence crop production in Pakistan?
9. Do climate change indicators affect food and crop production in Pakistan, particularly?
10. Can climate change having a close relationship with agricultural production be a reason for food scarcity?
11. Is temperature one of the major climate change indicators affecting food and crop production?
12. How this study will tell us about the impacts of average changes in climate change indicators e.g., temperature and precipitation on income inequality?
13. Do climate indicators e.g., temperature, precipitation, etc. assert differential effects on the income inequality between developing and developed countries or not?
14. Is there any relationship between carbon emissions and income inequality?

A few preliminary hypotheses are constructed which will be tested in this research. This study tries to extract the surging impacts of climate change on economic growth not only at the global level but also in developing as well as developed economies. Keeping in view the rising level of emissions, it is assumed that there would be any decoupling between climate change and economic growth. Thus, the following 4 hypotheses can be formulated:

H_1: Climate changes have a significant impact on economic performance.

The literature in the recent past explores the relationship between climate indicators like temperature, rainfall, windstorm, sea level rise, humidity, natural disasters, and economic growth by using different macroeconomic indicators e.g., real GDP, GDP per capita, level of income, and employment. The majority of the literature has used only two indicators, namely, temperature and precipitation for the assessment of the economic impacts of climate change (berg *et al.*, 2021; Kakkuhl & Wenz 2020; Barrious *et al.*, 2010; Pretis *et al.*, 2017; Alagidede *et al.*, 2015). This study using most of the indicators of climate change will try to capture the effect of surging climate changes on economic activities as assumed in hypothesis 1 of this study.

The agriculture sector of the economies is the most vulnerable sector which comes under the effect of climate change. Though existing work on this issue is divided into two different argumentative divisions, work on this relationship does not end on conclusive shreds of evidence. In most cases, the impacts of surging climate changes adversely impact the production of the agriculture sector. This study will try to test its second hypothesis which is formulated as under.

H_2: Climate changes do exert impacts on the agricultural production

Rising temperature hampers not only the climate conditions but also affects the health of the employees. It affects the agriculture sector the most with its devastation as extreme changes in climate may affect the growth of crop yields which lowers both production and productivity. Fewer pieces of literature show that climate change indicators may positively contribute to the productivity of the agriculture sector. However, its adverse effects are significant which makes it an alarming issue for policymakers.

The economy of Pakistan is under great threat due to changing climatic conditions. Unfortunately, Pakistan is not an emitter of carbon, yet the country faces many devastating circumstances over the years to climate change. This study will try to investigate another important hypothesis which takes the following form:

H_3: Climate changes have a significant effect on the agricultural production of Pakistan

Climate impacts are not restricted to a few sectors of an economy. They have impacted almost every sector over the years. Its distributional effects are of multiple natures that pose several challenges to the livelihood of humans. Its impacts on economic growth in general and incomes, in particular, cannot be denied. This study will analyze this relationship by formulating hypothesis 4 of the study.

H_4: Climate changes do leads to greater inequality in incomes

The economic assessment of climate change has become a not only challenging but also controversial issue over the years. Most of the attention is paid to the adverse effects of climate change. A study by Dasgupta *et al.* (2021) used the highest-resolution data on economic activity to revisit the association between climate change and economic growth. Cevik and Jalles (2022) analyzed the relationship between climate change and inequality. Climate change has complex and evolving dynamics that make it a defining challenge of current times. Another study by Nyiwul (2021) also explored the adverse effects of climate conditions in Africa and found damaging effects on incomes and social inequality.

1.5 Contributions of the Study

It is pertinent to mention before revealing the contributions of the study that this study is based on data analysis. It follows the theoretical support of the previous research studies. However, it is to the information of the researcher that this study is purely empirical. So, as it's an empirical study, its contributions to the field of research are also empirical rather than theoretical. The followings are the contributions of the study:

Some of the studies have used mean temperature and precipitation for investigating their impacts on economic growth and agricultural production but none of them used minimum and maximum values of temperature and precipitations for investigating the impact of climate changes on economic growth and agricultural production. This study assesses through a comprehensive empirical exercise how the temperature (minimum, maximum) can affect world economic growth, agricultural production, and income inequality. Simply, this study bifurcates which level of temperature and precipitation e.g., minimum, maximum, or mean temperature and precipitation are more influential in affecting the global economic indicators e.g., real GDP, GDP per capita, food production, crop production, and income inequality.

None of the existing studies used the deviations of climate variables from their mean deviations to assess their impacts on agricultural production. These asymmetric effects were ignored by the existing research studies in this area. This study contributes by using this strategy to assess the stress points of agricultural production which are caused due to the deviations of climate variables from their historical means.

Natural disasters in the form of floods, droughts, storms, and sea-level rise can be devastating for economic activities. To the best of our knowledge, existing studies ignored the effects of natural disasters on economic performance. This study is an attempt to investigate the influence of natural disasters on economic growth and income inequality. This attempt would be helpful to combat the future adversity of these disasters and also in the formulation of new climate-related policies.

Sunshine duration is changing around the globe which affects economic activities either by hampering the atmosphere or by boosting it, production of the agriculture sector through affecting the growth of crops, and distribution of incomes. The sunshine effect is of greater importance as due to the increased level of carbon emissions at the global level, hours of sunshine duration at the global level change. This factor was also neglected in previous research studies. This study contributes by bringing this factor into the arena of the climate-economy nexus. Being an unusual indicator of climate change, it may also extend the theoretical basis of the climate-economy relationship for future research.

Climate change can affect the welfare of the masses. It can increase the cost of living and can also cause a decline in the standard of living especially for those who cannot afford to meet the adverse effects of surging climate hazards. Due to an increase in the cost of living, income levels can decrease. This study investigates the asymmetric effects of climate changes on income inequality missed out by the existing studies. These differential effects of climate change surely open new insights into the climate-inequality nexus.

The impact of climate change on poverty in general and income inequality, in particular, is a new area of research. None of the present studies so far empirically analyzed this important and emerging issue at the global level. This study tries to provide new information on the issue of the climate-inequality nexus through the empirical assessment that how the hazard of climate changes is becoming an emerging cause of the unequal distribution of income among the masses throughout the world. How the global welfare in the form of increasing inequality in incomes is distorted by the persistency of the changes in climate.

Carbon emissions not only exert an influence on economic activities but also on the distribution of incomes. This study contributes by examining the symmetry and asymmetric effects of carbon emissions on income inequality. None of the studies separately investigated the impacts of climate change on food production, crop production, and income inequality in one study. This study made it happen for us to compare the differential effects easily. Through this comparison, it becomes much easier for researchers to distinguish the effectiveness of climate change on agricultural production and income inequality between developing and developed economies. Specifically, this study shows a clear picture that who is more vulnerable e.g., developing economies or developed ones.

Sea level pressure is a new indicator used in this study that is never used by any existing studies. This is the surface temperature of the sea that affects the sea level. This indicator works in the opposite direction of what the sea level rise does. Falling sea-level pressure indicates a rising sea level which can prove devastating for economic performance, whereas, rising sea-level pressure indicates a lower sea level. Although sea level pressure may not directly affect economic activities, however, its indirect effects cannot be denied at all. The inclusion of a new indicator of sea level pressure may increase the worth of this study.

Climate does not remain similar worldwide. The climate is different in Polar Regions as compared to equatorial regions. The impacts can change considerably from one continent to another and also from one region to another. Existing studies ignored this difference. It is necessary to investigate its differential effects on different continents and regions of the world.

This study also contributes by highlighting the differential effects of climate change on the economic performance of 6 continents and 3 selected regions[4].

This study can help devise policies to minimize the adverse impacts on developing economies in particular and the world economy in general. Besides, this study can be proven too helpful to adopt the policies of adaptation and mitigation based on its outcomes and policy recommendations. Better policy measures can be taken to minimize the detrimental impacts of climate change keeping the recommendations of this study upfront.

1.6 Significance of the Study

This study broadens the subject matter of "The Economics of Climate Change". It opens new horizons in the sphere of the climate-economy nexus. Climate change has become one of the emerging and important areas of concern for economists and meteorologists during the last few decades. This study paves the path for the researchers, especially of developing economies to conduct their research work to examine the nexus between climate-economy. It authenticates the perception that developed countries are less likely to be affected by climate change although their contribution to emissions is significant. The current analysis tries to ascertain the severity of differential impacts of climate change on not only the world economy but also by separating the analysis into two parts i-e developing and developed economies. This study tries to assess the important economic impacts of climate change, which hinder the process of economic growth globally.

This study brings the multi-dimensional differential effects of climate change into consideration which does not only hamper economic growth but also agricultural production.

[4] Continents include Asia, Europe, Africa, South America, North America, and Australia, whereas, selected sub-region are South Asia, Central Europe, and Western Africa.

The devastations of climate change are not limited as revealed by this study that how it boosts the gaps in incomes of the masses belonging to the rich and the poor economies. Unlike other studies, this study investigates the significance of different climate impacts on income inequality, which may open a new area for researchers. It will also develop a positive attitude among meteorologists in general and economists in particular to devise new mitigation and adaptation policies for tackling this hazard in the future. Policymakers can extract positive outcomes from the study for devising policies to combat climate-related issues. Their interaction, cooperation, analysis, discussion, interpretation, and policy formulation can mitigate socioeconomic climate adversity. To sum up, this study is a comprehensive analysis for the researchers which highlights the climate-economy nexus in a better way compared to existing studies.

1.8 Structure of the Thesis

This thesis consists of six chapters. The first chapter of this desertion starts with a detailed and brief introduction to the climate and the economic nexus. It discusses the issue of climate change in detail and also portrays the influence of climate change on economic activities already highlighted by the existing studies. This chapter does not only include an introduction of the thesis but also includes objectives, research questions, problem statement, the significance of the study, and contributions of the study.

Chapter 2 includes a detailed discussion of the theoretical background. This chapter tries to cover most of the relevant past theoretical research work comprehensively done on this topic. After background, the theoretical literature is also presented before concluding the chapter. Chapter 3 of this thesis includes the empirical review of existing literature. This section tries to bring most of the existing research work relevant to this study into the discussion. It discusses most of the existing research work related to climate change, economic growth, agriculture production, and income inequality. Besides, this chapter also uncovers the existing gaps in the literature.

Chapter 4 of this thesis consists of data and methodology. This chapter not includes the data sources but also presents the theoretical and empirical models of the study. Chapter 5 consists of results and discussions where all the estimation results and their interpretation are presented, whereas, Chapter 6 concludes the thesis, points out some limitations, and suggests policy recommendations. It will also share policy implications and ways for future research.

Chapter 2
Theoretical Background

2.1 Introduction

This chapter introduces and explains the theories, which describe why the research problem under study exists. For deep empirical analysis, it is imperative to design the theoretical framework. This chapter is important as for the enhancement of empiricism and rigor of research theoretical and conceptual frameworks play an important role. In other words, these two frameworks bring life to research work and make it easier for readers to ascertain the academic position of the research work. This chapter is designed to present different theoretical footprints, which support the empirics of the study. We present the theoretical work in the form of theories, hypotheses, and a few theoretically motivated empirical studies that are relevant to our study. These frameworks not only stimulate this research study by ensuring knowledge extension but also provide impetus and direction.

2.2 Theoretical Literature

2.2.1 Ibn Khaldun's Muqaddimah (Gate, 1967)

The main focus of the work of Ibn Khaldun was on the direct impact of climate and geographical conditions on human life. In his writing, Ibn Khaldun divided the world into seven regions. He considered one of the seven regions a central region. It is the fourth region which is located in the center of the six regions. According to him, geographers have divided the world by drawing a line called the equator line which distinguishes the world into the north region and south region. His division of seven regions was taken place from south to north. After the division by geographers, the north region was a region having more land, whereas the south has more seas.

That is why the north has more population. According to Ibn Khaldun, after the division into seven climatic regions, the fourth part is considered the central one. As we move away from the center, the facilities of life start declining. It is pertinent to mention that as per the advocacy of Ibn Khaldun, the most important element which makes life tough is the weather temperature. The central part which is the fourth part of the distribution has warm weather, whereas coldness and hotness are higher in the regions located around the center. Extreme weather may become a hindrance in the way of prosperity. So, for the establishment of civilization, it is important to consider how much the weather and climate allows humans to live. According to him, due to the presence of suitable climatic conditions, the best people in terms of colors, sizes, personalities, religions, and moralities are found in the central region of the division. The amenities of life i.e., houses, food, clothing, and profession are available and developed for the people of region four. Specifically, Ibn-Khuldon suggested that natural conditions affect both people and their communities. Climate affects the mental and physical attributes of people around the world.

2.2.2 Montesquieu's Climate Theory

The main driving force behind the need to assess the climate impact on economic and social indicators is Montesquieu's Climate Theory given in his book "The Spirit of Laws (1748)", which states that international differences in political institutions and economic development could be solely explained by temperature differences. Keeping in view the context of global warming, how an economy's sensitivity to fluctuations in temperature remains a crucial question. The starting point of the theory scientifically examines the effects of cold and hot on the "extremities of the body's surface fibers". Through this examination, it is deduced that temperature evokes some specific physical responses from the body. According to the theory, cold extracts the extremities of the body while hot relax these extremities. Simply, the theory says that a climate of colder nature makes men more courageous, vigorous, and strong in response to a physical cause while a hotter climate makes them indolent, slothful, and feeble. The theory affirms the Universality of human nature by showing through demonstration that it reacts when facing different environments in physical terms.

2.2.3 Huntington's Civilization and Climate Theory

Huntington published the book "Civilization and Climate" in 1915. This book includes a few very important topics concerning climate and civilization. One of the important chapters of his book is "The Effects of Humidity and Temperature". According to him, environmental changes and racial determinism are interrelated. He argued that racial differences arise through natural selection propelled by disparities in climate and climate change. He also stated that "both mental and physical energy vary from season to season to well-defined laws". In his book, he also mentioned another book "The Effect of Tropical Height on Men". This book presented its main thesis that the backwardness of tropical regions is due to excess sunlight. The actinic rays beyond the limits of our vision having chemical power when falling on the body of a human are thought to stimulate the cells to greater activity. Huntington was of the view that excess light may be highly injurious to the human body. The main crux of his work was that extreme climate is harmful to humans. A rise in the proportion of carbon dioxide emissions haled from the lungs shows an acceleration of the metabolic processes which consume and break down the tissues of the human body. Specifically, the climate work of Huntington can be divided into three large parts: First, the effects of weather and its changes on students and workers. Second, the effects of climate change on world civilization. Third, the impacts of solar radiation on climate change.

2.2.4 Economics of Climate Change and the DICE Model

William Nordhaus (a Nobel Laureate) is considered a pioneer to start an empirical investigation of climate hazards and their resultant consequences on the economy in the 1970s. He was awarded the Nobel Prize in 2018 for his work "integrating climate change into long-run macroeconomic Analysis". To integrate climate into the economy, Nordhaus created the DICE (Dynamic Integrated Climate Economy) model that is the part of Integrated Assessment Model (IAM) based on Cost-Benefit-Analysis (CBA). The initial point was based on the uncertainties about climate change and carbon emissions. He integrated a climate damage function, an abatement function, and an equation that relates Carbon dioxide (CO_2) and GDP growth. Further, this function also considered the issue that how rises in CO_2 levels lead to a rise in global average temperature. Nordhaus also presented a circular flow that showed the process that how climate change and its effects look like and how policy formulation affects it. According to him, the circular flow growth of an economy affects carbon emissions to rise in the form of heating, cooking, driving, etc. This results in not only the rise of CO_2 concentration but also causes a change in temperature, precipitation, sea-level rise, etc. which lead to climate change. Further climate change imposes economic impacts in the form of lower corn yield, ocean acidification, coastal flooding, etc, the circular flow chart states.

2.2.5 The Classical Growth Theory

Solow (1956), under the umbrella of classical growth theorists, assumes GDP as output, which is produced by using 'production factors'. According to the classical theory of growth, production factors are technology, human capital, and physical capital. This model is extended by the inclusion of ‘natural capital' as an additional factor of production. Natural capital consists of natural resources, ecosystems, environmental resources, and land. It is acknowledged and accepted that nature (ecosystem) plays an important role in the functioning of an economy and its well-being creation (Daily, 1997). Neoclassical economics is considered a dominant approach that uses traditional growth models in long run for modeling the relationship between the natural environment and the economy. In this endeavor, the Solow growth model is much helpful as it captures the dynamics of natural capital and its influence on economic growth (see, Dynamic of natural capital in neoclassical growth model by Kornafel 2020).

2.2.6 The Enumerative and the Dynamic Approach

To assess the impact of climate change on economic growth, two famous approaches are widely used around the globe. These approaches are the enumerative approach and the dynamic approach. The first approach is used to analyze the impact of climate change on economic growth by doing sector-by-sector assessments. Said differently, under this approach, the impact of changes in climate is assessed on sectors, industries, agriculture, tourism, the ecosystem, etc. To estimate the overall effects of climate change on economic growth, the effects of climate indicators are jointly evaluated. This approach uses only one period to assess the climate change impact and ignores the inter-temporal effects. Few researchers used this theoretical approach in their work (Nordhaus, 1994a: Tol, 1995: Fankhauser, 1994). The main drawback of this approach is that it does not address the climate change effects which are long-lasting. The enumerative approach also neglects the importance of the interaction of sectoral impacts termed "horizontal linkages". This approach is mainly based on the usage of computable general equilibrium (CGE) models and techniques of simulations.

This study uses an enumerative approach as a theoretical framework for the analysis to assess the effect of climate change on agricultural production and income inequality. This intent is backed by the reason that this approach is specifically designed for the sector by sector analysis. It is used to justify that the interpretations of our results are within the domain of the theory. The computable general equilibrium (CGE) models in this approach are specifically designed for real economic data and economic theory to extract the shocks and policies in the economy. These models fit data to a set of equations that aim to capture the behavioral response of agents (households, firms, and government) and the structure of the economy. CGE models are grounded in economic theory therefore they can be used to interpret results using economic intuition. These models are more flexible and can be used to simulate a wide range of shocks and policies.

The dynamic approach uses growth models with different specifications by incorporating the climate damage function. This function utilizes growth models for analysis like Ramsey-Cass-Koopmans and Solow-Swan models. These models are widely used for the assessment of climate change's effects on economic performance. Fankhauser and Tol (2005) also used the model of Mankiw, Romer, and Weil (1992), but to a lesser degree. These models depend upon the assumption of a constant saving rate. These studies assert that climate change damages the output of an economy. It has been found by using all these three models that if climate change adversely affects the output, it results in reduced investment levels. This in turn lowers the capital stock and consumption per capita in the long run. The aggregate demand shrinks and GDP declines thereby. This decline in GDP becomes worse when researchers used endogenous growth models as lower investment slows the improvements in the productivity of labor or accumulation of human capital and technical progress (Lecocq and Shalizi, 2007).

This study follows both approaches to some extent to analyze the impacts of climate change on economic growth and its components agricultural production and income inequality. The existing literature also supports this intuition that climate-related studies mostly used these two widely used approaches for the interpretation of the results (Belford et al., 2020; Akram 2013).

2.2.7 The Economics of Climate Change: The Stern Review

The Stern review is considered a landmark study that assessed a wide range of evidence on the effects of climate change on economic costs. It has been considered a very influential report on climate change. The review has used different techniques to investigate risks and costs. According to this review, climate change can exert serious effects on development and growth. Climate change is a market failure which is a unique challenge for economics. The review further indicated that GDP at a global level may decline by 5% each year due to climate change. This damage to GDP may reach 20% or more if timely steps are taken to deal with climate change issues. The review also pointed out the potential effects of climate change on food production, water resources, health, and the environment. The impacts of climate change vary across the globe as they are not evenly distributed. Due to this uneven distribution of impacts of climate change, developing countries suffer the most and earlier as these countries have fewer resources to cope with surging climate hazards. Climate changes may have fewer serious implications for developed countries but a higher increase in temperature than expected is more likely to be very damaging for the developed economies, the Review stated.

2.2.8 The Limits to Growth Theory

The era of the 1970s is considered the "golden age" of rapid economic growth in the West, which was uniquely proposed to keep focused on the "limits to growth". According to the limits to growth theory, there are five main factors that determined and influenced economic growth, i.e., food supply, population growth, industrial production, natural resources, and pollution. It is revealed in the theory that population growth leads to an increase in the demand for food, whereas economic growth leads to the use and results in depletion of natural resources which are non-renewable. The growth also leads to increased environmental pollution. All of these factors are necessary for exponential growth. This report (Meadows *et al.*, 1983) concluded with some vital points. According to the authors of the report, if current growth trends in industrial, population, food production, and resource depletion continued, the limits to growth will be reached sometime within the next century. Most of the consequences due to the persistence of these current trends in factors may bring an uncontrollable and sudden decline in industrial capacity.

2.2.9 Environmental Kuznets Curve (EKC)

This hypothesis investigated the quantitative relationship between per capita of pollutants and economic activity. It refers to and exhibits an inverse U-shaped relationship between per capita CO_2 emissions and economic activity usually measured in terms of real per capita GDP and real GDP. This hypothesis is developed by Simon Kuznets (1955) a Nobel Prize winner who postulated that an inverse relationship exists between the degree of income inequality and the level of economic development, which is presented during his presidential address to the American Economic Association (AEA) in 1954.

The theory postulates that up to a certain point, per capita income and environmental damage increase in the same direction i.e., an increase in GDP results in an increase in environmental damage. After reaching the turning point, the relationship becomes the opposite.

The increase in GDP per capita results in less damage to the environment (Dinda, 2004). It is worth mentioning that there is a common point in the existing literature that environmental damages occur at the early stage of economic growth but after a certain point, this situation improves.

2.2.10 Brundtland Curve Hypothesis (BCH)

EKC is not the only curve that explains the relationship between environmental degradation and economic growth, the Brundtland curve hypothesis is another curve that highlights the environment-growth nexus. Contrary to EKC, this curve is U-shaped. The Brundtland Curve Hypothesis reveals that as poor countries lack in prioritizing environmental wellbeing, their poverty leads to more damage to the environment. The growth of an economy increases with the decrease in environmental damage. However, after reaching the turning point, environmental degradation increases with the increase of economic growth. According to BCH, the increase in production in an economy is as damaging to the environment as the problems initially caused by poverty. It is also indicated that how the level of damage to the environment is only possible when economies have the resources to invest in the green, innovative production process to reduce the levels of pollution. Environmental-friendly technology can reduce environmental degradation and economic growth can positively affect the environment. Green development can occur if countries' willingness to pay for a cleaner environment increases (Larsson *et al.*, 2011; Field and Field, 2013).

2.2.11 Environmental Daly Curve (EDC)

In 1973, another ecological economist Daly presented his hypothesis "The Environmental Daly Curve (EDC) Hypothesis " in his writing "Towards a Steady State Economy". The hypothesis states that green technology is not the solution to environmental degradation. The usage of natural resources can be a better way to reduce degradation instead of relying on green technology. The EDC indicates that production increases in economies over the years resulting from innovation and human activities do not reduce pollution. This process does not countervail the usage of natural resources which are scarce. This, in turn, leads to overall climate damage. When countries have ample wealth and resources, they can incentivize environmental damage but it is said that damage already happened to the global economy cannot be reversed. So, economic growth and environmental damages move in the same direction. More damage to the environment may lead to more economic growth. The EDC indicated that a rise in GDP per capita results in more damage to the environment due to an increase in output. EDC simply describes a positive relationship between economic growth and environmental damage. Environmental degradation will increase with the increase in economic production no matter the willingness of policymakers and citizens (Daly and Farley, 2004).

During the mid-1990s, several theoretical arguments were developed to express the linkage between environmental degradation and economic inequality. Torras and Boyce (1998), Boyce (1994), and Borghesi (2006) proposed the "equality hypothesis" which exhibits a positive association between climate and inequality while few studies kept their focus on the emission-inequality relationship and reveal a negative relationship between the two factors (Scruggs, 1998; Ravallion *et al.* 2000; Heerink *et al.* 2001). Few studies also show that the marginal propensity to emit cannot remain stable over the years. They express the income-emission relationship and come up with the argument that marginal propensity to emit (MPE) fluctuates as income changes (Heerink *et al.* 2001; Ravallion *et al.* 2000).

2.2.12 Inequality and Pollution Nexus by Blackburn and Chivers (2015)

An important contribution from the existing literature as a theoretical framework is the model developed by Blackburn and Chivers (2015) to assess the nexus between income inequality and pollution. According to the study if the agents do not inherit sufficient human resources from their forefathers then they will not invest in risky activities. This condition leads them to leave lower resources to their offspring, bringing more persistence in income inequality. They also showed pollution has detrimental effects on output. It increases the losses of agents as the return on investment in human capital is reduced. Thus, more damage caused by pollution leads to greater inequality in incomes as agents' investments are reduced.

2.2.13 Other Theoretically Motivated Studies

To investigate the climate-economy relationship, most of the existing literature showed that using GDP as a function of variables of climate change is an appropriate way of modeling. According to Hanseler and Schumacher (2019), changes in climate affect components of production like labor, capital, and total factor productivity (TFP). This impact is similar to GDP too as these three components exert a positive impact on GDP. Weather changes influence the well-being and health of people. Extremely hot weather conditions are well-documented to have adverse effects on the health conditions of the people as well as the productive capacities of the working people (Kjellstorm *et al.*, 2009). The lack of rainfall may either result in poor harvests or crop failures. Thus, a low level of rainfall leads to lower economic growth (Barrious *et al.*, 2010). Similarly, in countries, where the average temperature remains low, any further decline in temperatures shortens the growth period of plants. The weather changes have more devastating effects on the economies that are heavily dependent on agriculture production. In these cases, bad climate conditions reduce economic outputs, which results in lower TFP in growth models. Hot and humid countries often experience a decline in productivity and growth (Brenner and Lee, 2014).

Several transmission mechanisms cause climate change and economic growth. Some of the models use the environment as an input, whereas, others as a negative by-product (Ricci 2007). Environmental policies generally damage economic performance as these policies are considered additional constraints. However, growth prospects are enhanced as the environment improves due to carbon reduction. The empirical work should capture the dynamic effects of the environment-energy-growth nexus. Some researchers added rainfall as a climate variable beside temperature to assess their impact on economic performance (Berlemann and Wenzel, 2018; Tebaldi and Beaudin, 2016). The literature typically incorporates climate factors e.g., temperature, precipitation, and windstorm by using the conventional Cobb-Douglas production function. The existing literature supports the usage of a damage function while modeling the nexus between climate-economy (Barrious *et al.*, 2010; Dell *et al.*, 2012).

The theoretical aspects of the climate-economy nexus can also be brought under discussion on macro and micro levels too (Abidoye and Odusola, 2015). By covering macroeconomic aspects of this issue, the influence of climate change can be measured on the level of output e.g., the economy's ability to grow and agricultural yields, etc. In this regard, institutions, and investments that affect the productivity growth of economies be emphasized (Dell *et al.* 2013).To incorporate the microeconomic aspects of this nexus, dimensions like conflict, health, cognitive and physical labor productivity, and democratization whose effects are economy-wide must be brought under consideration for analysis (IPCC, 2007a; Burke and Leigh, 2010; Gallup *et al.* 1999; Hanseler and Schumacher, 2019).

One of the studies focused on connections between weather and economic growth. On one hand, the weather may directly affect the production of the agriculture sector, whereas, on the other hand, it also affects the well-being and health of the people. These effects of weather influence the working capabilities of the workers. Crops are directly influenced by changes in weather as these changes directly affect the growth of the crops. The lack of rainfall may either result in poor harvests or crop failures. A low level of rainfall leads to lower economic growth (Barrious *et al.*, 2010). Similarly, in countries, where the average temperature remains low, further decline in temperatures shortens the growth period of plants. Low temperature also asserts detrimental effects on harvests. The changes in weather have more devastating effects on the economies which are dependent on agriculture production. In these cases, bad climate conditions reduce economic outputs, which results in lower TFP in growth models.

The changes in weather influence the well-being and health of people. Extremely hot weather conditions are well-documented to exert negative effects on the health conditions of the people as well as the productive capacities of the working people (Kjellstorm *et al.*, 2008). A rising heat index which is a physiologically grounded measure of comfort dependent on temperature and relative humidity can cause a reduction in productivity. Low productivity eventually leads to reduced economic output. Mostly hot and humid countries often experience a decline in productivity and growth (Brenner and Lee, 2014).

2.3 Conclusion

After presenting the theoretical background of this chapter, we can conclude based on several supportive theoretical footings. This chapter has thrown light based on reliable and historical research work.

This chapter includes the work of Ibn Khaldun's book "Muqaddimah (Gate 1967)". The main focus of the work of Ibn Khaldun was on the direct impact of climate and geographical conditions on human life. This chapter includes the theory named Montesquieu's climate theory, which is presented in his book "The Spirit of Laws (1748)". He discussed the relationship between weather and the functioning of the human body. He argued that an "excess of heat" made the men "dispirited and slothful". This theory is further used to develop the complex interaction of institutions, policies, and geography. Huntington (1915) has also discussed the dominant effect of climate on human affairs. His book includes a few very important topics concerning climate and civilization including an important topic "The Effects of Humidity and Temperature". He argued that racial differences arise through natural selection propelled by disparities in climate and climate change.

The important work of William Nordhaus "Integrating climate change into long-run macroeconomic analysis" and the Stern Review that states that climate change can exert serious effects on development and growth are also parts of our theoretical footprints. Our theoretical background also considered the growth theories i.e., the classical growth theory and limits to growth theory. Solo (1956) and other growth theorists have also something to offer as some theorists have used the extended version of production factors by including the 'natural capital (E) in their analyses. Further, theorists have adopted two approaches e.g. enumerative by using CGE models and dynamic approach by using 'Integrated Assessment Model (IAMs) to assess environment-inequality nexus. From these two approaches, the dynamic one usually favors using Ramsey-Cass-Koopmans and Solow-Swan growth models to assess the potential impact of climate change on economic growth.

Environmental Kuznets Curve hypothesis is a renowned hypothesis developed by Kuznets (1955) to analyze the nexus between climate and the economy further boosting our rationale to research this issue. Environmental Daly Curve and Brundtland Curve Hypothesis (BCH) are two other hypotheses that highlight the relationship between environmental degradation and GDP growth. Political economist Boyce (1994) has also analyzed the issue of environmental degradation and social inequality in his research study. Rezai *et al.* (2018) developed a model, which is based on the Keynesian aggregate demand and labor productivity growth in order to investigate the effect of climate change on long-term economic growth. They showed that due to environmental damages, Green House Gases (GHGs) increase which decreases investment and thereby output and profits. The contribution brought by Blackburn and Chivers (2015) to assess the relationship between inequality and pollution is another motivational source and supports the analysis of the climate-inequality nexus. Similarly, some of the other research work is also presented in this chapter to make its theoretical framework reliable, factual, and stronger.

There are shreds of evidence based on theoretical grounds that climate change affects economic growth, agricultural productivity, and income inequality in one way or the other. The contributions from renowned theorists are used to cement the very basis of this research study. On the basis of theoretical grounds, conceptualization for the empirical analysis is framed through a tree diagram. The conceptual framework uses both climatic and non-climatic variables considered for a comprehensive understanding.

Chapter 3
Empirical Literature

3.1 Introduction

This section includes the existing literature relevant to this study. This section comprehensively discusses the research work already done in the area of the climate-economy nexus which mainly focused on the relationships between climate changes, economic growth, agricultural production, and income inequality. Most of the empirical and theoretical aspects of the climate-economy nexus are brought under discussion to build strong empirical support for this research study. This theoretical framework shows the structural connections and linkages framed to analyze the relationship between the variables of the study in a systematic way. This chapter consists of three main parts. The first part discusses the empirical material about climate and growth relationships. The second part includes the existing comprehensive literature on the issue of climate and agricultural production. The third part is specific to the empirical literature relevant to the climate-inequality nexus. After this discussion, literature gaps are highlighted before concluding the chapter.

3.2 Climate Change and Economic Growth

The literature in the recent past explores the relationship between climate indicators like temperature, rainfall, windstorm, sea level rise, humidity, natural disasters, and economic growth by using different macroeconomic indicators e.g., real GDP, GDP per capita, level of income, and employment. The majority of the literature has used only two indicators, namely, temperature and precipitation for the assessment of the economic impacts of climate change (berg *et al.*, 2021; Kakkuhl & Wenz 2020; Barrious *et al.*, 2010; Pretis *et al.*, 2017; Alagidede *et al.*, 2015).

Temperature variations affect both growth and levels of real GDP per capita. The effects of climate change on different countries are different as every country possesses slightly different climate circumstances. The shocks in temperature are very important in influencing the economic performances of the economies. Berg *et al.* (2021) focused on temperature shocks based on local projections. The shocks in temperature affect growth and the level of real GDP per capita while imposing some restrictions. The main objective of their study was to estimate cross-country response distribution. Three forms of temperature were investigated: global temperature, country temperature, and idiosyncratic temperature. Global temperature and idiosyncratic measures are the decompositions of country temperature. The findings reveal that shocks in temperature are likely to exert adverse effects on the real GDP growth of rich economies while the growth effects for poor economies are positive. Overall, the growth of real GDP per capita is likely to decrease in 42 economies, whereas, it increases in 52 economies. Besides, shocks in temperature also affect the levels of real GDP per capita. Finally, the findings indicate that the changes in temperature are likely to positively affect the levels of GDP in 13 economies and affect negatively in 34 economies. These findings may be helpful in formulating climate change policy.

Recently, one of the studies by Kalkuhl and Wenz (2020) aimed at improving the damage function estimates, which play a vital role in the assessment of climate policy. There is strong evidence that changes in annual average temperatures affect economic production in a non-linear way. The rise in temperature tends to increase regional gross product in cold areas and reduces regional gross product in hot regions. There is no concrete evidence that a temperature increase changes the growth rate of the economy in the long run. However, it is indicated that a persistent rise in temperature will result in a permanent decline in economic production in hot areas. They identified the effects of a rise in mean global temperature by about 3.5°C at the end of this century on productivity growth and levels. The rise in temperature is likely to reduce output by 7-14% in 2100. In tropic regions, production losses may reach 20%. This change in temperature does not significantly affect the growth rate of productivity while affecting considerably the level of productivity. Variations in temperature historically affect the economic performance of poor countries. Temperature and precipitation are the two major and important indicators of climate change that potentially threaten economic growth. These findings may be helpful in improving the representation of climate change effects within current integrated assessment models (IAMs) in two ways: (i) distinguishing climate change effects among growth-rate and productivity effects, and (ii) better quantification of climate damage functions. Most integrated assessment models (IAMs) investigate only the effects of long-period climate changes on economic output but ignore yearly climate shocks, extreme changes, and uncertainty related to weather realizations. The social costs of carbon are more than triple as compared to what the original DICE-2016 damage function suggested as per the usage of the DICE-2016 model damage function for the panel regression.

Espoir *et al.* (2021) investigated the influence of carbon emissions on economic growth. Due to extended human activities, rising global population, and industrialization, energy demand has gone up. The usage of energy resulted in increased greenhouse gas (GHG) emissions. Carbon dioxide (CO_2) which is almost 65% of the total greenhouse gas emissions increased to a record new height of 36.4 million tons in 2018. They tested heterogeneous effects of carbon emissions, temperature, and income across different regimes of climate. Kernel density results show temperature, income, and emissions diversity. An augmented mean group estimator (AMG) is used to assess the long-run relationship between temperature, carbon dioxide, and income. This estimator accounts for financial-economic-pandemic-driven shocks, spillover impacts, and heterogeneous effects of unobserved common factors across countries. The rise in temperature causes a decline in income. The influence of lagged emission levels on the stock of carbon emissions currently is positive and significant in the long run. Similarly, the level of carbon emissions rises due to an increase in income in Africa. The use of fossil fuels increases wealth creation which is the cause of a strongly positive and significant relationship between carbon emissions and income. However, there is no significant long-run influential relationship between temperature and emissions. They also showed that a rise in emissions levels results in extreme temperatures in Sub-Tropical Moist and Tropical desert climatic zones. Further, an increase in emissions raises income levels in Tropical Moist, Warm Temperate Moist, and Tropical Dry, whereas, decreases income levels in Sub-Tropical Moist and Sub-Tropical Dry.

Rainfall potentially affects the economies of the developing world. Shortage or excess rain has both negative and positive economic implications. Historically, the shortage of rain in Africa poses damaging effects on its economies. The economies of Sub-Saharan Africa (SSA) are more vulnerable due to variations in rainfall. However, this evidence is not applicable to other developing economies outside SSA. The shortage of rain in this part of the world has had detrimental effects on its growth rate which is one of the causes of the poor economic performance of the area. Variations in climate in the form of changing rain patterns cause the GDP per capita of SSA to remain 15% to 40% lower relative to the other developing economies (Barrious *et al.*, 2010).

Local institutions play a significant role to influence both economic growth and climate change. These institutions become more important to countries having coastal economies as climate change affects these economies significantly. This surging issue is threatening the economy. The change in climate affects economic growth and its determinants in coastal regions. The estimation results of a study by Hoang and Huynh (2020) indicate that climate change and its various proxies have significantly negative effects on economic performance.

Any climate change produces several impacts on output, investment, institution, and conflict yet there is little knowledge available on whether climate change can affect beyond the level of income by including other channels which are non-economic. Adom and Amoani (2021) explored the impacts of climate-related changes on economic performance and political stability which are considered the measure of growth in productivity. To carry out empirical analysis, different robust checks are used. The findings of their study show that temperature significantly and negatively reduces the productivity growth and economic growth of these countries. These effects also depend on the level of adaptation. The countries having adaptation capacities may observe an increase in economic growth in response to an increase in temperature. However, countries having fewer adaptation capacities have damaging effects on productivity growth and economic growth. They also found that climate change also affects economic growth through the quality of institutions. Thus, it is not the level of income affected by climate change, beyond the level of income, institutional quality is one more channel through which climate change can affect economic performance. The models used for the estimation of the temperature-GDP relationship provide different results which raise uncertainty about their validity.

The difference in econometric models used in climate-growth relationships does not cater to the implications properly. Newell *et al.* (2020) employed model cross-validation to assess the uncertainty of the models. The usages of these econometric models though make it possible for researchers to investigate the effects of climate on growth. Though many of these models employ to investigate temperature and GDP relationship theory does not prescribe any particular estimate able form of the temperature-GDP nexus. To assess the ambiguity of these models, cross-validation is employed to these models. Cross-validation is employed in three aspects: (i) identifying the superior model, (ii) investigating of prediction accuracy of 800 variants of the model, and (iii) characterizing sampling uncertainty and magnitude of the model. The effects of temperature using GDP growth models on the basis of a 95% confidence interval in the range of -84% to 359% and GDP level model using a narrower 95% confidence interval of -8.5% to 1.8% centered around 1 to 3% losses in GDP are assessed. Modeling uncertainty is shown to rival sampling uncertainty. Growth models indicate greater uncertainty of climate impacts than do levels models. Using growth models and GDP levels models, it is revealed that both models provide different results. Hot temperature not only reduces levels of the GDPs of poor economies but also the GDPs of their agriculture sectors. However, there is no significant damaging effect of rising temperature on GDP growth.

The existing literature does not estimate a dynamic model that highlights different aspects of climate change effects on economic growth despite the fact that there is a strong linkage between climate change and economic performance. Due attention is not paid to establishing models which describe the mechanics of long-term growth effects of climate change. Piontek *et al.* (2019) developed a relatively better approach that enables us to study the climate-growth nexus more effectively. Their approach is based on the Ramsey-type growth model which draws five main insights by differentiating transition growth impacts, immediate effects, long-term growth impacts, long-term level impacts, and distributional impacts on factor incomes. These damaging effects allow us to study dynamic impacts on savings, factor allocation, and economic growth. The direct impacts of climate change on output are smaller than the direct effects on capital, productivity shocks, loss of labor, saving rate, and growth of specific factors. Repeated shocks not only cause greater welfare effects but also long-run growth effects. Shock anticipation and endogenous savings showed adaptive effects. There is a strong income effect due to climate shocks which may have distributional implications. This work not only fostered conceptual framework understanding but also opened new ways for the empirical linkages between the study variables. However, the study ignored other production factors like human capital and land. Human capital is an important channel through which climate damages economic growth.

More recently, a study by Giovanis and Ozdamar (2022) investigated the effects of climate change on public debt and fiscal balance in the MENA region. Greater government expenditure and fewer tax revenues result in public debt and fiscal deficits. Climate change affects these two indicators too. The findings indicated that a 1°C rise in temperature causes a decline in fiscal balance by 0.30% in the long run. The short-run relationship between temperature and fiscal balance is quadratic. At lower temperatures, a temperature rise enhances the government budget, whereas, at high temperatures, a rise in temperature reduces the fiscal balance. For comparison, they estimated the threshold mean temperature around 18°C to 20°C. Similarly, an increase in temperature decreases the debt-to-GDP ratio by 1.88% in the long run. Temperature increase reduces the debt-to-GDP rate up to 21°C to 22°C but after this range, the debt-to-GDP ratio starts increasing. They also projected the effects of rainfall and temperature on debt and fiscal balance. They found that in the case of a higher emissions scenario, a fiscal balance may decline between 2.35% and 7.27%, whereas, the value of public debt may remain between 55 to 15%.

It is often hypothesized that environmental conditions affect the incomes of wealthy nations because people have more resources which are also required to adapt to their climate. Deryugina and Hsiang (2014) tested this idea by focusing on one of the wealthiest economies. The basic aim was to investigate the impacts of daily temperature variation on annual income over 40 years. Temperature is usually considered one of the most important indicators of climate change. Temperature is the single climate indicator that plays a significant role in effect the overall performance of an economy. The findings reveal that when the temperature rises by 1°C (1.8°F) on daily basis above 15°C (59°C), it results in a decline in productivity of single days by 1.7% approximately. If the temperature rises above 30°C (86°C) on a single day of the week, it causes a loss of $20 per head. Hot weekends have little influence on income though. The temperature has not changed considerably since 1969, and measures to control environmental changes have been limited. The measure of adaptation takes the form e.g., defensive investment, factor reallocation, price changes, and transfers. The non-linear effects on many components of income also suggest that temperature is a major climate factor that causes a decline in the productivity of an economy by affecting workers and crops. If countries do not accept geographically-determined endowments and choose the daily temperature to maximize output, the yearly economic growth may rise by 1.7% points. If the population does not engage itself in a new form of adaptation, annual growth will go down by 0.06 to 0.16% points due to warm daily temperatures.

Indeed, the existing literature suggests that climate change affects economic performance across the country over time there is little knowledge about the relative effects of variation in climate on economic growth when the global mean surface temperature (GMST) stabilized at 1.5°C to 2°C. Besides, existing variations do not show any significant effect on economic performance when within-year monthly variability of temperature and precipitation is taken into account. However, the effects of temperature based on simulation in temperature of 1.5°C; in temperature under (GMST) exhibit higher warming in different hemispheres. Pretis *et al.* (2017) tested empirically whether changes in climate affect economic growth over time across countries. Those countries that fall around an optimal average temperature have little impact when the nexus between temperature and economic growth is empirically investigated.[5] Both high (and low) temperatures exert a significant impact on economic growth. They also found that the impact of 1.5°C warming is uncertain for most of the countries while 2°C warming shows significantly lower attainment of projected economic growth for most of the countries under analysis. Projections at levels of gross domestic product (GDP) per capita show high uncertainties, with global average GDP per capita projected at a median approximately 5% lower towards the end of the current century fewer than 2°C warming compared to 1.5°C. Poor countries experience greater losses, which can increase economic inequality between countries under study.

The empirical evidence on the climate change issue is not important for the whole world but also is of much relevance to growth and climate policies in developing economies, more so in SSA where levels of income are below acceptable standards. The existing literature also does show any significant effects of climate changes on long-run economic performance in SSA. Climate change can have implications both for a shorter period as well as for a longer period. The effects of climate indicators may differ when different indicators are considered for their impacts on economic growth in SSA. Alagidede *et al.* (2015) used a panel dataset of 18 Sub-

[5] Russia, Finland, Canada, Norway, Sweden, Switzerland, Austria, Poland, UK, USA, Serbia, Belgium, South Korea, Turkey, New Zeeland, Italy, Japan, China, Australia, Iran, South Africa, Jordan, Ethiopia, Zimbabwe, Namibia, Nepal, Brazil, Sri Lank, India, Bangladesh, Saudi Arabia, Sudan, UAE, Iraq, Congo, Denmark, Germany, and others.

Saharan Asia (SSA) on variations in temperature and precipitation for the period covering 1970-2009 to examine the impact of climate change on economic performance.[6] Their study significantly contributed to the empirics of the climate-economy relationship in SSA. They indicate an unanticipated long-run relationship between temperature and economic performance. The findings reveal that a significant decline may be observed in economic activities as the temperature rises above 24.9°C. There is a non-linear relationship between climate change (Temperature and Precipitation) and real GDP per capita. The findings also show that a percent rise in temperature affects economic growth and reduces it by 0.13% in a short period. In the long run, the findings indicate that below a certain threshold level of average temperature, a rise in temperature boosts economic growth but after that threshold level, a rise in temperature affects growth negatively. Given that SSA mostly relies on the agriculture sector for the bulk of economic production, it is anticipated that higher temperatures could reduce agricultural production which may have consequences for the growth of the industrial sector, the creation of a job, and efforts to reduce poverty.

Acaravci and Ozturk (2010) examined the causal relationship between energy consumption, carbon dioxide emissions, and economic growth in Europe. They considered the linkages between carbon dioxide emissions and economic growth as well as environmental pollution and economic growth important in their research work through existing literature on the issue of the emissions-growth nexus is ambiguous and controversial. There is a long-run relationship between GDP per capita and its square term, per capita emissions, and per capita energy consumption in countries (Greece, Germany, Italy, Iceland, Portugal, and Switzerland). However, they found no long-run relationship between study variables in countries (Luxemburg,

[6] The panel of countries includes Burkina Faso, Benin, Cote d'Ivoire, Senegal, Ghana, Mali, Togo, Niger, Congo DR, South Africa, Sudan, Zambia, Zimbabwe, Mauritania, Madagascar, Kenya, Cameroun, and Lesotho.

Hungry, the Netherlands, Sweden, Norway, and the UK). There is a positive relationship between energy consumption and emissions for Germany, Greece, Demark, Portugal, and Italy in the long run. This relationship is positive for Switzerland and negative for Iceland but it is insignificant. Similarly, they found a positive relationship between carbon dioxide emissions and the square term of real GDP in Denmark and Italy, whereas, these effects were found insignificant in the case of Greece, Germany, Portugal, and Iceland. They also found supporting evidence for the existence of the EKC hypothesis for Italy and Denmark. So, there is a long-run bidirectional relationship between most of the study variables towards carbon dioxide emissions per capita in most countries. The short-run relationships between emissions and other variables are mixed. The overall findings showed that policies of energy consumption rationing and carbon emission control are more likely to exert no adverse effects on the real growth of output for most countries.

The review by Stern (2006) was a report on the "Effect of Global Warming on the World Economy" released by the Government of the United Kingdom. This report is considered the largest and most popular report which discusses the issue of global warming and its resultant implications for the world economy. This review has highlighted several effects of surging climate changes on productivity and human activities and also warned about the hazardous impacts of global warming in years to come if proper action is not taken. According to the review, climate change is considered a market failure of the greatest nature. This review reveals that climate change harms food production, water resources, health, and the environment. The main crux of the review in the form of suggestions is that strong early action can minimize the cost of acting late by applying environmental taxes. The review also warns of the potential threat of not taking early action as global GDP may decline by 5% each year in the present and future.

The Stern review also proposes that 1% of GDP per year can be invested to avoid climate change's worst effect.

Natural disasters include floods, droughts, storms, and earthquakes. Natural disasters have serious effects on economic growth and human welfare. These disasters have damaging effects on economic performance. Panwar and Sen (2019) highlighted the serious human and economic losses due to natural disasters. They were of the view that there is limited literature that exists and discusses the relationship between natural disasters and economic growth. The existing literature does not significantly contribute to the study of natural disasters emerging throughout the world and their resultant economic implications which require re-visiting and re-examining of the supporting literature. However, after re-examination of the existing literature, it is concluded that the available literature exhibits ambiguity in it when discussing the effects of natural disasters on economic activities. These different types of disasters have different implications for economic growth. The findings reveal that natural disasters assert diverse effects across economic sectors. These adverse effects are too damaging for developing economies as compared to developed economies. Overall, the estimation results corroborate with a few earlier studies having little deviations concerning the magnitudes and statistical significance of estimates. Policy-makers may concentrate on devising such policies which safeguard both population and physical assets.

Catastrophic natural disasters i.e., floods and droughts adversely affect the short-run economic performance. Cavallo *et al.* (2021) focused on the catastrophic effects of natural disasters on economic performance. Mostly natural disasters damage the economic growth process of developing countries relative to developed countries. These differential effects on the two divisions show that natural disasters' effects on economic performance are an issue of economic development. The severity of natural disasters is determined by the physical intensity of the hazard rather than by mortality. The main focus of the study was on the detrimental effects of natural disasters on developing countries of the world. The relationship between natural disasters and economic growth is an issue of economic development. The adverse effects of natural disasters are damaging to small and poor economies. Besides these macro-level effects, the effects of natural disasters are also adverse for poor households, especially who work in the agricultural sectors of poor countries. When the severity of natural disasters is determined on the basis of mortality, their victims are the poor countries of the world as natural disasters affect the growth of poor economies. Contrary to this, when the severity of natural disasters is determined by the physical intensity of the hazard rather than by mortality, the growth effects are negligible both for developed as well as developing countries. On average, the economic performance of developing economies suffers between 2.1 to 3.7 percent points. While focusing on the poor economies, it is also revealed that poor economies are more vulnerable to the hazardous effects of natural disasters. These outcomes are indicators that the effects of natural disasters are an economic development issue.

The extreme climate conditions are threatening Pakistan's economy by affecting agriculture production which creates the surging issue of food security (Ali *et al.*, 2017). Climate change is treated as a global phenomenon; however, the effects are more widely felt in poor and developing countries. Poor countries are more vulnerable and have less ability to mitigate the negative effects of climate change. Because the majority of developing countries including Pakistan are mostly agriculture-dependent economies, their agriculture sectors are affected the most because of direct exposure to nature. Pakistan faced extreme weather conditions like excess rainfall and flash floods in hilly areas which brought greater damage to the major crops as well as the properties of farmers. It is anticipated on the basis of the current scenario that the above adverse situation will increase as a function of climate change. The extreme climate conditions are threatening Pakistan's economy by affecting agriculture production which creates the surging issue of food security. The extreme climate conditions in the form of maximum and minimum temperature, rainfall, sunshine, and relative humidity persistently affect Pakistan's major crops. The findings reveal that maximum temperature positively and minimum temperature negatively affect the yield of all crops. The impact of rainfall is positive on wheat yield, whereas it is negative for the yield of all other crops. Drought and heat-resistant varieties must be used to improve food security in Pakistan. Government must keep an eye on the availability of a sufficient food supply for the masses to avoid any adverse situations in the future times.

Climate change does not substantially damage the production of the agriculture sector (Greenstone & Deschenes, 2006). There is a growing consensus among researchers that emissions increase due to economic activity cause the climate to change. These climate changes in turn affect economic well-being. The agriculture sector faces most of the adversity of climate change. Climate hazard damages the agricultural sector land of the United States. The variations in precipitation and temperature patterns affect the agriculture sector of the U.S. and thereby affect the profits of the agriculture sector. Due to these climate changes, agriculture profits increase by 3.4% annually. The issue of heterogeneity also creeps in affecting the profit negatively of agricultural production in California by 50%. Most of the crop yields were found unaffected by climate changes. The hedonic approach is not reliable as it produces estimates which are more sensitive to a minor decision about the control variable, weighting, and sample. Overall, the findings are not found in accordance with the view that climate change substantially damages the agriculture sector.

The African region is the most vulnerable region of the world affected by surging climate change. Within Africa, SSA is more prone to climate change where a change in rainfall pattern potentially affects economic performance (Barrious *et al.*, 2010). Shortage or excess rain has both negative and positive economic implications. Historically, the shortage of rain in Africa poses damaging effects on its economies. The economies of Sub-Saharan Africa (SSA) are more vulnerable due to the variations in rainfall but this evidence is not applicable to other developing economies outside SSA. The shortage of rain in this part of the world has had detrimental effects on its growth rate which is one of the causes of the poor economic performance of the area. The variations in climate in the form of changing rain patterns cause the GDP per capita of SSA to remain 15% to 40% lower relative to the other developing economies. The study seems to ignore the issue of omitted variable issues. Policymakers in SSA must pay closer attention to the variations in rainfall and suggest accordingly.

Rainfall is considered an important climate change factor that is closely related to economic growth. Its effects are generally beneficial to areas of countries that generally depend on rain-fed agriculture. Thailand is an upper middle-income economy having a tropical environment although rainfall changes regionally. The level of precipitation in the northeastern and northern regions is rather low, whereas, the southern region has experienced the highest precipitation due to its narrow topography. The variation in rainfall affects the economic growth in Thailand where its patterns fluctuate regionally (Sangkhaphan and Shu, 2019). Variations in rainfall exert differential effects on sectors of the economy. It may assert damaging effects on one sector, whereas, its effects may be favorable for another sector. The findings reveal that rainfall damages provincial GDP growth at the national level. The agriculture and services sectors face detrimental effects of rainfall, whereas, for the industrial sector, its effects are beneficial. Although rainfall damages two main sectors of the Thai economy yet, it is considered vital in poor regions of the country. The results confirm that most of the damages due to rainfall are faced by the poor provinces which authenticate that rainfall as a climate change indicator is too important for the economic growth in Thailand. The modeling of the paper lacks in using the sunshine and relative humidity as other climate change indicators which might be useful for the study.

Poor people face much of the damage brought by climate change due to their geographical locations on the globe. The study by Mendelsohn and Dinar (2006) is considered one of the significant contributions to assessing the distributional implications of climate variations across countries using calibrated climate response functions and predictions about future climate changes in 2100. For the assessment of distributional effects, six scenarios were built and for each scenario, the world population is divided into quartiles in accordance with their GDPs per capita. For each quartile, market impacts are calculated. The findings reveal that the poorest quartile is vulnerable in all scenarios. If the climate conditions are mild, the next poorest and the third richest quartiles will also face damage. Climate change benefits the richest quartile in all scenarios except one. Overall, the richest economies will benefit while the poorest will face a loss due to climate change hazards. Further, the study also tests how the impacts differ in the presence of identical climate conditions and came up with similar findings again where the poor economies were found miserable, whereas rich economies likely benefit. These detrimental effects are concentrated in poor economies because they are located in low-altitude areas having hot climates, whereas rich economies are mostly located in high altitudes with cooler weather conditions. Consequently, the rise in temperature hurts poor countries more compared to rich economies.

Temperature and precipitation adversely affect the economic performance of the South Asian economies. The hazard of climate affects both GDPs as well as sector-wise productivity. Naeem (2012) focused on the climate-economy nexus in Asia which is considered one of the most vulnerable parts of the globe affected by surging changes in climate. Being the most populous region of the world, the phenomena of climate change presents serious concerns to the policymakers of Asia. Likewise the other climate change studies, temperature, and precipitation as major climate change indicators employed for analysis. The findings show that climate change in the form of rising temperature and changing patterns of precipitation poses detrimental effects on economic growth for South Asian economies. This hazard does not only affect the GDP growth but also poses sectorial implications on the productivity of the agriculture, services, and manufacturing sectors. The adversity is high for the agriculture sector compared to the services and manufacturing sectors. Lack of attention to this surging issue leads to considerable damage to the economic performances of Asian economies. Although the share of GHG emissions is small relative to developed economies, adaptation to mitigation strategies is a must for the improvement of climate conditions. Further, persistent decline in economic performance can also lead to poverty. Therefore, policies to control environmental changes are not crucial to the economic well-being of Asian economies but also crucial too for the alleviation of poverty. The findings further highlight the need to analyze the spatial climate variation in Asia.

The persistent changes in climate affect the ability of an economy to grow over time or level of output by affecting the agriculture sector, for instance. There are long-run effects of climate change on economic growth, labor productivity, and investment. Kahn *et al.* (2019) focused on the issue of climate change and economic growth by investigating the relationship across 174 economies from 1960-2014. The distinction and a novel econometric strategy and theoretical growth model are used that investigates and link deviations of climate indicators from their historical patterns to changes in the productivity of the labor and real per capita output. The persistent change in climate change indicators in their deviation forms damages economic performance. The deviation in temperature from its traditional pattern significantly reduces long-run economic growth. The detrimental effects of these climate changes are universal for the examined period and affect the economic growth of all countries e.g., rich or poor, cold or hot. These results were also confirmed through a robust check by using the panel data of 48 states of the U.S. These variations in climate change indicators pose damaging effects to several U.S. economic sectors like agriculture, manufacturing, construction, rental, services, and wholesale sector. The major drawback of the study is the inclusion of only two climate change indicators as independent variables. Due importance is not given to the non-climate indicators in modeling the effect of climate change on economic growth.

Yong (2021) analyzed sea level rise impacts on tourism prosperity. Severe impacts of sea level rise can hamper the tourism industry. The findings revealed that due to the rise in sea level, a 0.95 standard-deviation decline in tourism performance followed a 1 standard-deviation increase in economic losses. So, due to the rise in sea level, the cost of inundation affects economic growth. Bick et al (2021) examined the relationship between rising sea levels and inequality. Urban centers are under threat due to increasing coastal flooding. The effect of coastal flooding on the coastal population does not only hinge on the cost, but on the ability of households to pay for the damages. The damage cost exceeding the discretionary income put extra pressure on a substantial number of coastal populations due to coastal flooding. 50% of the coastal communities face financial instability. These damages revealed that rising seas and rising inequality are interrelated.

It is not easier to understand how agents adapt to a changing climate. This becomes even more complicated in the absence of knowledge about changes in temperature and precipitation (Burke and Emerick, 2015). Researchers have used different empirical projections which are either based on cross-sectional variations in hot versus cold areas to assess the climate-economy relationships (Schlenker *et al.*, 2005; Mendelsohn *et al.*, 1994) or used overtime variations to compare outcomes under hotter versus cooler conditions (Schlenker and Roberts 2009; Deschenes and Greenstone 2007; Dell *et al.*, 2012; Deschenes and Greenstone 2011). The latter approach is preferred over the first one due to omitted variable concerns.

3.3 Climate Change and Agricultural Production

Agriculture is considered an important part of the economy in Asia as it contributes to the economic growth of its countries with a significant share. This contribution is too important for the fast-growing countries of the East Asian region like China, South Korea, and Japan. According to the statistics of the Food and Agricultural Organization (FAO) statistics, the share of the agriculture sector to GDP for the period of 1970-1991 in East Asia has gone down to 19% from 35% while the same share also shows a decreasing trend for South Asian countries as their share of the agriculture sector to GDP fall short from 44% to 31%. This share showed a significant decline for Southeast Asian economies which cut down by almost 50% from 1970 to 1990. Contrary to this, some of the world economies are still heavily dependent on agriculture sectors as their share of agriculture sectors to their respective GDPs is significant yet e.g., Myanmar 53%, Laos 44%, Cambodia 33%, and Nepal 35% in the year 2005.

Pickson and Boateng (2021) examined how climate change affects human welfare. They focused on the hazardous effects of floods and droughts and their implication for food security. Does climate change acts as a friend to food security or does it brings devastation to food security were their issues of concern? According to them, the issue of climate change and its implications for food security is so complex that most of the concerning questions about this nexus are yet to be answered by researchers. They utilized the Sens' slope estimation and the Mann-Kendell test to assess the climate change trends. To investigate the effects of climate change on food security, they employed the Dumitrescu-Hurlin panel casualty test and pooled mean group (PMG) technique for 15 African economies. The findings revealed three aspects: First, there is no long-run robust effect of temperature on food security in Africa. However, extreme temperatures impede the security of food in the short run. Second, there is a bidirectional relationship between temperature and food security, whereas they found no bidirectional relationship between rainfall and food security. Further, they argued that dependence on rain-fed agriculture is suitable for boosting food production in African economies.

Lachand *et al.* (2021) examined the potential effects of climate change on agricultural productivity and production in Latin America and the Caribbean (LAC). They accounted for technological progress as important in the modeling of the climate-agricultural production relationship ignored by previous studies. Technological progress is critical in offsetting the effect of climate change. They found that climate change and climate variability have detrimental effects on the productivity and production of the agriculture sector. Both average yearly and monthly temperatures have adverse effects on agricultural production. These impacts vary across countries and increase over time. The results revealed that a positive relationship exists between changing patterns of precipitation and agricultural production. The results indicated that climate changes significantly affected the production of the agriculture sector and these changes can affect the agriculture sector in LAC countries more severely in years to come. They also found that progress in technology is a vital driver of productivity in the agriculture sector and TFP is the main driver behind the growth of agricultural productivity in the region of LAC.

Ozdemir (2021) investigated climate and agricultural relationships in Asian countries. The productivity of the agricultural sector does not only depend on patterns of rainfall and acceptable temperature but also on the concentration of CO_2 in the atmosphere. Climate change exerts a challenging effect on agricultural productivity. These effects vary from region to region, adaptation, and form of a production system, and their influence also depends upon the dynamic features of climate change indicators. They aimed and focused on the investigation that how climate change affects agricultural productivity in various forms in the long run and the short run in Asia. The findings of the study confirmed that climate change and agricultural productivity have a long-run relationship. However, carbon emissions have only a short-run relationship with agricultural productivity. Though the relationship is positive in the short run, yet, it turns negative which shows that carbon participation in the environment can exert positive effects on agricultural productivity. Nevertheless, both temperature and carbon emissions assert negative effects on the productivity of the agriculture sector in the long run. This trend exacerbates the issue of food security in Asian countries.

Chandio *et al.* (2021) assessed the impact of climate change and financial development on the production of the agriculture sector in ASEAN-4. They used institutional quality, renewable energy, and human capital as moderators. Due to the closer location of these countries, shocks in one country on climate change can affect others too. They used the ARDL approach to analyze the impact of climate change and financial development on agricultural production. The findings revealed that human capital, energy use, and institutional quality have favorable effects on agriculture production, whereas carbon dioxide exerts an adverse effect on agricultural production. They also introduced the interaction effect of renewable energy and carbon emission, institutional quality, and human capital using an augmented model. The findings of the interactional relationship showed that all the indicators significantly offset the carbon dioxide emissions to boost agricultural production in ASEAN-4 countries. Carbon emissions are harmful to the production of the agriculture sector in the ASEAN-4 region. Although studies indicated that agricultural production can be enhanced in the presence of carbon dioxide fertilization effect. The use of renewable energy does not only deal with carbon emissions but also directly affects the production of the agricultural sector. The use of renewable energy can also decrease fossil fuel energy consumption in the agriculture sector.

He *et al.* (2022) examined that credit in the agriculture sector can mitigate the effects of climate change on the production of cereal. They also investigated the effect of global climate change (via rainfall and temperature) on cereal production. They used mechanical forming as an indicator of technological progress combining agriculture credit to assess the mitigation effect of climate change. To investigate the short-run and long-run effects of climate indicators on cereal production, they used the auto-regressive distributive lags (ARDL) model. The estimation results confirmed the existence long-run relationship between cereal production, climate change, agricultural credit, agricultural labor force, mechanical farming, and farming size. The impact of climate change on cereal production is highly significant both in the short run and long run. Temperature decreases cereal production in the long run though this effect is not significant. However, in the short run, temperature significantly reduces cereal production. Rainfall exerts a significantly positive impact on the production of cereal in the long run and short run. Agricultural credit proves beneficial for cereal production as it is used to minimize the adverse effect of climate change on cereal production. These credits can be used for land consolidation and the purchase of agricultural machinery. Similarly, mechanical farming also enhances cereal production in the long and short run. The labor force used in the agriculture sector specifically for cereal production exerts positive effects on cereal production. Farming size enhances cereal production but its impact on cereal production is insignificant in the long run. However, in the short run, farming size significantly and negatively reduces cereal production.

The adverse effect of temperature on the production of cereal is likely to exert detrimental effects on food security. The changes in climate in the form of variations in temperature, rainfall, and CO_2 emissions influence the production of cereal in the selected lower-middle-income economies using balanced data spanning the period 1971-2016. A study by Kumar *et al.* (2021) used three main climatic indicators i-e., average temperature, carbon emissions, and average rainfall to assess their impacts on cereal production. Rural population and cultivated land were used as control variables of the study. The findings of the study reveal that an increase in temperature reduces the production of cereal in lower-middle-income countries while other climatic indicators like carbon emissions and rainfall positively enhanced cereal production. The detrimental effects exerted by the rise in temperature assert serious implications for the security of food. The findings would help the policymakers to focus on mitigating the bad effects of the rise in temperature and devise strategies to boost the adaptive capacity of the farmers to raise the production of cereal in low-income economies where a majority of the population consumes cereal crops. This issue is important as cereal is a staple food for the majority of households. They stressed that governments should implement programs and policies to increase cereals production in order to ensure food security for millions of poor people facing the hazard of climate change. To sum up, they suggested carrying out adaptation measures to combat the negative effects of climate hazards.

Ahmed *et al.* (2020) focused on how temperature and precipitation as climate indicators affect rice and wheat crop yields. The climatic changes i.e., temperature and precipitation play a vital role in the development of a crop and its growth but show a changing degree of relationship strength by location and season. Estimation using the sensitivity of crop yield to precipitation and temperature at a high temporal scale, e.g., crop phase-specific, exhibits that both rice and wheat crop yields are too much sensitive to the reproductive phase of temperatures For devising adaptation strategies to ensure water and food security, it is important to accurately estimate the effects of climate changes on crop yield in river basins of South Asia. These changes in climate pose significant impacts on the yield of crops in this region. Climate variability affects crop yield in the river basin areas of South Asia. The findings show that a 17-55% variation in rice yield and a 27-72% variation in the yield of wheat is the result of changes in temperature which are significant statistically. The variation in precipitation results in a 75% variation in rice crop yield while a 39% variation in wheat crop yield in the absence of irrigation facilities. Crop yields showed stringer significant effects of climate variability as temperature significantly and negatively affect them while precipitation exerted positive effects on the yields of these two crops during the reproductive phase. The yield of crops in river basin areas can be enhanced by adopting valuable mitigation measures.

Considering indicators influencing the yield, it is investigated that either the mean and variability of climate indicators statistically determine the yield or not. Technological progress also statistically influences yield with a non-linear effect. Moreover, farm-received labor and price in the past year also affect production. Pipitpukdee *et al* (2020) have examined the influence of change in climate on yield, production, and land use by using panel data spanning 1989-2016. The study employed a generalized method of moment (GMM) by using the instrumental variable method and spatial regression. The findings showed that due to the increased demand for residential needs of the population, harvested area decreased. The findings showed an inverted U-shaped association between temperature and yield. Further, they showed that changes in climate, technology, and extreme events significantly influenced the yield. According to projections of the study, yield, and harvested area decreased to 2.57-6.22% and 12.49-16.05% from their baselines. These declines may result in a decrease in the production of about 14.74%-21.26% from its baseline. It is imperative to raise voices and awareness of the severity of climate variability's effects on production and yield.

A study by Ray *et al.* (2019) revealed that climate change already affected world food production. Crop yield is projected to decline under future climate change conditions. It is also revealed that current effects on a diversity of crops sub-nationally and implications for the security of food remain ambiguous. Crop yields may decrease in the future due to extreme existing weather conditions. Although the current impacts of climate change are unclear yet, it is clear from the past literature that changes in climate pose damage to the production of food. To assess a clear current situation, linear regression is used to assess the potential effects of changes in climate on top ten crop yields like maize, barley, rice, oil palm, sugarcane, soybean, wheat, etc. The findings show different effects and consequences for different crops and regions of the world. For example, the changes in climate bring a decline of 13.4% to the production of oil palm while enhancing soybean production by 3.5%. The results of the study reveal further that effects for Latin America are positive while for Southern Africa, Europe, and Australia, these effects are negative while mixed results are found for Northern and Central America and Asia. The yields of crops across Sub-Saharan Africa (SSA), Australia, and Europe had generally decreased due to climate change, though few exceptions exist. In nearly 50% of the food-insecure economies, the availability of estimated caloric decreased over the years.

Ogundari and Onyeaghala (2021) highlighted the effects of climate change on agricultural productivity in Africa. Rainfall and temperature are the two major climate change indicators included in the model. These two indicators can influence TFP growth differently. The model of their study includes other confounding variables like capital intensity, education, and arable land. The findings reveal that agriculture TFP levels are converging over time in Africa, though the rate of convergence is slow. The findings also show that temperature does not affect TFP growth, but rainfall significantly increases it. The effect of compounding variables is positive for TFP growth. Ortiz-Bobea *et al* (2021) focused on the anthropogenic effects of climate change on the growth of global agriculture productivity. The effect of anthropogenic climate changes on productivity growth has not been quantified historically. The weather changes affect the TFP of the agriculture sector. The findings show that global agriculture productivity goes down by about 21% after 1961 due to anthropogenic climate changes. The effect is more harmful to Latin America, Africa, and the Caribbean where the decline goes up by about 26 to 34%.

Climate changes have far-reaching implications for the security and availability of food. Climate changes above and below average levels can affect food availability and security. Lobell *et al* (2011) anticipated that climate changes affect food availability in the future. It requires observing and understanding the impacts of environmental changes to date. The findings show that temperature tends to fluctuate from 1980 to 2008 by 1 standard deviation above the average level except in the United State of America. This variation in climate may lead to the effect of four crops which are the largest crops produced globally. The results show that due to an increase in 1 Standard Deviation temperature, world wheat and maize production declined by 5.5 and 3.8% respectively. The winners and losers in the case of soybean and rice production balanced out. The results of the study also indicate a decline in the productivity of yield in the presence of technology, CO_2 emission, and other related factors due to climatic changes in some of the countries.

Kim *et al.* (2009) showed that climate change is posing a serious threat to agricultural production in China. The change in climate asserts detrimental effects on irrigated land and agricultural production in the long run. Agricultural production and livestock farming is projected to be impacted considerably in the future. Three major crops rice, wheat, and corn's productivity will be on the lower side due to climate change hazards. The agriculture sector production in China is expected to decrease by 5 to 10% by 2030. The yield of these three crops is expected to decrease by 37% during the current century. The decline will surely affect the food supply and security in long run. Climate change mainly affects irrigated land which is 47% of total cultivated land in China. It is also shown that 67% of the food production comes from these irrigated land areas. They found that a 1% decline in moisture exerts a pressure of more than 1% on irrigated production areas. It is a serious impact on the food productivity of China. The findings revealed that it is not the irrigated land that is affected by climate; it is frigid crops in Northern areas of China that will suffer considerably. The findings further showed that drought will also be a cause of low food productivity in China.

Kang *et al.* (2009) focused on water, climate, and crop yield models to assess the impact of climate change on crop productivity. Climate change decreases the availability of water and the yield of crops. The effects of climate hazard change with change in the area. The location and latitude of an area are important as the influences of climate change concerning the latitude of a location. The study examined by making some projections using more than one climate model. Intensive irrigation may be a cause of the expansion of cultivated land in the future, which will increase crop production. The projections showed different levels of yield production in various areas affected by climate change. In some areas, crop production may increases while it may decrease in some regions of the world based on the latitude of the regions. The model results also show that an increase in precipitation will boost crop production. It is also shown by results that an increase in temperature and variation in precipitation is more likely to reduce water availability and crop yield ahead. It is further projected that if irrigated land area is increased, productivity will increase but environmental and food quality may diminish.

Balanagarajan and Gajapathy (2018) analyzed the impact of climate change on employees' productivity. Extreme climate changes raise the issue of health among the masses. The urban population of the world can become its major victim compared to the rural population. Besides other sectoral devastations, the health sector is also under its siege. The surging changes in climate have far-reaching consequences for the world economies as climate changes significantly affect the health of humans. Due to global warming, temperature, and humidity increase. This change affects many urban areas as they become more vulnerable due to this climatic change. This change affects the availability of water, drought and heat waves, flooding, and intense storms. All these affect human health and also the health of the working class in different industries across urban areas. The main effete sectors of this climate change are manufacturing, agriculture, and construction. It's a fact that the climate significantly affects human health and also feelings and emotions. The rise in temperature asserts many challenges to the working labor force. It is suggested that knowledge regarding environmental change helps the general public and workers to adopt new adaptation measures to remain healthy and more productive.

The effects of climate variation differ across different crops. These changes may enhance the production of some crops while damaging others. Extreme temperature and varying patterns of rainfall significantly influence crop production in Nepal. The study by Joshi *et al.* (2011) employed time series data to assess the influence of climate changes on major food crops in Nepal. The pattern of rainfall does not change considerably during the period of assessment, whereas temperature increased by 0.7°C, respectively. The yield of a few crops faced climate change effects throughout this period. Maximum temperature and rain in summer enhanced the yield of rice, whereas minimum temperature and summer rain damages the yield of maize and millet. An increase in winter rain and temperature exerts a favorable impact on wheat and barley yields. The need arises to support the agriculture sector of Nepal from the adversity of climate change. To identify which region is more vulnerable due to climate change in terms of crop yield, an assessment of spatial variation in a similar type of study is highly recommended. The drawback of the study is the treatment of the whole country as one basket despite the fact that there exists a huge diversity among the different regions within Nepal. These ecological variations and administrative divisions must be considered important for future studies.

Over the years changes in weather have exhibited serious challenges and threats to the agriculture sector globally, especially in underdeveloped countries. Global climate models indicate an increase in average global temperature between 2.9°C to 5.5°C in 2060, and the production of the crop is highly sensitive and vulnerable to climate change trends. Extreme temperature results in a significant decline in yields of the crop by negatively regulating the crop phenology. Model-based projections of 15 agro-meteorology stations revealed that the duration growth of the sowing-harvesting and sowing-boll opening stages declined significantly, in Pakistan. The rise in temperature in China also changed the sowing and harvesting timings. Furthermore, present findings exhibited that the climate change effect on sowing and harvest time in China was observed 2.16 days prematurely, and also delayed for 8.19, 2.44, and 5.33 days in the 1970s, 1980s, and 1990s. APSIM-cotton quantification showed that the sowing, flowering, emergence, and stages of maturity were negatively associated with temperature −2.04, −1.92, −1.11, and −0.40 days $\circ C^{-1}$ on an average basis, respectively. This study also revealed insight into the adaptation of smart and better production by improving agro-technological services (Arshad *et al.*, 2021).

The issue of climatic change is often linked to different economic variables which have received wide attention during the last few decades. Besides other effects of climate change, its effects on the agriculture sector are not a matter of routine to be ignored. Its effects change with changes in crops. Vegetable oils are important as these oils are an important part of food worldwide. Compared to different vegetable oils available for consumption, palm oil is considered one of the important productive crops having lower production costs and higher yields. However, climate change worldwide asserts a fundamental risk associated with agriculture. Tan *et al.* (2020) examined climate change's effects on the price of palm oil. Palm oil is considered a productive crop having higher yields and less production cost compared to other vegetable oil. Surging issues of climate change such as heavy floods, prolonged periods of droughts, wildfires, rising temperatures, and changing patterns of precipitation affect plant growth. Further, the authors found that there exists an asymmetric relationship between climate change and palm oil. The existence of asymmetries provides insights for concerned agencies to devise suitable agriculture policies to minimize the vulnerability of palm oil production to climate change. The outcome suggests that to combat the expected drought stress and rising temperature, climate-smart policies as adaptation measures can be proven helpful.

One of the studies highlighted the asymmetric effects of temperature on the yield of crops and quality grade (Kawaski & Ochida, 2016). Extreme changes in temperature cause adverse effects on the quality and quantity of the crops. Although both changes e.g., extremely high and extremely low temperatures both adversely affect the crops, however, extremely high temperature proves more devastating to the quality of the crop compared to extremely low temperature which affects the quantity. The findings based on Japanese rice production reveal that the effects of temperature are asymmetric. Extremely high-temperature damages quality, whereas extremely low temperature, makes quantity vulnerable. It is evident from the findings that quality matters a lot more than quantity as climate changes fall heavily on quality rather than quantity. However, mitigation policies can minimize the negative effects of climate change.

Symmetry and asymmetric effects are considered important in climate and agriculture-related research studies. Non-linear ARDL techniques developed by Shin *et al.* (2014), that is the extension of the linear ARDL model, which captures the asymmetry relationships between the indicators both in the long and the short run. This approach also provides a flexible and efficient approach to the transmission of negative and positive shocks in each variable to the productivity of rice. Baig *et al.* (2021) assessed the asymmetric impacts of climate change on rice production in India. Climate change has become a ubiquitous problem that globally gained the attention of environmentalists as it poses harmful effects on the production of the agriculture sector, supply of food and water, and livelihood of the poor population. Rising temperature exerts harmful effects on the production of rice in the long run while its effects are positive in the short run. Similarly, positive shocks in carbon emissions and rainfall result in the decline of rice production both in the short run and the long run. Contrary to this, negative shocks in rainfall have positive effects on rice production.

Climate change has become an important and concerning issue for both developed and developing countries. Besides other damages, a loss to the agriculture sector is a serious issue of concern. A long-run association exists between climate changes and agricultural production as climate changes affected the agriculture sector more than any other sector of the economies worldwide. The effects of climate change differ both in the short run and the long run. Temperature, rainfall, and carbon emissions are the major indicators that affect the production and productivity of the agriculture sector. Warsame *et al.* (2021) focused on the nexus between climate change and crop production in Somalia. The study shows the existence of a strong long-run relationship between variables of the study based on the outcomes of cointegration and causality tests. The empirical results also indicate that rainfall reduces crop production in the short run but enhances it in the long run. Contrary to this, the effect of temperature is adverse both in the short run and the long run. CO_2 emissions do not exert any significant effects on crop production. Similarly, agricultural land positively while agricultural labor negatively affects the productivity of crops in the long run. Policy-makers should devise coherent mitigation policies and also formulate adaptation measures to combat the increasing devastation due to climate hazards.

Climate changes bring both harmful and beneficial impacts to the production of crops. Climate indicators in the form of changing the minimum and maximum temperature, rainfall, sunshine, and humidity affect the yield and cropping area of major food crops. Maximum temperature positively and significantly affects all food crops except rice crops. The effects of rainfall are mixed for food crops. Humidity positively contributes to the yield of crops but negatively affects the cropping area. Sunshine significantly enhances rice yield (Amin *et al.*, 2015). Life on earth is facing the challenge of the ever-increasing and evolving issue of climate change. Recently, a study by Rehman *et al.* (2021) examined the relationship between carbon emissions and climate changes in land use and major agricultural crop production. The environment is degraded persistently as a result of the combustion of fossil fuels and GHG emissions. This degradation also exerts consequences on agriculture production. Rising CO_2 emissions and agricultural production are closely related to each other. The empirical output shows a close association between different crops mainly produced in Pakistan and CO_2 emissions. There is a positive relationship between the major food crops of Pakistan and CO_2 emissions, whereas temperature, precipitation, jawar, rice, and barley have adverse linkages to CO_2 emissions.

Rehman *et al.* (2021) focused on the impact of climate change factors on wheat production in Pakistan. Using panel data from 10 districts, the empirical findings show a U-shaped relationship between temperature and wheat productivity. Similarly, a U-shaped relationship also exists between rainfall and wheat production. Wheat productivity has a quadratic relationship rather than linear towards the average precipitation and temperature during the specific period of cultivation which consists of planting, flowering, and harvesting. The findings also revealed that the usage of fertilizers enhances wheat productivity, whereas humidity reduces it. Climate change and lack of investment cause a reduction in the productivity of the agriculture sector. Shakeel *et al.* (2020) highlight the dwindling growth of the agriculture sector in Pakistan due to insufficient foreign direct investment (FDI) and rising temperature. There exists a long-run causal relationship between climate change, CO_2 emissions, and agricultural productivity. Climate changes and CO_2 emissions both pose damaging effects on agriculture growth in Pakistan in the short run and the long run.

Most recently, another study by Hussain *et al.* (2021) focusing on the climate change issue examined the effect of CO_2 emissions on major fruit production in Pakistan. The ubiquitous and surging issue of climate change in the form of rising CO_2 emissions levels within Pakistan is one of the serious concerns for policymakers. Shocks in carbon emissions lower the productivity of the agriculture sector in general and of fruits in particular. Both positive and negative shocks in CO_2 emissions contribute significantly to the production of fruits either by enhancing or by bringing about detrimental effects. Koondhar *et al.* (2021) studied the asymmetric relationship among CO_2 emissions stemming from the agriculture sector, cereal food production, energy consumption, and fertilizers. Cereal crops are consumed as a staple food, yet over time, cereal production declines considerably due to climate change hazards. The empirical results confirm the causality running from fertilizer and energy consumption to cereal food production. The authors also found a unidirectional causality among the study variables. The negative and positive shocks in CO_2 emissions stem from the agriculture sector, energy consumption, and fertilizers causing cereal food production to change considerably.

The extreme climate conditions are threatening Pakistan's economy by affecting agriculture production which creates the surging issue of food security (Ali *et al.*, 2017). The extreme climate conditions in the form of maximum and minimum temperature, rainfall, sunshine, and relative humidity persistently affect Pakistan's major crops. The surging changes in climate are causing the production and yields of crops. The extreme changes in climate change indicators also proved influential toward the production and yield of the agriculture sector. The findings reveal that maximum temperature positively and minimum temperature negatively affect the yield of all crops. The impact of rainfall is positive on wheat yield, whereas it is negative for the yield of all other crops. Drought and heat-resistant varieties must be used to improve food security in Pakistan. Climatic change is posing harmful threats to the production of different crops and food insecurity across the globe. Rising temperature is one of the major factors which influence crop production in Pakistan. Besides rising temperature, fertilizer and area under cultivation are the other variables which cause the productivity of the agriculture sector to decline. Abbas *et al.* (2021) examined the effect of climate change on the major crops such as rice, wheat, jowar, bajra, maize, sugar cane, barley, gram, mastered oil, and cotton in Pakistan. Rising temperature reduces, whereas, the area under cultivation and fertilizers enhance the production of major crops in Pakistan. Improved seed quality showed insignificant impacts and urged authorities to boost quality research towards the development of climate change-resilient crops.

3.4 Climate Change and Income Inequality

Climate change is projected to adversely affect the economic development of the African economies (Baarsch *et al.*, 2020). Most countries are facing the problem of income inequalities. It is also pertinent to mention that this region is among the highest on the planet that faces greater income inequalities. They examined the effects of climate change on incomes and convergence in Africa. Although this region faces the severe issue of income inequalities, income levels would converge in the region. Three dimensions of risk i-e., vulnerability, exposure, and hazards were used to analyze convergence on the basis of climate-induced damages at the country level. The findings of the study show that the losses related to climate change are between 10-15% of per capita GDP growth due to the poor measure of adaptation. Eastern and Western African countries are more prone to climate changes in the region.

It is also worthwhile to mention that countries having hotter climate conditions are projected to face ever-increasing income inequality if the issue of surging climate is not tackled properly. It is better to use mitigation policies to keep the global average temperature rise below 1.5°C. The deficit of current adaptation must be addressed as early as possible. It is necessary to finance by giving special treatment to these countries to help them cope with adversity caused by climate change which results in income inequality. The risk of instability decreased trade, and mitigation across African economies are other factors that may exacerbate the adverse effects of climate change. Another study by Nyiwul (2021) also explored the adverse effects of climate conditions in Africa and found damaging effects on incomes and social inequality. Over the years, African countries failed to respond to surging climate change threats. The actions pertinent to adaptation and mitigation fall by about 23 percent which results in a 1% increase in social inequality in Africa. It is also evident that countries which are emitting more pollutants are lazy and reluctant to take early actions to reduce social inequality.

The economic assessment of climate change has become a not only challenging but also controversial issue over the years. Most of the attention is paid to the adverse effects of climate change. A study by Dasgupta *et al.* (2021) used the highest-resolution data on economic activity to revisit the association between climate change and economic growth. The basic aim of the study was to investigate the future damages associated with climate change through projections and by using spatial analysis. The findings reveal that the optimal global temperature which maximizes economic activity is 9°C. If this threshold temperature rises by 1°C, it may reduce economic activity by 7.9 percent. Extreme changes in temperature exacerbate the adverse effects of climate change. Similarly, a rise in 1 standard deviation above 9°C results in a decline of mean global economic activity by 1.6%. Due to this decline in economic growth, income inequality rises both within and across countries. The findings further show that due to the decline in mean global economic activity, the global mean Gini coefficient goes up from its historical value of 0.33 to 0.46 in 2100. South America and Asia are the two regions that face most of the vulnerabilities of climate change as income inequality increases in all the countries generally and within these two regions particularly.

The shocks in temperature deteriorate income inequality. Using panel data from 17 APEC member countries, Kim (2021) investigated the dynamic impacts of climate change on income inequality. The local projections method is used for impulse response estimation. Shocks in temperature and precipitation are used as climate indicators to measure within-country inequality. The findings show that temperature and precipitation shocks deteriorate income inequality in the long run. The effects become asymmetric as droughts and heat waves more significantly enhance income inequality compared to floods and cold waves. The existing policies do not effectively reduce the harmful effects of climate hazards. It is also pertinent to mention that carbon pricing/tax can minimize the damaging effects of climate change on income inequality.

Climate changes affect inequalities between economies in two ways: first, due to increased emissions, and temperature rises that cause consequences to low-income countries. This effect of temperature falls more heavily on these low-income countries. Secondly, the cost of mitigation exerts financial pressure on the countries as they lack capital. This issue remains persistent over the years in these countries. Whether and how much decline the recent times' between-country inequalities will persist in the current century is uncertain, and the current projections hardly account for climate indicators. Few scenarios are built that account for the combined impacts of mitigation costs as well as climate adverse effects on inequality. It is worthwhile to mention that the emission pathway also affects future inequalities, whereas, the temperature effect, the costs of mitigation, and their distribution have a lesser role to play. In the majority of the scenarios, among countries inequalities decline in the short run to medium run, but may start rising as climate change effects gradually outweigh the economic convergence which is expected between low-income and high-income economies.

Cevik and Jalles (2022) analyzed the relationship between climate change and inequality. Climate change has complex and evolving dynamics that make it a defining challenge of current times. On one side, the impacts of climate change on economic growth and financial stability attained considerable attention, but on the other hand, the relationship between climate change and income inequality was ignored. The findings showed that surging climate change hazards and income inequality are positively associated with each other. The income distribution is not affected in developed countries; however, climate change significantly affected it in developing economies. This poor performance is mainly attributed to developing economies due to weaker capacity for mitigation and adaptation.

Otrachshenko and Popova (2022) examined the association between weather and income inequality using sub-national panel data. Cold and hot extreme temperatures and precipitation are important indicators that affect economic activity and the distribution of income. The results indicated that extremely hot days cause a decline in GDP per capita. Contrary to this, the hot temperature does not affect income inequality. Poor regions are more likely to bear the adverse effects of surging climate change compared to rich regions. Raise in unemployment, prices, and changes in the structure of industrial employment cause these adverse regional effects. However, it is worth mentioning that extremely cold weather and extreme precipitation have fever impacts on income distribution and economic activity.

Palagi et al (2022) examined the relationship between precipitation and income inequality. Climate changes such as draughts and floods negatively affect societies and economies. The role of rainfall as a climate change indicator is significant as it affects economic activities. Climate change increases income inequality between countries whereas the effects of climate change on income inequality across different groups are not clear. The economies that are heavily dependent upon the agriculture sector observe a significant rise in income inequality due to anomalies in rainfall. The increase in 1.5 SD in rainfall from mean values has a 35 times stronger effect on bottom income shares. The anomalies in precipitation result in higher income inequality in countries mostly relying on agricultural output compared to countries that are less dependent on agricultural production.

Khan and Yahong (2021) investigated the causal association between income inequality and carbon emissions by focusing on ecological footprint. The reduction in environmental vulnerability and income inequality are considered two important features which can cause the target of achieving sustainable development goals (SDGs). Using ecological footprint as a measure of the vulnerability of the environment and carbon emissions revealed and confirmed a causal relationship between economic footprint, income inequality, and carbon emissions. It is worth mentioning that easy access to electricity, foreign direct investment (FDI), and control of population growth reduce income inequality, but they exert detrimental effects on both carbon emissions and ecological footprint.

Damage estimates show whether mitigation cost reduces inequalities or not (Taconet *et al.*, 2021). Considering the estimates having the highest damage, it is more likely that inequalities among economies may rise again, particularly in socioeconomic pathways having the low challenge to mitigation, and also a time when costs of mitigation of estimates are low.

Mitigation may reduce inequalities in less regressive damage functions. It is also revealed that IAM and econometric-based damage functions provide different results which require a division between the two functions showing as they do not only differ in terms of their effect on inequality but also in terms of the aggregate level of damage. The econometrics-based damage functions suggest that climate change is regressive, so, mitigation policies related to climate are key to controlling the increase of inequalities between countries in the future. To sum up, the damage costs and uncertainties connected with socioeconomic assumptions are the main drivers of inequalities in the future.

One of the studies examined the relationship between temperature changes and workplace safety in order to assess their effects on labor market inequality. Park *et al.* (2021) focused on the issue of rising temperature and its relationship with safety-related issues in the workplace. Many production aspects can be responsive to temperature. Temperature variation may pose direct effects on the health of workers that requires costly investments in safety measures to mitigate. Hotter temperatures can be proven harmful both for indoor and outdoor economic activities. Safety measures at the workplace may be a vital measure of non-wage compensation, especially for employees located at the lower end of the income distribution. The relationship affects the level of inequality in the labor market. For instance, higher temperature significantly leads to injuries in the workplace. These effects are persistent in indoor and outdoor activities. These effects are larger substantially for men compared to women, younger versus older employees. These issues are mostly related to employees having lower incomes. Using existing technologies and adaptation measures can be useful to cope with the issue and reduce the risk of climate change damage to the labor market.

More recently, the study of Blanz and Kalkuhl (2022) indicated that climate change in the future could impact wealth inequality through food prices in the long run. They showed that the distributive effects of climate change affect the saving behavior of the public. They addressed the distributive impacts of climate change on agricultural productivity where it brings devastations. The modeling relationship exhibits why and how the households fall into poverty. This relationship allows us to compare the indirect and direct impacts of climate change on inequality in the long run. The general equilibrium effect matters a lot for assessing the distributive effects of environmental-related productivity losses in the agriculture sector. According to them, higher food prices not only increase the cost of living but also a precautionary saving motive. Wealthy individuals can cope with such a situation because of having more resources compared to the poor masses. Rich people cannot only increase their capital income but also their asset holdings. The findings revealed that the distributive impacts of surging climate changes could be more multidimensional and dynamic for developing economies. The findings also indicated that the incomes of people are not only affected by structural changes but also by changing the saving behavior of other people. In such a situation, only rich individuals could increase their holdings of assets due to stronger precautionary saving behavior. All these factors lead to more significant wealth inequality between the rich and the poor. It is worth mentioning that due to climate change, capital and labor in the unproductive agriculture sector can reduce the incomes of poor households and further strengthen the negative effects on poor people.

Burzynski *et al.* (2022) investigated the long-run implications of climate change on inequality and human migration. Global climate change has already exerted observable effects on the environment. These changes are persistent over the years as they are advancing at an unprecedented speed. Many areas of the planet observed not only catastrophic natural disasters but also the hottest July recorded ever, in the recent summer of 2021. Unless a significant reduction in greenhouse gas (GHG) emissions, climate change is highly likely to exacerbate even more in the years to come in the current century. Climate change affects all regions and countries in a heterogeneous manner which is making many areas of the planet less productive, less attractive, and even inhabitable.

The findings showed that rural regions having low latitudes would be most vulnerable due to climate change which can raise the issue of reinforcing inequality of opportunities across the globe. One of the concerning issues that emerged due to climate change is the resultant human migration over the years. They predicted that due to climate change, the working age will increase of migrants of all types from 45-95 million in the coming years of the 21^{st} century. Most of the migrants belong to Asia, Sub-Saharan Africa, and South America. Moderate response to migrants due to climate change; implies that a significant number of migrants will be trapped in trouble and impoverished regions inducing a significant rise in extreme poverty. Given the issue of extreme poverty due to climate change, it is imperative to decrease emissions to control inequality, poverty, and pressure on the healthcare system related to climate change.

Otrachshenko and Popova (2021) documented that both extreme temperature and precipitation have different impacts on regional per capita GDP and the distribution of income. The change in climate is expected to grow more in years to come. Uneven development may take place for the poor and the rich due to intense weather changes in the form of extreme changes in temperature. They found that real GDP declined due to consecutive hot days, whereas, a single hot day was favorable for the pro-poor income distribution of the poorer masses. The findings also revealed that global warming is adverse for both the rich and the poor regions. However, the poor regions are relatively more vulnerable to climate change as they experienced a relatively greater fall in per capita GDP compared to the rich regions. Similarly, due to consecutive hot days, the poor regions experienced a relatively more increase in prices and unemployment. Climate change also hurt the agriculture sectors of the poor regions more as compared to regions having rich people. They do not find any significant change in the share of employment in the agriculture sector of the poor regions.

Yang and Tang (2022) assessed the nexus between climate change and regional inequality by focusing on the effect of extreme temperatures on fiscal stress. They claimed that due to local fiscal stress, climate change leads to regional inequality. Densely populated areas, hot regions, and eastern China are susceptible to climate change. The effects of higher temperature on fiscal stress are non-linear. A fiscal deficit is induced only when the daily mean temperature rises above 32 degrees centigrade. Further, the fiscal deficit is also more sensitive to a higher temperature in other areas that are developed and counties that are performing poorly concerning their fiscal matters.

Hsiang *et al.* (2017) estimated the damages of the economic nature brought by climate change in the United States. This damage is an as important issue to be tackled in the future as per the design of climate change policies. A feasible econometric approach is used to estimate the damages caused by climate change. This approach is a way of integrating climate science, process models, and econometric analysis. This approach is constructed on the basis of probabilities, spatially explicit, and empirically tested estimates for damage of economic nature brought by climate variations in the United States. Due to the damages brought by climate changes to sectors like agriculture, energy, labor, etc., the average temperature has gone up. The rise in temperature by about $1^{o}C$ on average has resulted in a lower gross domestic product by about approximately 1.2%. The results also revealed that this risk is distributed unequally among different sectors of the economy, which has increased inequality among analyzed sectors. It is projected that in the lower part of this century; the poorest countries of the world will face damage of 2-20% of income by a chance of 90%.

Aloi and Tournemaine (2013) formulated a model showing that human capital accumulation as shown by Lucas (1988) is considered the engine of long-run growth. Pollution is considered a source of negative externality asserting adverse impacts on human capital accumulation and thereby reducing growth in the long run. To analyze the issue, workers were divided into two segments i-e unskilled workers living in the areas close to production units and skilled workers who prefer to live away from the production areas to afford the expenses of commuting. Living away from factory areas was just due to the reason that pollution prevailing in nearby areas of the workplace can be too harmful to the health of the residents. There is a consensus that a better environmental policy can mitigate the adverse impact posing threats to the poorer agents for minimizing inequality. This policy may benefit workers with low incomes. They can earn a higher return by investing in human capital when the negative effect of pollution is reduced.

Rising temperature has heterogeneous effects on economic activity, which slows the process of income convergence and boosts inequalities. The rise in temperature asserts impacts on two interrelated transmission mechanisms e.g., crop yield and agricultural TFP. The shocks in temperature and their resultant consequences are problematic for households. These shocks have damaging effects on household growth in the case when the initial consumption of households lies below a threshold. Poor households do not have ample resources as they face liquidity and credit constraints to combat the adversity of climate change. The usage of modern technology plays an important role in bringing down the damaging effects associated with surging climate change on the agriculture sector. However, it depends upon the available resources for bearing the mitigation costs related to climate change. Due to resource constraints, poor households do not have the access to modern technologies which forces them to stick to less risky activities having low returns. Besides, the shocks in temperature do not assert any positive effects on the richest households. Bringing modernization in the agriculture sector and favoring structural changes in an economy are all important issues to consider for reducing the adverse impact of climate change (Letta *et al.*, 2018).

Marx (2018) examined the issue of global warming and its impact on income and inequality. Past studies concentrated on the problem of inequality due to climate change between countries discussing uneven economic effects. It is shown that these economic effects of environmental variables are not only uneven between countries but within countries as well. This study explored the weather effects on the mean level of income and income distribution in France. The study was used to combine the climate data with the data on fiscal indicators collected from weather stations located in France. The study computed the marginal effect for the examination of the effect of weather changes on income. The empirical analysis results reveal that if the temperature goes above 30C, the income level goes down by 0.1% on average. The study also used Regional Climate Models (RCM) to assess the cost incurred due to global warming. The findings showed that due to global warming, the Gross Domestic Product of France hurts. It is estimated that GDP has gone down by 0.1% in the medium run while a decline of 0.3% is experienced in long run each year. Though these estimates seem to be smaller in magnitude but are posing some serious consequences over time if the effect is accumulated on a long-run basis. This study opted to minimize the chance of spurious relations among variables by using Randomization Inference.

Burke *et al.* (2015) examined the influence of temperature on the economic productivity of countries by considering the data of 166 countries over the period 1960-2010. They revealed based on empirical analysis that the countries, which are colder, perform better up to a threshold point of temperature. According to them, the optimal temperature is approximately 13^{O}C. The colder countries' economies perform better up to this threshold level of temperature but after this point, growth starts declining. Economic productivity keeps declining if the temperature goes up beyond 13C. The results showed that the building blocks of economies like crops and workers perform with the highest productivity if the temperature is moderate. They are of the view that the results of the productivity of crops and the performance of workers are at par with the outcomes of previous research studies more or less.

The findings of the study make them able to compute the projected impact of global warming throughout the globe. They found that the variations in climate forced the economies to reshape themselves. The projections show that countries with colder climates perform in better way as compared to the countries with hot climate conditions due to a rise in temperature. It is also projected that due to the temperature rise, the world average income will go down by 23% by 2100. The study further showed that on the one hand, rich colder countries experience a benefit from global warming while on the other hand, poorer countries located in the tropics are hurt. This in turn exhibited and projected that global inequality among world countries may rise further. According to them; rainfall impact is minimal on the world economies. The effect of temperature is considered the main cause of global warming. It is further suggested that with the passage of time, rainfall impact may come into play but for the current scenario, its impact is ignorable.

Skoufias (2011) examined the impact of weather shocks on welfare across Mexico. He has adopted more than one standard deviation from the long-run means approach to express this impact on per capita household consumption. The study findings show that changing weather patterns globally is expected to decrease the effectiveness of ongoing policies to mitigate the impact of climate change. These climate changes in turn raise the vulnerability of households. The results of the study reveal that variations in weather exert both positive and negative effects on the welfare of the household. The results also depict that welfare varies across different regions like North versus Central and South. The welfare also varies for characteristics of socioeconomic like gender and education. These varying impacts of climate change require designing policies that are useful to increase the welfare of the household. These programs may prove useful to boost the capacity of households in rural Mexico and are likely to increase their welfare by mitigating the adverse impacts of climate change.

Dell *et al.* (2009) suggested two new ways to investigate the linkage between climate and income. The first evidence is examined, which is based on cross-sectional information after examining the income-temperature relationship, by using both sub-national and cross-country data of 12 economies. The findings based within the country and even within states located within countries show a negative relationship between income and temperature. This relationship is found weaker for within-country cross-sectional nexus as compared to cross-country relationships. The results are considered important as the estimates are statistically significant and exhibit their economic importance. The results showed that a rise of 1°C temperature exerts negative impacts on municipal's per capita income which goes down by 1.2 to 1.9%. The findings also revealed that omitted country features are not the only cause of the cross-sectional nexus between income and temperature as this relationship holds not only between countries but also within countries. Second, a theoretical framework is formulated for the reconciliation of cross-sectoral effects of temperature with the short-run effect of temperature presented in panel models. The study has built an income and climate panel, which is used to explore how national growth paths balance in the presence of hot and cold weather within countries. Finally, adaptation and convergence factors are used to reconcile the panel and cross-sectional results. The estimates of the study also suggested that almost half of the negative effects are offset by adaptation policy usage.

Galor and Zeira (1993) are considered among the pioneers to model inequality of persistent nature followed by other growth theorists like Romer (1986) and Lucas (1988). They brought heterogeneous agents under analysis by bifurcating them into two dynasties i-e poor and rich. A rich dynasty is assumed to invest in human capital. Due to their investment in human capital, they can earn high wages. On the other hand, poor dynasties are unable to invest in acquiring education, which is the key to future returns on investment. Poor dynasties face hurdles in access to avail financial resources due to their limitations. This discrimination raises the inequality of perpetual nature between the two dynasties. To examine the nexus between climate change and income inequality, Blackburn and Shivers (2015) have introduced an overlapping generation model with no credit market imperfections. They have used pollution functions for examining the nexus between pollution and inequality in income. Pollution exerts negative pressure on production. Without abatement policies, agents hesitate to invest in human capital as it requires greater risk and availability of financial resources. However, applying abatement policies to increase the productivity of human capital and decrease the threshold in human capital can mitigate this effect. Due to the usage of abatement policies, more agents take interest in investment in human capital and thereby reducing income inequality. The Findings indicate a lower level of damage to climate leads to lower income inequality and vice versa.

Damania *et al.* (2019) examined the importance of precipitation for economic indicators by demonstrating that existing literature on the agriculture sector, industry performance, conflict, and health finds a causal relationship between rainfall and economic indicators. And yet, the existing literature has failed to find any statistically significant and robust effect. The relationship between precipitation and economic outcomes is concave which employs that the areas which are dry have greater marginal returns compared to the areas which are wetter. The concave relationship is found mainly in the areas which are mostly dependent upon the agriculture sector. Besides, existing literature focused on the effects of rising temperatures on economic outcomes and ignored the importance of precipitation which can play an important role in influencing economic indicators. Rainfall is equally critical and important when estimating the economic damages caused by climate variations. Previous climate models also significantly diverge on the impact of climate change on precipitation across different regions. Developing economies are more vulnerable compared to developed economies due to changes in precipitation as it significantly affects the aggregate economic activity in former economies. The findings suggested that it is important to include precipitation in climate models rather than focusing on temperature only. The findings also imply that it is not easier to estimate the exact damaging effects of climate change at present and in the future.

Cabral (2014) assessed the effects of rainfall shocks on poverty in Senegal and Burkina Faso by using the Computable General Equilibrium (CGE) model. The results reveal that predicted increase in annual rainfall, poverty in Senegal will increase while a decline in poverty will be experienced in Burkina Faso if rainfall shows a declining trend. Asiimwe and Mpuga

(2007) focused on the implications of rainfall on the income and consumption of households in Uganda. According to them, most of the agricultural production of Uganda depends on rainfall. Due to this dependency, the weather's role becomes too important to consider for its implication on the agriculture sector. They have used the household production model to capture the impact of shocks in rainfall on households' income from farms and consumption expenditure. The data is extracted from the National Household Surveys of Uganda for the period 1992-93, 1999-2000, and 2002-03, which contain household characteristics, income statistics, expenditure records, and response to variation in rainfall, etc. Some Statistical Abstracts are used to draw the data regarding rainfall.

The results reveal that variations in rainfall have a significant impact on the income and expenditure behaviors of the households in Uganda. It is found that an increase in rainfall above the mean level has resulted in a decline in income and thereby expenditure. The study reveals that as 40% of the output is obtained from the agriculture sector of Uganda so, it is important to discuss the implications of variations in rainfall. The study also shows that other factors like education, size of households, and land ownership are important determinants besides rainfall variations. It is further suggested that in order to reduce the variability in welfare and poverty, the economy must focus on education, health care, and related elements of welfare.

One of the existing studies divided European Union (EU) into two groups of countries to investigate the relationship between income inequality and carbon emissions. The reduction in environmental degradation and carbon emissions not only boosts GDP per capita but also causes a decline in income inequality. Cristina and Livin (2020) investigated the relationship between climate change and income inequality in 28 member countries of the EU by dividing them into two groups e.g., EU 15 and EU 13, respectively. Most developing economies are vulnerable to climate change. The EU countries believe in the view that the transition towards zero-carbon emissions will lead to convergence and social inclusion among EU economies. The results of the study show that there exists a difference between the effects of climate change for EU 13, the less developed countries (LDCs), and EU-15, the rich countries.

The EU countries experienced a reduction in carbon emissions which is associated with a lower Gini index that results in increased economic development with a lower level of income inequality, whereas, EU-13 economies still face the issue of high CO_2 emissions that results in reduced economic development and also have higher income inequality. This difference is due to the reason that rich countries (EU-15) have ample resources to combat the damages of climate change by investing in technologies and clean energy to modernize the production of industrial sectors. To ensure a transition toward a green economy and zero-carbon emissions, per capita income, must increase which can also lower income inequality. From the convergence point of view, if we treat EU-15 and EU-13 as one group, the EU will reach the same level of economic development, not otherwise.

Khan et al (2022) analyzed the effect of economic growth, carbon emissions, and political stability on income inequality. To achieve sustainable development, it is necessary to reduce environmental frailty and income inequality. The results revealed that financial development, carbon emissions, and political stability raise income inequality, whereas economic growth significantly reduces income inequality. Carbon emissions and political stability adversely affect income inequality in developing countries while financial development raises it. Zhang and Zhang (2021) examined the relationship between economic growth, transport infrastructure, and income inequality. The results showed a long-run relationship between economic growth, carbon emissions, transport infrastructure, and income inequality. It is pertinent to mention that carbon emissions significantly increase income inequality.

We presented the crux of a few studies in Table 3.1. This presentation mainly covers different past studies pertinent to climate growth and climate-agricultural relationships. A few studies in Table 3.1 also highlighted the climate-inequality nexus. The results of existing studies on the relationship between climate change, economic growth, agricultural production, and income inequality differ due to the usage of different periods, variables, and methodologies.

Table 3.1: Summary of the existing empirical literature on the relationships between climate change, economic growth, agricultural production, and income inequality.

Study	Country/ Region/Data	Periods	Variables	Methodology	No of the Country (s)	Conclusions
Barrios *et al.* (2003)	Developing countries' Panel data	1960-1990	Real GDP, Precipitation	OLS	62	Change in the patterns of precipitation harms growth in SSA. It does not affect all the developing economies under study.
Abraha and Savage (2006)	South Africa	1971-2000	CO_2 Emissions, Temperature, Precipitation, Maize Yield	Crop Simulation Modeling	01	In the presence of CO_2 concentration regimes, temperature affects grain production more as compared to precipitation.
Schlenker and Roberts (2006)	USA	1950-2004	Temperature, Crop Yield	Parametric-Elevation Regression	01	Temperature exceeding 30°C harms yields.
Dell *et al.* (2008)	Global Panel Data	1950-2003	Temperature, Precipitation	OLS, Fixed Effect Method	136	Temperature does not only affect the level of output but also the growth rate of output in poor economies.
Kemal *et al.* (2009)	Global Panel Data	1997-2006	Temperature, Labor Productivity	OLS	111	Temperature significantly and negatively affects labor productivity in all countries.
Brown *et al.* (2010)	------	1961-2003	Temperature, Precipitation	Fixed Effect Method	137	Rainfall positively, whereas, temperature adversely affects agriculture production.
Acaravci & Ozturk (2010)	Europe	1960-2005	CO_2 Emissions per capita, Energy Consumption per capita, real GDP per capita	ARDL Bound Testing Approach	18	There is a long-run positive relationship between carbon emission and energy consumption in Germany, Denmark, Italy, Greece, and Portugal. There also exists a long-run relationship between carbon emission per capita and real GDP per capita, the negative relationship found between carbon emissions and the square terms of GDP per capita of Italy and Denmark.

Table 3.1(Contd): Summary of the existing empirical literature on the relationships between climate change, economic growth, agricultural production, and income inequality.

Ayinda *et al.* (2011)	Africa	1996-2000	Temperature, Rainfall, Agricultural productivity	OLS	01	Rainfall enhances agricultural productivity, whereas temperature hampers it.
Akram (2012)	Asian Region Panel data	1972-2009	GDP, Human Capital, Population growth, Temperature, precipitation, urbanization	Seemingly-Unrelated Regressions (SUR)	16	Temperature, precipitation, and population growth adversely affect economic growth. Urbanization and human capital enhance GDP.
Dell *et al.*(2012)	Global Panel Data	1950-2003	GDP per capita, Temperature, Precipitation	Quintile Regression	136	A % increase in temperature reduces economic growth by 1.1% points, on average. The substantial negative effect of high temperature on economic growth in poor countries.
Balnc (2012)	Sub-Saharan Africa(SSA)	1961-2002	Temperature, Precipitation	Fixed Effect Method and Pooled OLS	37	The calculation based on projection shows that crop yields are expected to increase in 2100 compared to the era of 1960 onwards.
Koubi *et al.* (2012)	Global Panel Data	1980-2004	GDP per capita, Energy Consumption, CO_2 Emissions	Granger Causality Test	---	CO_2 Emission does not affect GDP per capita. Energy consumption does not affect GDP per capita.

Table 3.1(Contd): Summary of the existing empirical literature on the relationships between climate change, economic growth, agricultural production, and income inequality. (Contd)

Akram (2012)	Selected Asian countries	1972-2009	Temperature, Precipitation	Fixed Effect Method and Seemingly-Unrelated Regressions (SUR)	8	Rainfall and temperature exert a negative effect on agriculture production.
Dasgupta (2013)	Global Panel Data	1971-2002	Temperature, Precipitation	Quintile Regression	66	Rainfall and temperature adversely affect the production of maize and rice.
Bozkurt & Akan (2014)	Turkey	1960-2010	GDP, CO_2 Emission, Energy Consumption	Unit Root, Cointegration tests, and Impulse Response Function	01	Carbon dioxide emission negatively, while energy consumption positively affects economic growth.
Hassan *et al*. (2014)	Pakistan	1980-2011	GDP, CO_2 Emission, Gini Coefficient, and Poverty	OLS	01	There is a positive relationship between GDP and income inequality, CO_2 Emissions, income inequality, and poverty and income inequality. The relationship between CO_2 Emission and economic growth, CO_2 Emission and income inequality in the short run, and income inequality and economic growth.
Alagidede *et al.* (2015)	Sub-Saharan Africa(SSA)	1970-2009	GDP, Temperature, Precipitation	ARDL Approach, Panel Cointegration	18	Temperature beyond $24.9^{0}C$ reduces the economic growth of SSA. Temperature and GDP have a non-linear relationship.

Table 3.1(Contd): Summary of the existing empirical literature on the relationships between climate change, economic growth, agricultural production, and income inequality.

Tack *et al.* (2015)	USA	1985-2013	Temperature and yield	Fixed Effect Regression and Graphic Analysis	1	Yield loss was found significant due to low temperature in the fall, whereas, it declined in the spring season due to extreme heat events. The overall impact of climate on yields varies across seasons.
Amin *et al.* (2015)	Bangladesh	1972-2010	Rainfall and maximum temperature	Feasible Generalized Least Square (FGLS)	1	Maximum temperature reduces crop yield and cropping area, whereas, rainfall causes a decline in the production of rice.
Ochieng *et al.* (2016)	Africa	2000,2004, 2007,2010	Rainfall, temperature, and Agricultural Productivity	Fixed Effect Method	1	Temperature rise and excessive rainfall reduce agricultural productivity.
Du *et al.* (2017)	Europe and USA	-------	GDP, Temperature	Graphic Analysis	----	The projected increase in temperature above the optimal has a significantly negative effect on the economic growth of Europe and the USA.
Ali *et al.* (2017)	Pakistan	1989-2015	Rainfall and temperature	Feasible Generalized Least Square (FGLS)	1	Temperature hampers crop yield. Rainfall also harms crop yields except for wheat.
Berlemann & Wenzel (2018)	Global Panel Dataset	1951-2013	GDP, Rainfall	Panel Fixed Effects Method	150	There is a long-run negative effect of the shortage of rainfall on growth in poor and developing countries.
Baarsch *et al.* (2019)	Panel Data	1980-2014	GDP, Temperature, Precipitation	Panel Data Regressions e.g., Fixed Effect Method	51	The climate-induced losses are 10-15% of GDP per capita. Western and Eastern African economies are more vulnerable to climate change.

Table 3.1(Contd): Summary of the existing empirical literature on the relationships between climate change, economic growth, agricultural production, and income inequality.

Mahrous (2019)	East Africa	2000-2014	Temperature, Precipitation	Pooled Fixed Effect Method	5	Temperature adversely affects food security in East Africa, whereas, precipitation and cultivation enhance food security.
Ray *et al.* (2019)	Global Panel Data	1974-2008	Temperature, yields of cassava, yields of maize, and sugarcane	Multi-method Analysis with Statistical Regression	---	Temperature increases the yields of cassava and drought-tolerant sorghum, whereas, it reduces the yields of maize and sugarcane.
Angelis *et al.* (2019)	Pooled Data (Mostly Developed Countries)	1992-2012	GDP, CO_2 Emissions	Fixed Effect Estimation	32	There is a U-shaped relationship between CO_2 Emissions and economic growth.
Sheng & Xu (2019)	Australia	1961-2011	TFP, Drought dummy, Capital-Labor ratio	OLS, Panel Random Effect, Dynamic Panel	1	Droughts have caused an 18% decline in TFP in the agriculture sector.
Henseler & Schumacher (2019)	Global Panel Data	1961-2010	Temperature	OLS	103	Temperature negatively affects economic growth and its factor of production. Climate change is an important driver of world inequality.
Sangkhaphan & Shu, (2019)	Thailand	1995-2015	Rainfall and GDP	Feasible Generalized Least Squares (FGLS)	1	Rainfall significantly reduces the GDP of Thailand's agricultural and services sectors.

Table 3.1(Contd): Summary of the existing empirical literature on the relationships between climate change, economic growth, agricultural production, and income inequality.

Newel *et al.* (2020)	Global Panel Data	1960-2010	GDP, Temperature, Precipitation	Cross-Validation Methods	166	Rising temperature exerts detrimental effects on the levels of poor economy's GDP as well as on agricultural GDP.
Kadanali & Yalcinkaya (2020)	Panel Data	1990-2016	GDP, Temperature, precipitation, and TFP	Panel Two-Stage-Least-Square (TSLS)	20	Temperature and precipitation negatively and significantly affect economic growth.
Chandio *et al.* (2020)	Turkey	1968-2014	Crop Yield, CO_2 Emissions, temperature	FGLS	1	Temperature and CO2 harm crop yield, whereas, rainfall asserts a positive effect on crop yield both in the short run and the long run.
Chandio *et al.* (2020b)	Turkey	1968-2014	Cereal Yield, CO_2 Emission, temperature	ARDL approach	1	Temperature and CO2 Emission exert varying effects on the yield of cereal in the short run and long run.
Ahmed *et al.* (2020)	South Asia	1981-2010	Crop yield, Temperature, Precipitation	----------	7	Crop yield has a statistically negative relationship with temperature, whereas, it has a positive relationship with precipitation.
Cristina & Liviu (2020)	European Union (EU) Countries	2000-2018	Gini Coefficient, GDP, CO_2 Emission	Two-Stage OLS	28	Climate change has varying effects on two groups of EU countries.
Chandio *et al.* (2020b)	Turkey	1968-2014	Cereal Yield, CO_2 Emission, temperature	ARDL approach	1	Temperature and CO2 Emission exert varying effects on the yield of cereal in the short run and long run.

Table 3.1(Contd): Summary of the existing empirical literature on the relationships between climate change, economic growth, agricultural production, and income inequality.

Ahmed *et al.* (2020)	South Asia	1981-2010	Crop yield, Temperature, Precipitation	----------	7	Crop yield has a statistically negative relationship with temperature, whereas, it has a positive relationship with precipitation.
Ashenafi (2021)	Africa	1981-2015	Greenhouse gas (GHG) emissions and income inequality	Fixed Effect Regression and Instrumental Variable (IV) approach	48	Greenhouse gas (GHG) emission has widened the inequality in income.
Warsame *et al.* (2021)	Somalia	1985-2016	CO_2 Emission, temperature, and Rainfall	ARDL Bound Testing Approach	1	Rainfall exerts a positive effect on crop production in the long run but hampers it in the short run. Temperature poses an adverse effect on crop production both in the short run and long run. CO_2 Emissions do not affect crop production significantly.
Kim (2021)	Asia-Pacific Economic Cooperation (APEC)	-------	Temperature Precipitation	Local Projection Method by Jorda (2005)	17	Temperature and precipitation shocks deteriorate income inequality in the long run. Heatwaves and droughts significantly increase income inequality compared to cold waves and floods.
Otrchsenko & Popova (2021)	Russia	1995-2015	Temperature, Precipitation, GDP per capita, Income inequality	Fixed Effect Regression	1	Extremely hot days significantly reduce GDP per capita, while hot days do not significantly affect income inequality. Poor regions are more vulnerable to climate change as compared to rich regions.

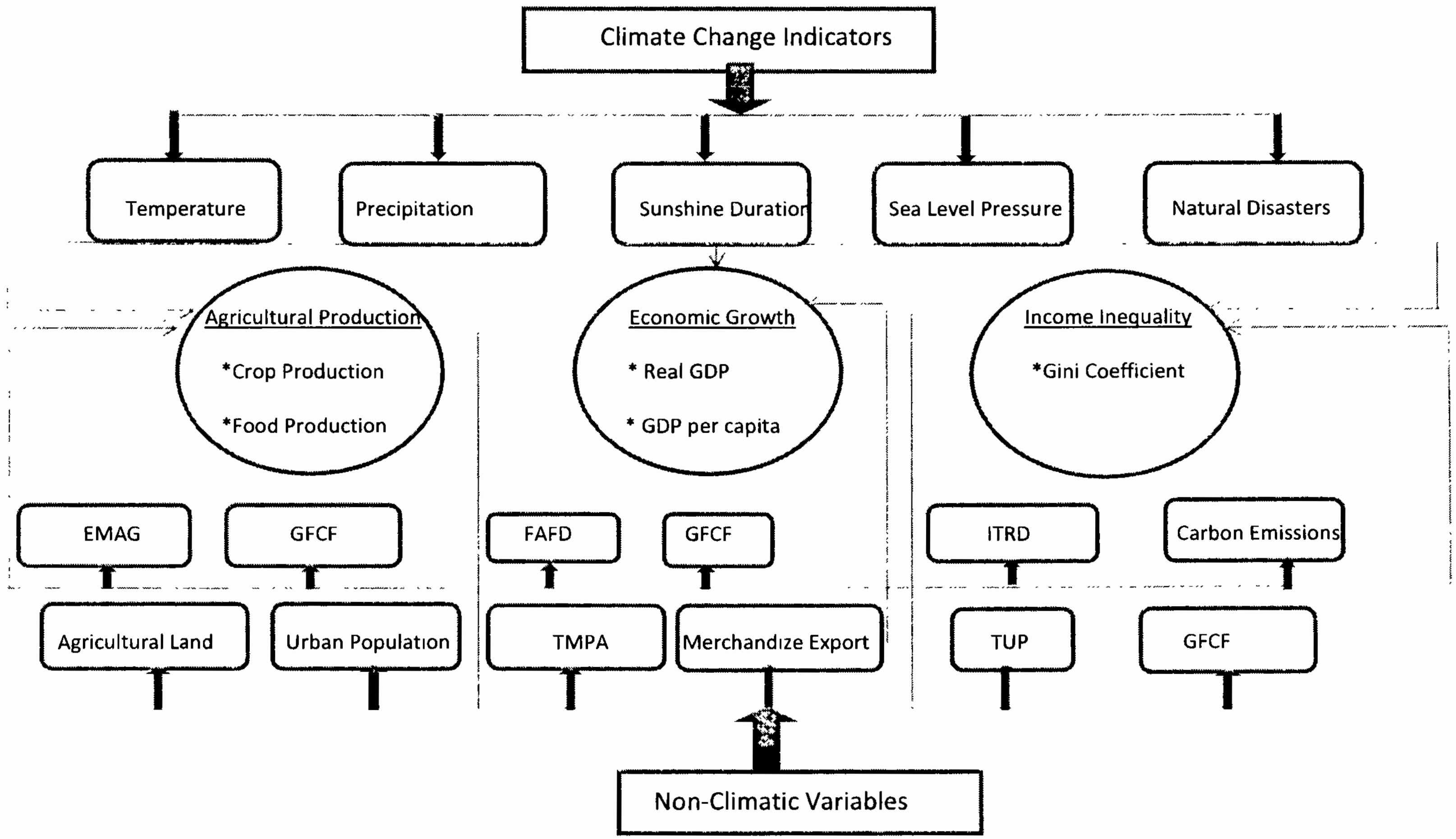
Table 3.1(Contd): Summary of the existing empirical literature on the relationships between climate change, economic growth, agricultural production, and income inequality.

Ozdemir (2021)	Asia	1980-2016	Agricultural productivity, Temperature, Precipitation, CO_2 Emission	ARDL Approach	11	Temperature and CO_2 Emissions adversely affect agricultural productivity in the Asian region in the long run.
Chandio *et al*. (2021)	MENA Countries	1960-2016	Agriculture Production, CO_2 Emission, HDI, Financial Development, Renewable Energy, Institutional Quality	ARDL Approach	4	Climate change adversely affects agricultural production. Human capital, renewable energy, and institutional quality positively affect the production of the agriculture sector. However, institutional quality increases agricultural production conditionally.
Chandio *et al*. (2021)	India	1965-2015	Cereal Production, CO_2 Emission, Temperature, and Rainfall	ARDL approach	1	CO_2 Emissions and temperature reduce agricultural production, while rainfall enhances it. Financial development and energy consumption boost agricultural production. CO_2 Emission and rainfall enhance crop yield, whereas, temperature damages it.
Pickson & Boateng (2021)	Africa	1970-2016	Food Security, Extreme Temperature, Rainfall, Cultivated Area, Population Growth	ARDL Approach	15	Rainfall significantly enhances food security. Temperature hampers it only in the short run.
Lachand *et al*. (2021)	Latin America and the Caribbean (LAC)	1961-2014	Temperature, Precipitation, Annual average TFP, Agricultural Productivity	------	28	0.95% change in output is driven by TFP growth. Climate change reduces productivity by 9.03% to 12.7%.

Table 3.1(Contd): Summary of the existing empirical literature on the relationships between climate change, economic growth, agricultural production, and income inequality.

Magazzino *et al.* (2021)	Panel Data	1960-2014	GDP per capita, Temperature, CO_2 Emission per capita	Pooled Regression and Fixed Effect Method	4	A percent increase in temperature reduces income by 0.39%, whereas a 1% rise in the levels of emissions stimulates income by 0.22%.
Blanz & Kalkuhl (2022)	Developing Countries	--------	Agricultural Productivity, Food prices, Saving ratio	Standard Incomplete Market Model and Engel Curve	92	Climate change affects wealth inequality through an increase in food prices.
Giovanis & Ozdamar (2022)	MENA Region	1990-2019	Temperature, Budget Balance, and Public debt	OLS, GMM, FGLS	19	Temperature changes negatively affect the budget balance and raise debt. They found no significant effect of rainfall on budget balance and public debt.
He *et al.* (2022)	China	1978-2018	Temperature, Rainfall, Cereal Production	ARDL Approach	1	Temperature reduces cereal production, while rainfall significantly enhances it.
Rehman *et al.* (2022)	Pakistan	1975-2019	Fossil fuel energy, Renewable energy, CO_2 Emission, GDP per capita, Electricity Production	ARDL Approach	1	There is a productive relationship between GDP per capita and CO_2 Emissions, renewable energy, and fossil fuel, whereas electricity production and energy consumption have a negative relationship with GDP per capita.

3.5 Conceptual Framework of the Thesis



FAFD=Financial Assistance and Development

GFCF= Gross Fixed Capital Formation TMPA=Trademark and Patent Applications ITRD=Openness to International Trade TUP=Total Urban Population EMAG=Employment in Agriculture Sector

Figure 3.1 Conceptual Framework

The conceptual framework of the study explains the goals and purpose of this research. It shows how the main variables gel together to influence the outcome variables of the study. The upper part of the figure shows different climatic indicators that affect economic growth, agricultural production, and income inequality. Similarly, the lower part of the figure portrays non-climatic indicators which in combination with climatic indicators can influence our dependent variables. It is pertinent to mention that outcome variables include proxy variables like real GDP, GDP per capita in place of economic growth, crop, and food production for agricultural production, and the Gini coefficient for income inequality.

3.6 Projected Effects of Climate Change

Most of the literature supports the notion that climate change is a surging hazard the global Scientists working on climate change issues have modeled the findings of a projected doubling of CO_2 accumulation in the earth's atmosphere. Some of the many predicted adverse effects of climate change highlighted by Stern (2007) and IPCC (2007b) through projections are as under:

- Sea-level rise is a result of melting glaciers and ice sheets combined with seawater thermal expansion which is primarily caused by rising temperatures. The rise in sea level may result in coastal flooding, and loss of wetlands, beaches, and fisheries.
- It can affect economies and businesses across countries as well as across the world.
- Due to human-caused climate change, the capacity of the environment is reduced to support different species. It potentially reduces ecological resilience and ecosystem biodiversity.
- Climate change may increase the incidents of extreme weather conditions as heat waves, cold waves, and patterns of precipitation become less frequent and more intense.

- The survival of an individual organism depends on a specific level of temperature, precipitation, sunlight, and humidity. The extreme change in climate may force them to migrate or delete them. It can affect the functions and health of the ecosystem and the survival of all species.
- Changing temperature and precipitation trends may disrupt the availability of freshwater reservoirs, and water supplies to agriculture and urban areas.
- Human health and well-being also depend on climate. Climate change disrupts ecosystems. Health-related adverse effects and deaths due to the spread of tropical diseases and heat waves. Viruses, bacteria, animals, and plants may migrate in search of favorable climate conditions. Infectious diseases may have an increasing trend due to abrupt climate change. It can affect human health and mortality rates. Cold areas may benefit from climate change but hot climate areas may face immense risks. Climate-sensitive infectious diseases like dengue fever, malaria, and tick-borne diseases will increase due to climate change.
- Acidification and ocean warming can increase greenhouse gas outputs which can reduce the pH of seawater. Acidification may directly affect the development and growth of fish and plankton.
- Extreme climate change such as floods, droughts, and storms can make the agriculture sector more vulnerable.
- Increased costs of air conditioning, loss of forest area and species, etc.
- There will remain uncertainty about the surging effects of climate change as the impacts cannot be understood accurately.

Some positive effects might include

- In cold climates, agricultural production may increase. Climate change lowers heating costs and reduces deaths from exposure to cold.

The potentially positive effects would be experienced mainly in northern parts of the Northern Hemisphere, such as Siberia, Iceland, and Canada. Tropical and semi-tropical areas and most of the rest of the world are likely to face strongly adverse impacts from rising warming. The negative effects of climate change may not only offset the positive effects but also intensified in the future. Following adverse effects due to increasing emissions and higher temperatures are projected by IPCC:

- The Projected Temperature increase in the range of Relative to Pre-Industrial Temperatures 1^{O}C to 5^{O}C will affect food and agricultural production.
- Millions of people will face health-related issues due to the above-mentioned temperature rise worldwide.
- The potential water supply declined by 30 to 50%, especially in the Mediterranean and Southern Africa. Large glaciers in the Himalayas may disappear, causing ¼ of China's population.
- Millions of people may be exposed to coastal flooding and sea-level rise threatens major cities like New York, London, and Tokyo.
- 10% to 50% of land species may face extinction and increased wildfire risk.

There are other less predictable but potentially more adverse and persistent impacts including:

• Disruption of weather patterns, with increased frequency of droughts, hurricanes, and other intense weather events.

• Greenland and West Antarctic Ice Sheets may collapse, which would cause a rise in sea levels by 12 meters or even more, bringing devastations to major coastal cities.

• The sudden climate change like a shift in the Atlantic Gulf Stream, may change the climate of Europe to that of Alaska.

There is uncertainty related to the expected global warming in the years to come. We must keep uncertainties in mind and try to assess the economic effects of global climate change (Stern, 2007; IPCC, 2007b; Haris *et al.*, 2007).

3.7 Conclusions

Most of the literature supports the notion that climate change is a surging hazard the global economy is facing nowadays. Its effects are not only harmful to economic activities at present but also have more serious consequences for the year to come. This study tried to include not only previous historical literature under discussion but also included most of the recent literature pertinent to climate change, economic growth, agricultural production, and income inequality. Existing literature shows that most climate changes assert adverse effects on economic activities. Climate change affects economic performance by affecting employment conditions and thereby incomes of the masses. Numerous studies highlighted the impact of climate change on economic growth using two major climate change indicators. However, the existing literature ignored the asymmetric effects of climate change.

Rising temperature hampers not only the climate conditions but also affects the health of the employees. It affects the agriculture sector the most with its devastation as extreme changes in climate may affect the growth of crop yields which lowers both production and productivity. Fewer pieces of literature show that climate change indicators may positively contribute to the productivity of the agriculture sector. However, its adverse effects are significant which makes it an alarming issue for policymakers. Climate change in the form of natural disasters also exerts damaging effects on economic activities through its effects on the world are not discussed in the literature in detail. Sea-level rise and sea-level pressure are other new indicators that also show their influence on economic growth. Both of these two indicators work in opposite directions. Sea-level rise affects the countries having coastal lines. Most of their economic growth is based on coastal activities. However, its damages to economic outputs are not significant. Existing literature does not show any significant adverse effects of climate change on income inequality as there is no comprehensive study that caters to this issue. Few studies theoretically highlighted that climate change may bring poverty among the masses by affecting economic activities and thereby the incomes of the people. Some studies focused on the emissions-growth relationship but ignored the (a) symmetric effects of carbon emissions on income inequality.

To sum up, the existing literature exhibits that climate changes in the form of changing temperatures, variations in the level of precipitation, natural disasters, and sea-level rise can influence economic growth, productivity growth, savings, human health, employee productivity, political stability, etc. Besides, climate change also asserts effects on the agriculture sector by affecting production, productivity, TFP growth, yields, fisheries, freshwater supplies, food availability, food security, etc. Further, the literature also supports that climate change can influence the levels of inequalities among countries though there is not enough empirical support behind this effect.

Chapter 4

Data and Methodology

4.1 Introduction

This chapter is important because it paves the path of analysis by providing information on research design, data sources, enumeration of study variables, derivations of different unit root and cointegration tests, theoretical framework, empirical models, etc. on the nexus between climate change and economic growth. It also includes a description of MG and PMG estimators. The second part includes empirical models on the topic of climate change impacts on agricultural production at the global level as well as in Pakistan. The third and final part of this chapter includes empirical models to capture the relationship between climate change and income inequality. This part also discusses the fixed-effects and random-effects models.

4.2 Research Design

The research design influences the research outcomes. The design of any study, in general, provides a guide to answering the research questions of the study. According to Bryman (2012), it is a framework for collecting and analyzing data for a research study. The fundamental components of the research design are the data obtaining and analysis approach and the adopted strategies for the research work. This study employs a quantitative research methodology for analyzing and interpreting the data used.

The quantitative research methodology helps to obtain, analyze, interpret, and predict the linkages or relationships between variables (Creswell, 2009). Bryman and Bell (2015) defined the quantitative research approach as "entailing the collection of numerical data and exhibiting the view of the relationship between theory and research as deductive, a predilection of natural science approach, and as having as an objectivist conception of social reality". This research method examines the linkages between numerical variables by using different statistical methods.

Dudovskiy (2016) believed that the quantitative research approach provides clear answers to different research questions by using structured methods of data collection from reliable and well-defined data sources. This approach, he described, also helps in generalizing the findings of a research study using a large sample size. We objectively divided our sample size into developed and developing countries of the world and also into regions and sub-regions for the study to help verify insights about the effect of climate change, adaptation, and mitigation efforts, and to help devise a course of action. The adoption of a quantitative research approach is therefore appropriate for this research study as we seek to collect, analyze and interpret numerical data on climate change, economic growth, agricultural production, and income inequality.

4.3 Variable Selection for the Study

Big data contains thousands of variables pertinent to economic study. It often becomes difficult to manage and handle data and variables efficiently. Due to this reason, the selection of a relevant variable becomes a challenge in research. Proper selection of variables can improve the performance of models in economics. This study also tries to include the most relevant variables by referring to the selection of selected variables in different studies.

The outcome variables of interest in this study are real GDP, GDP per capita, food production index, crop production index, and GINI coefficient are chosen and defined following the existing literature (Alagidede *et al.*, 2015; Sheng *et al.*, 2019; Dell *et al.*, 2009:1012:2014; Kahn *et al.*, 2019; Lu *et al.*, 2019; Ochieng *et al.*, 2016; Almeida *et al.*, 2017; Asteriou *et al.*, 2014). The explanatory variables like temperature, precipitation, flooding, population density, CO2 emissions, etc. are chosen from the studies on growth, agricultural production, and poverty (Alagidede *et al.*, 2015; Dell *et al.*, 2009:2012:2014; Moore *et al.*, 2017; Bozkurt and Akan, 2014). These studies were used to assess the impact of explanatory variables like sea-level rise and sunshine on outcome variables about growth and agricultural productivity (Anthoff *et al.*, 2010; Brown *et al.*, 2018; Ali *et al.*, 2017; Palmer 1919; Malla 2008). This study follows their framework for the selection of these two explanatory variables, e.g., sea-level rise and sunshine.

Carbon emission and GDP are used as explanatory variables by Hassan *et al.*, (2015), GDP per capita and GINI, and literacy rate as independent variables by Torras and Boyce (1998). For achieving one of the objectives, this study followed the framework of Pretis *et al.* (2017) who employed minimum and maximum temperature and precipitation for simulation to investigate the impact of climate change on economic growth.

4.4 Data and Sources

To investigate the impact of climate change on economic growth and agricultural production, this study uses panel data for the period 1980-2020 for 179 countries, and to investigate climate change's impact on agricultural production in Pakistan, the annual data for the period 1960-2020 is used. For investigating the impact of climate change on income inequality, this study used panel data for the period 1990-2020 for 179 counties. The data is derived from World Development Indicators (WDI) of the World Bank (WB), the world metrological Organization (WMO), food and agriculture organization (FAO), International Monetary Fund (IMF), and OECD National Accounts Data Files. The data on GDP (real) and GDP per capita is extracted from the World Bank (WB). The data on annual mean, maximum, and minimum temperature in centigrade as well as precipitation in millimeters is derived from the knowledge portal of the World Bank (WB). The data also includes monthly sunshine duration in hours, mean sea level pressure[7] in millibars which are gleaned from the World Metrological Organization (WMO), gross fixed capital formation in constant US dollars, the value of merchandise exports in US dollars, total numbers of trademark and patent applications of the residents of a country, and total urban population is obtained from the World Bank (WB). Similarly, data on foreign aid and financial development in the US dollar is gathered from IMF data sources.

Further, the data on the food production index (FPI), crop production index (CPI), agricultural land in acres, employment in the agriculture sector (percentage of total employment), and urban population percentage of the total is extracted from food and agricultural organization (FAO). The data on the Gini coefficient is gathered from the World Bank (WB) estimates and its country departments and research articles. Similarly, carbon dioxide (CO2) emissions data is obtained from the World Bank (WB) and Carbon Dioxide Information Centre, Environmental Science Division, USA. To incorporate the effects of disasters in the time series analysis, a dummy variable for natural disasters is used where (ND=1 when a year witnesses a natural disaster, 0 otherwise), whereas, it takes the value 1 when a country is developing, 0 otherwise). Further, the data is divided into two parts i-e developed and developing countries. We followed this division as suggested by UNDP for developed economies and by IMF for developing countries.

[7] Sea level pressure (air or atmospheric pressure at sea level) is inversely related to sea-level rise as higher sea level pressure exhibits lower levels of sea-level rise and vice versa. This paper also found a declining trend in mean sea level pressure by plotting which indicates that sea level rises over the years which is also known as the "Barometric Effect". The lower sea level pressure causes a rise in sea level which further causes coastal flooding, soil erosion, loss of wetlands, and loss of fisheries. In short, sea-level pressure does not affect economic activity rather it affects indirectly economic performance.

4.5 Why Panel Data Analysis for this Study

Panel data usage in empirical research has emerged as a populous way to extract the causal relationship between variables in social sciences. The rationale to use panel data modeling is due to the reason that its main goal in empirical research is to make inferences regarding the causal relationship between variables. The usage of cross-sectional data does not properly address the issue of causal ordering. It takes correlation between variables but it has limited inference power to express a causal relationship. The usage of cross-sectional data raises issues like (i) unobserved bias of variable (Holland, 1986), (ii) endogeneity bias (Hausman, 1978), and (iii) indeterminacy to sequence the causal relationship.

To tackle the issue of individual trajectories over time and to handle the time ordering of variables, it is required to use panel data. In 1986, Hasio (1986) completed and get published his first edition "Panel Data Analysis" by using 29 reference studies to support his usage of panel data. The importance and excess usage of panel data can be assessed by viewing the social science index too. The usage of panel data shows a remarkable increasing trend in research as 773 research studies using panel data in the year 2005 as compared to 687 in the year 2004. There are three basic factors, which are playing important role in the geometric growth of panel data. These factors include (i) greater ability to model the human behavior complexity as compared to time series or cross-section data (e.g. Ben-Porath, 1973), (ii) availability of data (iii) challenging methodology (Hasio, 1986). Its usage is further justified by the research work of Baltagi (2001), Hsiao (2003), and Nerlove (2002), etc.

Stationarity and panel unit root tests are widely used and are extremely popular over the last few decades. Although testing unit roots in time series data analysis has become a popular practice over the years yet its application to panel data is considered a recent development. This study uses unit root tests as the power of panel unit root tests is higher as compared to the power of unit root tests used in time series data for infinite samples. This problem is also raised while using Monto-Carlo simulations for small samples (Campbell and Perron, 1991). Unit root tests' power depends on total variation in the data. Panel unit root tests exhibit more power than standard time series unit root tests due to the reason that variation across countries affects and add more information to the variation concerning time. This characteristic in the usage of panel unit root potentially results in more precision of parameter estimates (Taylor and Sarno, 1998). Besides, the asymptotic distribution is standard normal for panel unit root tests while it is a non-standard limiting distribution for individual time series unit root tests (e.g., DF and ADF).

Unit root and cointegration have attained much attention from the researchers while using data of a time series nature but no greater attention is paid to the account of panel data analysis. Some of the theoretical studies concentrated on the issue of testing unit root in the panel data. These studies include Levin and Lin (1993); Pesaran and Shin (1995); Maddala and Wu (1996); Quah (1991); Breitung and Meyer (1994); Hadri (1999) and Choi (1999). Breitung and Meyer (1994) discussed asymptotic properties possessed by Dicky-Fuller test. They have used these statistics for panel data analysis having small time-series dimensions and large cross-section dimensions. Quah (1994) used the extension form of time series and cross-section dimensions to study unit root for panel data. His asymptotic distribution consists of standard normal and Dicky-Fuller-Phillips asymptotic. Levin and Lin (1993) showed that the power of these tests increases as the cross-section dimension increases. Im *et al.* (1995) opposed the stance presented by Levin and Lin (1993) and proposed their developed alternative dimension renowned as the IPS test. Maddala and Wu (1996) presented their view on unit root by comparing the presented tests of Im *et al.* (1995) and Levin and Lin (1993). Their test for unit root testing is based on the Fisher-type test and Choi (2001).

Some researchers have recently used regression models in panel data analysis for Cointegration and estimation. These include Kao (1997), Pedroni (1996, 1997), and Phillips and Moon (1998). Kao (1997) has mainly studied three major issues in panel data e.g. spurious regression, properties of OLS estimators of asymptotic nature, and conventional statistics. He has also examined DF and ADF tests of Cointegration using panel data to test the null hypothesis. Pedroni (1997) has drawn the asymptotic properties in the cointegration of heterogeneous and homogeneous nature for residual-based tests. Phillips and Moon (1998) developed theories known as joint limit and sequential limit theories for analyzing non-stationary panel data. Pedroni (1998) has also proposed a completely modified estimator, which is used for heterogeneous panel data models. Pesaran and Smith (1995) have indirectly discussed the issue of homogeneity among co-integrated panels.

The issue of heterogeneous panels attained much attention after the year 2000. Baltagi and Kao (2000) were considered the pioneers to review this issue. After the consensus that the de-meaning of cross-section nature does not work in general where co-variances of distribution terms vary across single series. This deficiency has led the researchers to develop and proposed new changes in the existing literature for the year 2000. These researchers include Chang (2002), Breitung and Das (2005), and Smith, Leybourne, Kim, and Newbold (2004). The detailed description of panel unit root and cointegration tests is as under. The Westerlund (2007) test uses yet another approach based on variance ratio, one that imposes fewer restrictions. It tests the null hypothesis as other tests do, but the alternative hypothesis is different that some (not necessarily all) of the panels are cointegrated.

4.6 Panel Unit Root Tests

To assess the stationarity of the study variables, this study uses the following unit root tests:

4.6.1 Levin, Lin, and Chu Test

Levin, Lin, and Chu (2002) proposed a unit root test for the panel data to test the null hypothesis of a unit root against the alternative hypothesis of homogeneous stationarity. The model of the LLC test is specified as:

$$\Delta y_{it} = \delta y_{it-1} + \sum_{L=1}^{pi} Q_{iL}\, \Delta y_{i,t-L} + \propto_{mi} d_{mt} + \epsilon_{it} \tag{4.1}$$

The null hypothesis of the LLC unit root tests is $H_0 = \delta = 0$, for all I, against an alternative hypothesis$H_0 = \delta < 0$, for all i. The necessary condition for the LLC test is that$\frac{\sqrt{N}}{T} \to 0$. LLC test assumes cross-sectional independencies by assuming that errors ϵ_{it} are iid $(0\ \delta_{i,t}^2)$. It is considered a restrictive test as it assumes δ to be homogeneous across i. It considers three models: (i) $d_{1t} = \emptyset$(with no individual effects; (ii) $d_{2t} = \{1\}$, where series y_{it} has an individual specific mean having no time trend, and (iii) $d_{3t} = \{1, t\}$, where a series y_{it} has individual specific mean and linear time trend.

4.6.2 Im, Pesaran, and Shin Test

To test the heterogeneous panel, IPS (2003) proposed a standard t-bar test statistic that is based on averaging the Dicky-Fuller statistic across groups while based on averaging having a standard normal distribution. The IPS test is specified as

$$\Delta y_{it} = \beta_i y_{it-1} + \sum_{j=1}^{pi} p_{ij}\, \Delta y_{i,t-j} + \propto_{mi} d_{mt} + \epsilon_{it} \quad \text{m=1,2,3} \tag{4.2}$$

where p_i is the lag order and β_i may differ across groups. The null of the IPS test is $H_0 = \beta_i = 0$, for all i, against heterogeneous alternative hypothesis $H_0 = \beta_i < 0$, for i=1,......., N, β_i=0, for N_1+1,........N. The IPS test allows for some (but not all series) of the individual series to have a unit root. In the IPS test, we assume T→∞ sequentially.

4.6.3 Breitung's Unbiased Test

IPS (2003) and LLC (2002) tests proposed a biased-adjusted t-statistic which results in a severe loss of power. Breitung proposed an alternative approach to counter the issue of biasedness by the alternative estimates of the deterministic term. The series y_{it} is adjusted for biasedness by subtracting the initial value of y_{it}. The proposed equation after the subtraction becomes:

$$\Delta y_{it} = \delta^*(y_{i,t-1} - y_{it}) + v_{it} \tag{4.3}$$

4.6.4 Hadri Test

Hadri (2000) adopted a procedure in which an individual time series can be written as the sum of a deterministic trend, a white-noise disturbance term, and a random walk. Under the null hypothesis, the variance of the random walk equals 0. Hadri considered two models:

Model 1 assumes the time series y_{it} is stationary around $the\ \gamma_{i0}$ level,

$$y_{it} = r_{it} + \beta_{it} + \varepsilon_{it} \tag{4.4}$$

where i=1,........N, and t=1,.......T, and where r_{it} is a component of random walk, $r_{it} = r_{it-1} - u_{it}$, i=1,......N, t=1,.......T.

The error u_{it} and ε_{it} satisfy $u_{it} \backsim iid\,\mathcal{N}(0, \delta_u^2)$, $\varepsilon_{it} \backsim iid\,\mathcal{N}(0, \delta_\varepsilon^2)$, and both are mutually independent. The null hypothesis of the Hadri test with stationarity assumption is $H_0 = \delta_u^2 = 0$, against random walk alternative hypothesis $H_1 = \delta_u^2 > 0$.

4.6.5 Fisher-type Tests

To conduct a Fisher-type test of unit root, we use ADF and Phillips-Perron unit root tests on an unbalanced panel. It is panel specific test in which T→ ∞, where N may be infinite or finite. The null hypothesis is tested that all panels have a unit root, whereas the alternative hypothesis exhibits that at least one panel is stationary. If N is finite then the P test is

$$P = -2\sum_{i=1}^{N} \ln (p_i) \qquad (4.5)$$

P$\backsim x^2(2\text{N})$ and large values are obtained after applying the P test then cast doubt on H_0.

$$Z = \frac{1}{\sqrt{N}} \sum_{i=1}^{N} \emptyset^{-1}(p_i) \qquad (4.6)$$

where $\emptyset^{-1}$ is the opposite of the standard normal distribution factor. If Z$\backsim$N $(0, 1)$ and if the Z test has too many negative values then cast doubt on H_0.

4.7 Panel Cointegration Tests

4.7.1 Kao Test

Kao (1999) presented two important tests for cointegration in panel data, the augmented Dicky-Fuller and the Dicky-Fuller tests. Kao test of Dicky-Fuller type can be expressed from the residuals of the following equation:

$$y_{it} = x'_{it}\beta + z'_{it}\gamma + \varepsilon_{it} \qquad (4.7)$$

which looks as $\hat{e}_{it} = \rho\hat{e}_{it-1} + v_{it}$, and where $\hat{e}_{it} = \hat{y}_{it} - \hat{x}_{it}\hat{\beta}$ and $\tilde{y}_{it} = x_{it} - \sum_{s=1}^{T} h(t,s)y_{is}$, and $\tilde{x}_{it} = x_{it} - \sum_{s=1}^{T} h(t,s)x_{is}$

For no cointegration, the null can be expressed as $H_0 = \rho = 1$.

For the ADF type test of Kao, we estimate the following regression

$$\hat{e}_{it} = \rho\hat{e}_{it-1} - \sum_{j=1}^{p} \vartheta_j \Delta\hat{e}_{it-1} + v_{itp} \tag{4.8}$$

4.7.2 Pedroni Test

For allowing considerable heterogeneity, Pedroni (1997) proposed several tests to assess cointegration in panel data. His first type of test was similar to that of the Kao test which assumes average test statistics for cointegration across the cross-sections in time series. In the second type of test, averaging is done in pieces. For the first type of test, we use Phillips-Perron (1990) statistic:

$$\tilde{Z}_p = \sum_{i=1}^{N} \frac{\sum_{t=1}^{T}(\hat{e}_{it-1}\Delta\hat{e}_{it} - \hat{\gamma}_i)}{(\sum_{t=1}^{T} \hat{e}_{it-1}{}^2)} \tag{4.9}$$

where $\hat{e}_{it}$ is calculated from the first equation used in the Kao test.

$$\hat{\gamma}_i = \frac{1}{2}(\hat{\delta}_i{}^2 - \hat{s}_i{}^2) \tag{4.10}$$

where $\hat{\delta}_i{}^2$ and $\hat{s}_i{}^2$ are individual contemporaneous and long-run variances of the residual $\hat{e}_{it}$, respectively. The second test is based on a statistic

$$\tilde{Z}_{t_{\beta NT}} = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T} \hat{L}_{it}{}^{-2}\,(\hat{e}_{it-1}\Delta\hat{e}_{it} - \hat{\gamma}_i)}{\sqrt{\hat{\delta}_i{}^2{}_{NT}(\sum_{i=1}^{N}\sum_{t=1}^{T} \hat{L}_{it}{}^{-2}\,\hat{e}_{it-1}{}^2)}} \tag{4.11}$$

$$\tilde{\delta}_{NT} = \frac{1}{N}\sum_{i=1}^{N}\frac{\hat{\delta}_i^{\,2}}{\hat{L}_{it}^{\,2}} \tag{4.12}$$

It is important to note that, the Pedroni test is based on the denominator and Numerator terms, respectively, rather than the statistic average as a whole.

4.7.3 Westerlund Cointegration Test

This test has the characteristic to allow a large degree of heterogeneity both in the short run and long run. It also allows within as well as across dependence among the cross-sectional units. The null hypothesis of the Westerlund cointegration test exhibits no cointegration in the panel. The equation based on the error correction (EC) is expressed as

$$\Delta y_{it} = \delta_1' d_t + \alpha_1 (y_{i,t-1} - \beta_i' x_{i,t-1}) + \sum_{j=1}^{pi} \emptyset_{ij} \Delta y_{i,t-j} + \sum_{j=-q_i}^{pi} \emptyset_{ij} \Delta x_{i,t-j} + e_{it} \tag{4.13}$$

where d represents the deterministic components and x contains fundamental economic variables.

4.8 Theoretical Model

To analyze the impact of climate change variables on economic growth indicators, this study aims at modeling the relationship for comprehensive empirical analysis in the following sections. For empirical estimation, this study uses the Cobb-Douglas production function. The Cobb-Douglas production function defines a technical relationship between the physical quantity of output (Y) and the physical quantity of inputs employed during a production process. This first phase of empirical modeling is to generalize the production function and then incorporate inputs following the need of this study.

Solow (1969) introduced the Solow-neutral production function which defined technological progress to be neutrally named as Solow-neutral if the inputs in relative terms remain unaltered for a particular labor-output ratio. This growth model uses a standard neoclassical production function having constant returns to scale of each input and decreasing returns to capital. The fundamental assumptions of the growth model by Solow are population growth, the rate of saving, and technological change are exogenous. Assuming a Cobb-Douglas production function having two inputs i.e., capital and labor, the model is expressed as

$$Y(t) = F[K(t)^{\beta}(A(t)L(t))^{1-\beta}] \qquad 0<\beta < 1 \tag{4.14}$$

where $Y(t)$ is production or output, K(t) and L(t) are physical capital and labor, respectively, and A(t) is the state of the technology.

It is assumed in the Solow growth model that s a constant fraction of production or output is invested in physical capital. Assuming k as the capital stock per effective labor unit, $k = \frac{K}{AL}$, and y as the output level per effective labor unit, $y = \frac{Y}{AL}$, the equations can be expressed as

$$k^{*}(t) = sy(t) - (n + g + \sigma)k(t) \tag{4.15}$$

$$k^{*}(t) = sk(t)^{\beta} - (n + g + \sigma)k(t) \tag{4.16}$$

where 0< σ<1, is the depreciation rate and k^{*} is the derivative of k with respect to time, t. It shows that steady-state convergence of k and k^{*} can be expressed as:

$$k^{*} = [s/(n + g + \sigma)]^{1/(1-\beta)} \tag{4.17}$$

k^* which is the steady-state capital-labor ratio is related negatively to the population growth rate and positively to the savings rate. By substituting equation 4.17 into equation 4.14 and by taking the logarithm, the steady-state level of per capita income is expressed as:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = LnA(0) + gt + \frac{\beta}{1-\beta}\ln(s) - \frac{\beta}{1-\beta} - \ln(n+g+\sigma) \qquad (4.18)$$

Furthermore, as per assumption,

$$\ln A(0) = a + \varepsilon \qquad (4.19)$$

where a represents a constant and ε is a country-specific shock. So, per capita income in log form at time 0 for simplicity is

$$\ln\left[\frac{Y}{L}\right] = a + \frac{\beta}{1-\beta}\ln(s) - \ln(n+g+\sigma) + \varepsilon \qquad (4.20)$$

In exogenous technical progress, technical growth happens at a constant rate g and it does not depend on any other factor. The exogenous form of technical progress takes the following form:

$$\frac{\dot{A}}{A} = g \leftrightarrow A_t = A_{\circ}e^{gt} \qquad (4.21)$$

For Cobb-Douglas production function with CRS implies

$$\lambda Y = F(\lambda K, \lambda AL) \qquad (4.22)$$

Now, setting $\lambda = 1/(AL)$ to get intensive form of production function

$$\frac{Y}{AL} = (\frac{K}{AL}, 1) \qquad (4.23)$$

or $$\hat{y} = f(\hat{k}) \qquad (4.24)$$

where $\hat{y}$ =Y/(AL)=y/A which is output per effective unit of labor and similarly, $\hat{k}$ = K/(AL) = k/A represents capital per effective unit of labor. On the basis of this generalization, the capital-labor ratio K/L can be written as $A\hat{k}$.

The Cobb-Douglas production function with CRS assumption having labor augmenting technical progress can be expressed as

$$F(K, AL) = K^{\alpha}(AL)^{1-\alpha} \qquad (4.25)$$

where 0< α<1 and intensive form equation (4.25) takes the following form

$$f(\hat{k})=F(K/(AL),1)= (K/(AL)^{\alpha} = \hat{k}^{\alpha} \qquad (4.26)$$

4.9 Empirical Model

This study used the following procedure to build an empirical model for estimation. We formulated this procedure for the empirical framework by following the practices of the existing research studies.

4.9.1 Formulation of Climate-Induced Production Function

This study for further generalization of the empirical modeling developed the empirical model based on an augmented neoclassical stochastic aggregate production function having a structure of Cobb-Douglas nature (see Alagidede *et al.*, 2015; Dell *et al.*, 2012; Barrios *et al.*, 2010; Stern, 2013; Dietz and Stern, 2015). To fix ideas and after the inclusion of basic climatic variables, the following framework was formulated as an empirical model by Alagidede *et al.* (2015).

$$y_{it} = A_{it}k_{it}^{\alpha}T_{it}^{\beta}P_{it}^{\gamma}e^{\varepsilon it} \qquad (4.27)$$

y_{it} is real GDP and GDP per capita for a given country, k_{it} is used for capital per worker, T_{it} is annual mean temperature, P_{it} is the average annual rate of precipitation; ε_{it} is the error term, i and t are capturing the individual and time effects respectively.

4.9.2 Extension of Empirical Model

The effect of mean sea level pressure is considered important for the measurement of climate impacts on economic growth. The rise in sea level can cause soil erosion, flood, and other climatic issues (Asuncion and Lee, 2017; Novackova and Tol, 2016). This study intends to include this particular variable to make the empirical model a more comprehensive one. The inclusion of this variable also reduces the chance of excluding a relevant variable (omitted variable case). Sunshine hours can play an important role in the impacts of climate on growth in general and agricultural productivity in particular (Ali *et al.*, 2017; Ouwehand and Ruth 2014; Palmer 1919; Malla 2008; Chen *et al.*, 2012). So, besides, mean sea level pressure and hourly sunshine are also taken as an indicator of climatic factors affecting the economic growth of the global economy.

To investigate the relationship between climate change and economic growth, we employ a similar methodology proposed by Alagidede *et al.* (2016) and Kadanal and Yalcinkaya (2020) to examine the effect of climate change on economic growth. This paper uses the empirical model developed from an augmented neoclassical stochastic aggregate production function with Cobb–Douglas structure as:

$$y_{it} = A_{it} k_{it}^{\alpha} T_{it}^{\beta} P_{it}^{\gamma} M_{it}^{\tau} S_{it}^{\theta} \, e^{\varepsilon it} \quad (4.28)$$

where y_{it} is real GDP and GDP per capita for a given country, k_{it} is used for capital per worker, T_{it} is annual mean temperature, P_{it} is the average annual rate of precipitation, N_{it} and M_{it} represent natural disasters[8] and mean sea level pressure, S_{it} represents the hourly sunshine duration per month and ε_{it} is the error term, i and t are capturing the individual and time effects respectively. Since all the climatic variables like temperature, precipitation, natural disasters, sea level pressure, and sunshine duration are global public goods (bad), they enter the model in aggregate terms rather than per worker terms.

4.9.3 State of the Technology Function

Technology is considered an important booster for the improved production process in economics and other sciences. Modernization in the production process cannot take place until and unless the state of the technology improves over the years persistently. Besides, it is an important variable in the production process in economics along with other economic and non-economic variables. This study includes this important variable by using three proxy variables to capture its overall impact on a production function following Alagidede *et al.* (2015). Three proxy variables include foreign aid and financial development (FAFD), merchandise exports (MREX), and trademark and patent applications of residents (TMPA). The technology function takes the form as:

$$A_{it} = \mathrm{FAFD}_{it}^{\sigma}\mathrm{MREX}_{it}^{\omega}\, TMPA_{it}^{\lambda} \tag{4.29}$$

where FAFD represents foreign aid and financial development, MREX and TMPA are used for the value of merchandise export in US dollars and the total number of trademark and patent applications of the residents, respectively. By substituting equation (4.29) into equation (4.28) to

[8] A natural disaster is a dummy variable used in place of floods, droughts, storms, and sea-level rise.

incorporate the technology function into the proposed model of the study, we have the following model:

$$y_{it} = \mathrm{FAFD}_{\mathrm{it}}^{\sigma}\mathrm{MREX}_{\mathrm{it}}^{\omega}\, TMPA_{it}^{\lambda}\mathrm{k}_{\mathrm{it}}^{\alpha}\mathrm{T}_{\mathrm{it}}^{\beta}\mathrm{P}_{\mathrm{it}}^{\gamma}N_{it}^{\partial}\mathrm{M}_{\mathrm{it}}^{\tau}\,\mathrm{S}_{\mathrm{it}}^{\Theta}\,\varepsilon_{it} \tag{4.30}$$

Now, by taking logs of variables on both sides of equation (4.30), the final empirical model takes the form shown in equation (4.31). The rationale to take the log of variables is that it would make the distribution of our transformed variable more normal, which may be highly skewed otherwise. Besides, as we are using a production function, which is non-linear and takes logs on both sides, makes it easy and feasible to estimate an equation by using linear regression.

4.9.4 Econometric Model for Measuring the Climate-Growth Relationship

To address the research gap found in the literature reviewed and to achieve its first objective, this study uses temperature and precipitation which are traditionally used for such type of analysis. This study extends the climate variables by including sea level pressure, sunshine duration, and dummy variable in place of natural disasters. Now, by taking logs of variables on both sides of equation (4.30), the empirical model takes the form shown in equation (4.31).

$$lny_{it} = \beta_0 + \beta_1 lnTEMP_{it} + \beta_2 lnPRCP_{it} + \beta_3 lnND_{it} + \beta_4 lnMSLP_{it} + \beta_5 lnSS_{it} + \beta_6 lnGFCF_{it} + \beta_7 \ln FAFD_{it} + \beta_8 \ln MREX_{it} + \beta_9 \ln TMPA_{it} + \varepsilon_{it} \tag{4.31}$$

where y is real GDP and GDP per capita, TEMP and PRCP are annual mean temperature and precipitation while ND is the natural disaster dummy variable used in place of the flood, drought, and storm sea level rise, respectively (where 0 represents the countries which less likely to be affected by disasters, whereas, 1 shows the countries which are more likely to be affected by climate hazards). MSLP and SS are mean annual sea level pressure and mean hourly sunshine hours, whereas, GFCF and FAFD represent gross fixed capital formation, foreign aid and financial development. MREX and TMPA are used for merchandizing exports, and trademark and patent applications, respectively.

Pretis *et al.* (2017) used a model to estimate the impact of extreme values (minimum and maximum temperature and precipitation) on economic growth. Extreme changes in major climate change indicators e.g., temperature and precipitation can be influential on economic growth as these changes can affect the economic growth of countries. To investigate the relationship between extreme climate changes and economic growth which is also a part of our first objective, we specified the following empirical model:

$$lny_{it} = \beta_0 + \beta_1 lnMINT + \beta_2 lnMAXT + \beta_3 lnMINP_{it} + \beta_4 lnMAXP_{it} + \beta_5 lnFDS_{it} + \beta_6 lnMSLP_{it} + \beta_7 lnSS_{it} + \beta_8 lnGFCF_{it} + \beta_9 \ln FAFD_{it} + \beta_{10} \ln MREX_{it} + \beta_{11} \ln TMPA_{it} + \varepsilon_{it} \quad (4.32)$$

where MINT and MAXT are minimum and maximum temperatures while MINP and MAXP represent minimum and maximum precipitation, respectively.

We consider average temperature (Tit) and precipitation (Pit) as the main climate indicators but assume economic growth is affected by climate variables only when they deviate from their historical means, which is denoted by $T^*_{i,t-1}$ and$P^*_{i,t-1}$, respectively. Accordingly, in what follows we also allow for an asymmetry in the effects of deviations from the historical mean on economic growth, and introduce the following threshold climate variables:

$$\text{POST}=(T^*_{it} - T^*_{i.t-1})^+ = (T^*_{it} - T^*_{i.t-1})I(T^*_{it} - T^*_{i.t-1} \geq 0),$$

$$\text{NEGT} = (T^*_{it} - T^*_{i.t-1})^- = (T^*_{it} - T^*_{i.t-1})I(T^*_{it} - T^*_{i.t-1} < 0), \quad (4.33)$$

and POSP=$(T_{it}^{*} - T_{i.t-1}^{*})^{+} = (T_{it}^{*} - T_{i.t-1}^{*})I(T_{it}^{*} - T_{i.t-1}^{*} \geq 0)$,

$$\text{NEGP} = (T_{it}^{*} - T_{i.t-1}^{*})^{-} = (T_{it}^{*} - T_{i.t-1}^{*})I(T_{it}^{*} - T_{i.t-1}^{*} < 0) \quad (4.34)$$

By distinguishing the positive and negative deviations of the climate indicators from their historical means deviations, we have also taken into account of potential nonlinear effects of climate change on economic growth. Asymmetric effects of climate change can affect economic indicators in particular and economic growth in particular. We specify the following model to investigate the asymmetric effects of climate changes on economic growth following the methodology proposed by Kahn *et al.* (2019) using the threshold variables introduced in equations (4.33) and (4.34):

$$lny_{it} = \beta_0 + \beta_1 lnPOST_{it} + \beta_2 lnNEGT_{it} + \beta_3 lnPOSP_{it} + \beta_4 lnNEGP_{it} + \beta_5 lnFDS_{it} + \beta_6 lnMSLP_{it} + \beta_7 lnSS_{it} + \beta_8 lnGFCF_{it} + \beta_9 \ln FAFD_{it} + \beta_{10} \ln MREX_{it} + \beta_{11} \ln TMPA_{it} + \varepsilon_{it} \quad (4.35)$$

where POST, NEGT, POSP, and NEGP are positive and negative changes above and below the mean values of temperature and precipitation, respectively, ε_{it} is for the error terms.

4.9.5 Linear and Non-Linear ARDL Econometric Models

To estimate the impacts in the short run and the long run, this study intends to form the following econometric model from its baseline equation (4.31) as used by Alagidede *et al.* (2015) following error correction mechanism representation of the panel ARDL model:

$$\Delta lny_{it} = a_{it} + \Sigma_{i=1}^{n}\lambda_{it} lny_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{1it}\Delta lnTEMP_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{2it}\Delta lnPRCP_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{3it}\Delta lnND_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{4it}\Delta lnMSLP_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{5it}\Delta lnSS_{i,t-1} +$$

$$\Sigma_{i=1}^{n} \alpha_{6it} \Delta lnGFCF_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{7it}\Delta l n \text{FAFD}_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{8it}\Delta l n \text{MREX}_{i,t-1} +$$

$$\Sigma_{i=1}^{n}\alpha_{9it}\Delta l n \text{TMPA}_{i,t-1} + \lambda_{it} lny_{i,t-1} + \beta_{1it} lnTEMP_{i,t-1} + \beta_{2it} lnPRCP_{i,t-1} +$$

$$\beta_{3it} lnND_{i,t-1} + \beta_{4it} lnMSLP_{i,t-1} + \beta_{5it} lnSS_{i,t-1} + \beta_{6it} lnGFCF_{i,t-1} + \beta_{7it} lnFAFD_{i,t-1} +$$

$$\beta_{8it} lnMREX_{i,t-1} + \beta_{9it} ln\,(TMPA)_{i,t-1} + \omega_{it} \quad (4.36)$$

where α_s and β_s are used to capture the impacts of the study variables in the short run and the long run on dependent variables, respectively. $\boldsymbol{\lambda}_{it}$ is the coefficient of the lagged variable of the dependent variable used as an explanatory variable, which is GDP per capita (or real GDP).

Similarly, the non-linear ARDL equation using equation (4.35) can be specified as under:

$$\Delta lny_{it} = a_{it} + \Sigma_{i=1}^{n}\lambda_{it} lny_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{1it}\Delta lnPOST_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{2it}\Delta lnNEGT_{i,t-1} +$$

$$\Sigma_{i=1}^{n} \alpha_{3it} \Delta lnPOSP_{i,t-1} + \Sigma_{i=1}^{n} \alpha_{4it} \Delta lnNEGP_{i,t-1} + \Sigma_{i=1}^{n} \alpha_{5it} \Delta lnND_{i,t-1} +$$

$$\Sigma_{i=1}^{n} \alpha_{6it} \Delta lnMSLP_{i,t-1} + \Sigma_{i=1}^{n} \alpha_{7it} \Delta lnSS_{i,t-1} + \Sigma_{i=1}^{n} \alpha_{8it} \Delta lnGFCF_{i,t-1} +$$

$$\Sigma_{i=1}^{n}\alpha_{9it}\Delta l n \text{FAFD}_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{10it}\Delta l n \text{MREX}_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{11it}\Delta l n \text{TMPA}_{i,t-1} +$$

$$\lambda_{it} lny_{i,t-1} + \beta_{1it} lnPOST_{i,t-1} + \beta_{2it} lnNEGT_{i,t-1} + \beta_{3it} lnPOSP_{i,t-1} + \beta_{4it} lnNEGP_{i,t-1} +$$

$$\beta_{5it} lnND_{i,t-1} + \beta_{6it} lnMSLP_{i,t-1} + \beta_{7it} lnSS_{i,t-1} + \beta_{8it} lnGFCF_{i,t-1} + \beta_{9it} lnFAFD_{i,t-1} +$$

$$\beta_{10it} lnMREX_{i,t-1} + \beta_{11it} ln\,(TMPA)_{i,t-1} + \omega_{it} \quad (4.37)$$

The estimation of equations (4.36) and (4.37) is a challenging task while using cross-country panel data. Specifically, a few key challenges include parameter heterogeneity, omitted variables, outliers, model uncertainty, endogeneity, and measurement error in cross-country regressions which are highlighted by Rodrik (2012). These problems are considered while choosing an approach and estimator for this paper. Keeping in view the possible estimation issue, we use the auto-regressive distributive lags (ARDL) approach that caters to most of the challenges. The ARDL model with an error correction mechanism is useful for forecasting and disentangling short-run dynamics from long-run relationships. These issues are discussed in literature based on cross-country regressions available on growth (Temple 2000; Rodrik 2012; Levin and Renelt 1992).

4.10 Measuring Climate Impacts on Agriculture

To investigate the relationship between climate change and agricultural production, we employed the methodology proposed by Sangkhaphan and Shen (2019) who used it for the investigation of rainfall effect on economic growth, Mahrous (2019) and Blanc (2012) employed it for analyzing climate effect on food security and crop yields, and Dell *et al.* (2014) who employed it for the assessment of temperature and precipitation effect on economic output.

$$Y_{i,t} = \beta_0 + \beta_1 TEMP_{i,t} + \beta_2 PRCP_{i,t} + \beta_4 SS_{i,t} + \beta_5 EMAG_{i,t} + \beta_6 UPOP_{i,t} + \beta_7 AGLD_{i,t} + \mu_{i,t} \quad (4.38)$$

where Y_{it} is the food production index or crop production index, TEMP and PRCP are mean annual temperature and precipitation, respectively. SS is hourly sunshine per month. EMAG is employment in the agriculture sector percentage of the total, UPOP represents the urban population in millions, AGLD is agriculture land, and μ_{it} is the disturbance term.

To assess the climate impact on agriculture production, we employ the methodology proposed by Pretis *et al.* (2017) who used a similar model for the projections of the climate-growth nexus. To achieve the objective of extreme changes and their impact on agriculture production, this study specifies the following model:

$$Y_{i,t} = \beta_0 + \beta_1 MINT_{i,t} + \beta_2 MAXT_{i,t} + \beta_3 MINP_{i,t} + \beta_4 MAXP_{i,t} + \beta_6 HSS_{i,t} + \beta_5 EMAG_{i,t} + \beta_6 UPOP_{i,t} + +\beta_7 AGLD_{i,t} + \mu_{i,t} \quad (4.39)$$

where MINT, MAXT, MINP, and MAXP are the annual minimum and maximum levels of temperature and precipitation, respectively.

The effect of asymmetric changes is another important modeling dimension widely used for the assessment of climate-economy relationships nowadays. We employed the methodology to investigate the asymmetric effects of major climate indicators e.g., temperature and precipitation on agricultural production as proposed by Kahn *et al.* (2019) who employed a similar model which only considered two major climate indicators e.g., temperature and precipitation for the assessment of asymmetric effects of these two indicators on economic growth and employment. The model is specified as under:

$$Y_{i,t} = \beta_0 + \beta_1 POST_{i,t} + \beta_2 NEGT_{i,t} + \beta_3 POSP_{i,t} + \beta_4 NEGP_{i,t} + \beta_6 HSS_{i,t} + \beta_5 EMAG_{i,t} + \beta_6 UPOP_{i,t} + \beta_7 AGLD_{i,t} + \mu_{i,t} \quad (4.40)$$

where POST, NEGT, POSP, and NEGP are positive and negative mean deviations of temperature and precipitation above and below their mean levels, respectively.

4.11 Measuring Climate Impacts on Agriculture in Pakistan

To examine the linear relationship between climate change and agricultural production in Pakistan, we employ the methodology proposed by Gul *et al.* (2021), Ahmed *et al.* (2020), and Ali *et al.* (2017). The long-run relationship between the variables of the linear model is specified as follows:

$$lnY_t = \alpha_0 + \beta_1 lnTEMP_t + \alpha_2 lnPRCP_t + \alpha_3 lnSS_t + \alpha_4 ND_t + \alpha_5 \ln AGLD_t + \alpha_6 \ln UPOP_t + \alpha_7 \ln GFCF_t + \varepsilon_t \quad (4.41)$$

where Y is the food production index or crop production index, TEMP and PRCP are mean annual temperature and precipitation, respectively. SS is hourly sunshine per month, ND is a dummy variable used for natural disasters where (ND=1 when a year witnesses a natural disaster, 0 otherwise). AGLD is agricultural land, UPOP represents the urban population in millions, GFCF is gross fixed capital formation in constant US dollars, and ε_t is disturbance term.

To differentiate the short-run and the long-run relationship, this study follows the approach introduced by Pesaran *et al.* (2001). Specifically, the model in the Error Correction Mechanism (ECM) is specified as follows:

$$\Delta LnY_t = \alpha_0 + \sum_{k=1}^{n1} \alpha_{1k}\, \Delta LnY_{t-k} + \sum_{k=0}^{n2} \alpha_{2k}\, \Delta LnTEMP_{t-k} + \sum_{k=0}^{n3} \alpha_{3k}\, \Delta LnPRCP_{t-k} + \sum_{k=0}^{n2} \alpha_{4k}\, \Delta LnSS_{t-k} + \sum_{k=0}^{n3} \alpha_{5k}\, \Delta ND_{t-k} + \sum_{k=0}^{n2} \alpha_{6k}\, \Delta LnAGLD_{t-k} + \sum_{k=0}^{n3} \alpha_{7k}\, \Delta LnUPOP_{t-k} + \sum_{k=0}^{n3} \alpha_{8k}\, \Delta LnGFCF_{t-k} + \beta_0 LnY_{t-1} + \beta_1 LnTEMP_{t-1} + \beta_2 LnPRCP_{t-1} + \beta_3 LnSS_{t-1} + \beta_4 ND_{t-1} + \beta_5 LnAGLD_{t-1} + \beta_6 LnUPOP_{t-1} + \beta_7 LnGFCF_{t-1} + \varepsilon_t \quad (4.42)$$

In equation (4.42) α_1 to α_8 are coefficients of the variables showing short-run impacts, whereas the long-run relationships are represented by betas i.e., from β_1 to β_8. Pesaran *et al* (2001) recommended F-test to assess the joint significance of lagged variables to determine cointegration. The F-test values are based on the two new critical values, where an upper bound critical value assumes that the variables are I (1) and this critical value is also valid in case all the variables are I (0). This method is also beneficial in cases where variables are of order I (1) and I (0).

The variables of the ECM are assumed to have asymmetric effects on the output. Behmani-Oskooee and Mohammadian (2017) used a similar cointegration strategy to assess the asymmetric effects of changes in the exchange rate on output in Japan. There are not only the symmetric changes that can affect agriculture production, asymmetric effects of major climate indicators (temperature and precipitation) deviating from their mean deviations can also play important role in influencing the output of the agriculture sector. We follow the methodology proposed by Kahn *et al.* (2021) for the investigation of asymmetric effects. To assess the asymmetric effects of changes from their threshold (mean deviation) levels of major climate indicators (temperature and precipitation) on food and crop production, this paper introduces the following threshold variables[9]:

$$\text{POST} = (T - T^*_{t-1}) = (T - T^*_{t-1})I(T - T^*_{t-1} \geq 0),$$

$$\text{NEGT} = (T - T^*_{t-1}) = (T - T^*_{t-1})I(T - T^*_{t-1} < 0), \quad (4.43)$$

and $$\text{POSP} = (P - P^*_{t-1}) = (P - P^*_{t-1})I(P - P^*_{t-1} \geq 0),$$

$$\text{NEGP} = (P - P^*_{t-1}) = (P - P^*_{t-1})I(P - P^*_{t-1} < 0), \quad (4.44)$$

This study uses equations (4.43) and (4.44) to construct an error correction mechanism (ECM) for the assessment of asymmetric effects of climate change indicators in the following model:

$$\Delta LnY_t = \alpha_0 + \sum_{k=1}^{n1} \theta_{1k}\, \Delta LnY_{t-k} + \sum_{k=0}^{n2} \theta_{2k}\, \Delta POST_{t-k} + \sum_{k=0}^{n3} \theta_{3k}\, \Delta NEGT_{t-k} + \sum_{k=0}^{n4} \theta_{4k}\, \Delta POSP_{t-k} + \sum_{k=0}^{n5} \theta_{5k}\, \Delta NEGP_{t-k} + \sum_{k=0}^{n6} \theta_{6k}\, \Delta LnSS_{t-k} + \sum_{k=0}^{n7} \theta_{7k}\, \Delta ND_{t-k} + \sum_{k=0}^{n8} \theta_{8k}\, \Delta LnAGLD_{t-k} + \sum_{k=0}^{n9} \theta_{9k}\, \Delta LnUPOP_{t-k} + \sum_{k=0}^{n10} \theta_{10k}\, \Delta LnGFCF_{t-k} + \lambda_0 LnY_{t-1} + \lambda_1 POST_{t-1} + \lambda_2 NEGT_{t-1} + \lambda_3 POSP_{t-1} + \lambda_4 NEGP_{t-1} + \lambda_5 LnSS_{t-1} + \lambda_6 ND_{t-1} + \lambda_7 LnAGLD_{t-1} + \lambda_8 LnUPOP_{t-1} + \lambda_9 LnGFCF_{t-1} + w_t \quad (4.45)$$

[9] POST deviations show the positive mean difference between mean values of temperature for a given year and the overall historical mean for the study period and vice versa. Similarly, POSP deviations show the positive mean difference between mean values of precipitation for a given year and the overall historical mean for the study period, and vice ver.

The effects of minimum and maximum (precipitation and temperature) are also important for the production and productivity of the agriculture sector. To investigate the effects of these extreme changes e.g., minimum and maximum temperature and precipitation on food and crop production, we specify the following ECM framework:

$$\Delta LnY_t = \alpha_0 + \sum_{k=1}^{n1} \beta_{1k}\,\Delta LnY_{t-k} + \sum_{k=0}^{n2} \beta_{2k}\,\Delta MINT_{t-k} + \sum_{k=0}^{n3} \beta_{3k}\,\Delta MAXT_{t-k} + \sum_{k=0}^{n4} \beta_{4k}\,\Delta MINP_{t-k} + \sum_{k=0}^{n5} \beta_{5k}\,\Delta MAXP_{t-k} + \sum_{k=0}^{n6} \beta_{6k}\,\Delta LnSS_{t-k} + \sum_{k=0}^{n7} \beta_{7k}\,\Delta LnND_{t-k} + \sum_{k=0}^{n8} \beta_{8k}\,\Delta LnAGLD_{t-k} + \sum_{k=0}^{n9} \beta_{9k}\,\Delta LnUPOP_{t-k} + \sum_{k=0}^{n10} \beta_{10k}\,\Delta LnGFCF_{t-k} + \gamma_0 LnY_{t-1} + \gamma_1 MINT_{t-1} + \gamma_2 MAXT_{t-1} + \gamma_3 MINP_{t-1} + \gamma_4 MAXP_{t-1} + \gamma_5 LnSS_{t-1} + \gamma_6 LnND_{t-1} + \gamma_7 LnAGLD_{t-1} + \gamma_8 LnUPOP_{t-1} + \gamma_9 LnGFCF_{t-1} + w_t \quad (4.46)$$

Equation (4.46) is usually estimated by using OLS. Shin *et al.* (2014) explained that the Pesaran *et al.* (2001) method of bound testing is also applicable to equations (4.35) and (4.36). The construction of new variables e.g., POST, NEGT, POSP, and NEGP introduces non-linearity into the adjustment process. Therefore, equations (4.41) and (4.42) are labeled as linear ARDL models whereas equations (4.46) represent non-linear models, respectively. Our purpose is to judge asymmetries out of equation (4.45) and equation (4.46) after their estimations. These asymmetries are established as follows: first, the short-run effect asymmetry assumes that $\sum_{k=0}^{n2} \hat{\beta}_{2k} \neq \sum_{k=0}^{n3} \hat{\beta}_{3k}$ and second is established based on assumption that $\sum_{k=0}^{n4} \hat{\beta}_{4k} \neq \sum_{k=0}^{n5} \hat{\beta}_{5k}$ whereas the third asymmetry is established for the long-run relationship on the assumption that $\gamma_1 \neq \gamma_2$.

Finally, another long-run asymmetry assumes that $\gamma_3 \neq \gamma_4$. Similarly, asymmetries are established based on equation (4.45) as follows: first, we assume two short-run asymmetries if $\theta_{2k}^{+} \neq \theta_{3k}^{-}$and $\theta_{4k}^{+} \neq \theta_{5k}^{-}$for each k. Second, we assume two more short-run asymmetries if

$\Sigma\theta_{2k}^{+} \neq \theta_{3k}^{-}$ and $\Sigma\theta_{4k}^{+} \neq \theta_{5k}^{-}$, respectively. Third, two long-run asymmetries are established based on assumptions of $\lambda_1 \neq \lambda_2$ and $\lambda_3 \neq \lambda_4$, respectively. Finally, to capture adjustment asymmetries, we use the patterns of dynamic multipliers. To test all the asymmetries, we use the Wald test, whereas asymmetries in the last case are judged based on observing the patterns of adjustments.

4.12 Models to Measure the Climate-Inequality Nexus

Investigating the dynamic relationship between climate change and income inequality requires estimation by using a dynamic regression model which provides results that are consistent and reliable. The ARDL model is one of the better choices to analyze the effect of climate change on income inequality. This ARDL estimation caters to several econometric issues i.e., omitted variable bias, parameter heterogeneity, outliers, endogeneity, measurement error, etc.

To investigate the relationship between climate change and income inequality, we employ the similar methodology proposed by Apergis and Payne (2010), Arouri *et al.* (2012), and Lean and Smyth (2010) to examine the relationship between carbon emissions, economic growth, and energy consumption. The long-run relationship between the study variables is specified as follows:

$$GINI_{it} = \alpha + \beta_1 TEMP_{it} + \beta_2 PRCP_{it} + \beta_3 MSLP_{it} + \beta_4 SS_{it} + \beta_5 ND_{it} + \beta_6 GFCF_{it} + \beta_7 ITRD_{it} + \beta_8 TUP_{it} + \varepsilon_{it} \quad (4.47)$$

where GINI is the measure of income inequality, TEMP and PRCP are mean annual temperature and precipitation, respectively. MSLP and SS are the mean annual sea level pressure and mean hourly sunshine hours, respectively. ND is a dummy variable used for natural disasters where

(ND=1 when a year witnesses a natural disaster, 0 otherwise). GFCF, ITRD, and TUP are gross fixed capital formation, openness to international trade, and total urban population, respectively. To differentiate the short-run and the long-run relationship, this study follows the approach introduced by Pesaran *et al.* (2001). Specifically, the model in the Error Correction Mechanism (ECM) is specified as follows:

$$\Delta lny_{it} = a_{it} + \Sigma_{i=1}^{n}\lambda_{it}lny_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{1it}\Delta lnTEMP_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{2it}\Delta lnPRCP_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{3it}\Delta lnND_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{4it}\Delta lnMSLP_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{5it}\Delta lnSS_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{6it}\Delta lnGFCF_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{7it}\Delta ln\,\mathrm{ITRD}_{i,t-1} + \Sigma_{i=1}^{n}\alpha_{8it}\Delta ln\,\mathrm{TUP}_{i,t-1} + \lambda_{it}lny_{i,t-1} + \beta_{1it}lnTEMP_{i,t-1} + \beta_{2it}lnPRCP_{i,t-1} + \beta_{3it}lnND_{i,t-1} + \beta_{4it}lnMSLP_{i,t-1} + \beta_{5it}lnSS_{i,t-1} + \beta_{6it}lnGFCF_{i,t-1} + \beta_{7it}lnITRD_{i,t-1} + \beta_{8it}lnTUP_{i,t-1} + \omega_{it} \quad (4.48)$$

Asymmetric effects of climate change can affect the economic indicators in general and the incomes of the people in particular. We specify the following model to investigate the asymmetric effects of climate change on income inequality.

$$GINI_{it} = \alpha + \beta_1 POST_{it} + \beta_2 NEGT_{it} + \beta_3 POSP_{it} + \beta_4 NEGP_{it} + \beta_5 MSLP_{it} + \beta_6 SS_{it} + \beta_7 ND_{it} + \beta_8 GFCF_{it} + \beta_9 ITRD_{it} + \beta_{10} TUP_{it} + \varepsilon_{it} \quad (4.49)$$

where POST, NEGT, POSP, and NEGP are positive and negative changes in temperature and precipitation above and below their mean deviations, respectively[10].

Extreme changes in major climate change indicators e.g., temperature and precipitation can be influential on income inequality as these changes can affect the economic growth of

[10] We used the same non-linear ARDL specification for the climate-inequality nexus discussed earlier in the climate-growth relationship.

countries. To investigate the relationship between extreme climate changes and income inequality, we specified the following empirical model:

$$GINI_{it} = \alpha + \beta_1 MINT_{it} + \beta_2 MAXT_{it} + \beta_3 MINP_{it} + \beta_4 MAXP_{it} + \beta_5 MSLP_{it} + \beta_6 SS_{it} + \beta_7 ND_{it} + \beta_8 GFCF_{it} + \beta_9 ITRD_{it} + \beta_{10} TUP_{it} + \varepsilon_{it} \quad (4.50)$$

where MINT, MAXT, MINP, and MAXT are the annual minimum and maximum temperature and precipitation, respectively.

Carbon emissions and temperature both are indicators of climate change. According to FAO (2018), both can be used to measure climate change. It is pertinent to mention here that the Symmetry and asymmetric effects of carbon emissions on income inequality have not been investigated yet, by the existing studies. To find whether the carbon emissions have an asymmetric effect on income inequality or it is asymmetry, we employed the following models to assess the symmetry and asymmetric effects of carbon emissions on income inequality:

$$GINI_{it} = \alpha + \beta_1 COEM_{it} + \beta_2 ND_{it} + \beta_3 GFCF_{it} + \beta_4 ITRD_{it} + \beta_5 TUP_{it} + \varepsilon_{it} \quad (4.51)$$

$$GINI_{it} = \alpha + \beta_1 POSC_{it} + \beta_2 NEGC_{it} + \beta_3 ND_{it} + \beta_4 GFCF_{it} + \beta_5 ITRD_{it} + \beta_6 TUP_{it} + \varepsilon_{it} \quad (4.52)$$

where COEM is carbon emissions, POSC and NEGC are positive and negative changes in carbon emissions above and below their mean deviations, respectively.

4.13 Estimation Methods

To assess the effects of climate change on economic growth, we employ Auto Regressive Distributive Lags (ARDL) model. We employed this estimation technique by following Pesaran and Shin (1995), Shin and Smith (1999; 1997), Im *et al.* (2003), and Phillips and Moon (2001). This technique uses to fit the Auto Regressive Distributed Lag (ARDL) model to data. An ARDL model makes it easier to disentangle a relationship between the short run and the long run. It also reduces the estimation issues like endogeneity, parameter heterogeneity, omitted variables, outliers, model uncertainty, etc.

To investigate the effects of climate change on agricultural productivity, this study intends to adopt the empirical strategy adopted by Sheng and Xu (2019) and Lu *et al.* (2019) in their respective research studies. These studies used OLS, panel data regression, and dynamic panel regression as estimation methods for analysis. We employed a fixed-effect model and a random effect model for estimation. When variations are allowed to vary in one or two dimensions, the fixed effect model is feasible (Matyas and Sevestre, 1996). The omission of important variables causes bias in the estimator and the random effect model is capable to deal with the issue of omitted variables case (Kennedy, 2008). The random effects estimator is efficient as it takes both between and within estimators into consideration as compared to the fixed effects model. It considers both cross-section and time-series components (Kennedy, 2008). Hsiao (2007) has provided detailed benefits using panel data analysis considering different effects.

Finally, we employed the ARDL technique to assess the effects of climate change and carbon emissions on income inequality. Although no significant literature exists that guides us that which methodology is feasible to cover the climate-inequality nexus, we believe that using ARDL as an estimation strategy can minimize the estimation issues already raised in the climate-growth relationship. A detailed discussion on both of ARDL approach and panel linear regression models is presented below:

4.13.1 ARDL Approach

Measure the long-run relationship, requires the study variables to be stationary and co-integrated. If such a condition is violated then peculiarity may arise in the efficient estimation process of the economic relationship between them in long run. This study aims to follow the estimation techniques developed by Pesaran and Smith (1995) and Pesaran *et al.* (1999; 1997), Im *et al.* (2003); Phillips and Moon (2001). This technique uses to fit the Autoregressive Distributed Lag (ARDL) model to data. This model further can be specified according to the emerging need to explain and interpret the economic variables through an error correction equation. The proposed error correction equation of panel ARDL form for overall developed and developing economies' analysis is presented as:

$$\Delta y_{it} = \emptyset_i y_{i,t-1} + \beta_i' X_{it} + \Sigma_{j=i}^{\rho-1} \lambda_{ij} \Delta y_{i,t-j} + \Sigma_{j=0}^{q-1} \delta_{ij} \Delta X_{i,t-j} + \mu_{it} + \varepsilon_{it} \quad (4.53)$$

$$\Delta y_{it} = \emptyset_i y_{i,t-1} + \beta_i' X_{it} + \Sigma_{j=i}^{\rho-1} \lambda_{ij} \Delta y_{i,t-j} + \Sigma_{j=0}^{q-1} \delta_{ij} \Delta X_{i,t-j} + \Sigma_{j=0}^{q-1} \gamma_{ij} \Delta X_{i,t-j} \times I(country\ i\ is\ developed) + \mu_{it} + \varepsilon_{it} \quad (4.54)$$

$$\Delta y_{it} = \emptyset_i y_{i,t-1} + \beta_i' X_{it} + \Sigma_{j=i}^{\rho-1} \lambda_{ij} \Delta y_{i,t-j} + \Sigma_{j=0}^{q-1} \delta_{ij} \Delta X_{i,t-j} + \Sigma_{j=0}^{q-1} \gamma_{ij} \Delta X_{i,t-j} \times I(country\ i\ is\ develing) + \mu_{it} + \varepsilon_{it} \quad (4.55)$$

where a country is defined as developed and developing as per the justification provided by the UN in its latest issue "World Economic Situation and Prospects 2019".

The autoregressive Distributive Lag (ARDL) cointegration or bound testing technique presented by Pesaran *et al.* (2001) and Pesaran and Shin (1990) is considered a solution to the problem which arises due to non-stationarity of a series in the long run. It not only considers the non-stationarity issue of a series but also divides an impact of a relationship into the short run and the long run irrespective of whether the variable underlying I(0) or I(1) or a combination of both. The approach is used for time series analysis, but in recent times, its application to panel data is very much evident. Pesaran *et al.* (2001) developed a combined time series and cross-section model for applying it to panel data by adding location to the model. After adding location to a time series model, the ARDL (p,q,......,qk) model is

$$Y_{it} = \sum_{j=1}^{p} \lambda_{ij}\, y_{i,t-j} + \sum_{j=0}^{q} \emptyset'_{ij}\, x_{i,t-j} + \gamma'_i\, d_t + \varepsilon_{it} \quad (4.56)$$

where Y_{it} is a dependent variable having i-th location at a time, t, x_{it} is a vector of explanatory variables at t-time, d_t represents a dummy variable or time trend. Chudik and Pesaran (2015) further developed a model known as the cross-sectional ARDL (CS-ARDL) model as follows:

$$Y_{it} = c_{yi} + \sum_{j=1}^{py} \theta_{ij}\, y_{i,t-j} + \sum_{j=0}^{px} \beta'_{ij}\, x_{i,t-j} + \sum_{j=0}^{pz} \vartheta'_{ij}\, \bar{z}_{t-j} + \varepsilon_{it} \quad (4.57)$$

where $\bar{z} = (\bar{y}_t - \bar{x}_t{}')'$

4.13.1a Mean Group (MG) Estimator

In the dynamic panel, heterogeneity bias emerges due to heterogeneous slopes. To solve the issue of heterogeneity bias Pesaran and Smith (1995) and Pesaran *et al.* (1999) suggested two different estimators. These two estimators are Mean Group (MG) and Pooled Mean Group (PMG) estimators. There is a least restrictive procedure in the MG estimator. MG estimator allows for heterogeneity of parameters where no cross-section or cross-country restriction is imposed. It drives the long-run parameters using ARDL models for individual entities or countries. It estimates regression separately for each country. For estimation using the MG estimator, the following ARDL model is employed:

$$Y_{it} = a_i + \gamma_1 Y_{i,t-1} + \beta_1 X_{it} + u_{it}, \tag{4.58}$$

for all i, and where i=1,2,3,....., N. θ_t as a long-run parameter for country i is:

$$\theta_t = \frac{\beta_i}{1-\gamma_i} \tag{4.59}$$

And for the whole panel, MG estimates are given by:

$$\hat{\theta} = \frac{1}{N}\sum_{i=1}^{N}\theta_i, \tag{4.60}$$

$$\hat{a} = \frac{1}{N}\sum_{i=1}^{N}a_i \tag{4.61}$$

4.13.1b Pooled Mean Group (PMG) Estimator

For the PMG estimator, the ARDL equation system with unrestricted specification $(p, q_1, q_2, ... q_k)$ for period t=1,2,......., T, and for countries i=1,2,........, N for the outcome indicator Y is

$$Y_{it} = \sum_{j=1}^{p}\lambda_{ij}\, y_{i,t-j} + \sum_{j=1}^{q}\gamma_{ij}\, x_{i,t-j} + \mu_i + \varepsilon_{it} \tag{4.62}$$

where Y_{it} is the outcome variable, $x_{i,t-j}$ is the vector of explanatory variables for entity i, λ_{ij} is a scaler, and μ_i contains a fixed effect. The reparametrized VECM system can be modeled as:

$$\Delta Y_{it} = \theta_i(y_{i,t-1} - \beta_i' x_{i,t-1}) + \sum_{j=1}^{p-1}\lambda_{ij}\,\Delta y_{i,t-j} + \sum_{j=1}^{q-1}\gamma_{ij}'\,\Delta x_{i,t-j} + \mu_i + \varepsilon_{it} \tag{4.63}$$

where θ_i is the EC parameter, whereas β_i are parameters in the long run. The PMG estimator assumes the restriction that β elements are common across all countries.

All ECM terms and dynamics are free to change in the OMG estimator. For the selection of the lag length criterion, both PMG and MG estimators require the selection of a lag length that is appropriate for the equation of an individual country. Akaike Information Criterion (AIC) and Schwarz Bayesian Criterion (SBC) can opt for lag-length selection.

Banerjee *et al.* (1998) defined the error correction (EC) term exhibits the speed of adjustment to gain equilibrium using a dynamic model. The ECM indicates how quickly indicators converge or diverge to an equilibrium position after a shock happened to them. It should have a negative and significant coefficient. In equation 4.49, θ_i contains the speed of adjustment which must be negative and significant which indicates convergence in the long run. The highly significant value of ECM shows the existence of a stable relationship in the long run.

For the appropriateness of the estimator between PMG and MG, we employed the Hausman Test. It can assist in the determination of the effects of heterogeneity on the mean values of the coefficient. If parameters are homogeneous, then PMG estimation of regression is more efficient than that of MG. More specifically, if it cannot reject the null hypothesis, then PMG estimation is an efficient one. Contrary to this, if we reject the null hypothesis, the MG estimation is considered an efficient estimator for regression analysis.

4.13.2 Linear Regression Methods

To assess the impact of climate changes on agricultural production, we employed a linear regression model i.e., fixed effects model and random effects model.

4.13.2a Fixed Effects Model

In a fixed effects model, it is assumed that time/group have different intercepts in a regression equation. It is also assumed that the characteristics of an individual that are time-invariant should not be correlated with the characteristics of the other individual. We considered each entity different from the other, therefore, the constant (which captures the characteristics of the individual) and error term of the entity should not be correlated with each other in a fixed effects model. Each entity or cross-section contains characteristics that may or may not affect the predictor variables. For instance, the political condition of a country can affect the trade or GDP of that country, or the business engagements of a firm or company may affect its stock price. The equation of the fixed effects model can be expressed as

$$Y_{it} = \beta_1 X_{it} + \alpha_i + u_{it} \tag{4.64}$$

where Y_{it} is the outcome variable when i=entity and t=time, β_1 is the coefficient for the independent variable, X_{it} is a vector of independent variables, α_i (which ranges from i=1,2,3,.....n) is the intercept of each entity that is unknown, and u_{it} is the error term.

In the case of using binary variables, the fixed effects model becomes:

$$Y_{it} = \alpha_0 + \alpha_1 X_{1,it} + \cdots \dots \dots \dots \dots + \alpha_k X_{k,it} + \beta_2 E_2 + \cdots \dots \dots \dots ... \beta_n E_n + u_{it} \tag{4.65}$$

where Y_{it} is the outcome variable when i=entity and t=time, α_k is the coefficient of the independent variables (IVs), $and\ E_n$ is the nth entity, so we can include n-1 entities in a regression model, and β_2 is the coefficient of a binary variable.

We further can add time effects beside entity effects for obtaining entity and time fixed effects regression model:

$$Y_{it} = \alpha_0 + \alpha_1 X_{1,it} \dots \dots + \alpha_k X_{k,it} + \beta_2 E_2 \dots ... \beta_n E_n + \sigma_2 T_2 + \cdots \dots \dots \sigma_t T_t + u_{it} \tag{4.66}$$

where Y_{it} is the outcome variable when i=entity and t=time, σ_t is the coefficient of the binary time variable, and T_t represents time as a binary variable (dummy), so we have t-1 periods.

4.13.2b Random Effects Model

In the random effects model, we assume that the independent variables (IVs) and the error term of all the entities are not correlated with each other. It allows for time-invariant indicators to play as independent variables. More specifically, it is assumed that variations across entities are random with respect to the independent variables (IVs) or predictors included in the model. In the fixed effects model, time-invariant variables i.e., gender are observed by the intercept. So, it is advantageous in the random effects model that, we can include variables that are time-invariant. The model for the random effects method can be expressed as for unit or entity i:

$$y_i = X_i\beta_i + \alpha + (u_i - \epsilon_i) \tag{4.67}$$

For a specific time period and for unit or entity i, the random effects model becomes:

$$y_{it} = X_{it}\beta_i + \alpha + (u_i - \epsilon_{it}) \tag{4.68}$$

where y_{it} is the outcome variable, β_i is the coefficient of independent variables, X_{it} is the vector of IVs, α is the intercept of the linear regression model, and u_i is the variance of unit-specific effect for each entity i. ϵ_{it} is the error term for entity i at t-time. We can also write the equation of the fixed effects model in a matrix form:

$$y_{it} = [x_{i1t} \;\; x_{i2t}, \dots \dots \dots, x_{ikt}] \begin{bmatrix} \beta_{i1} \\ \vdots \\ \beta_{ik} \end{bmatrix} + \alpha + (u_i - \epsilon_{it}) \tag{4.69}$$

4.14 Conclusion

This chapter presented the methodology of the study. Following the panel data analyses, we highlighted the importance of different unit root and panel cointegration tests. Empirical methods are specified to estimate the influences of climate change on economic growth, agricultural production, and income inequality. We employed two estimation methods i.e., the ARDL approach and panel linear regression. In an ARDL approach, we further employed two estimation strategies i.e., PMG and MG estimations. Similarly, in panel linear regression models, we used fixed effects and random effects, models. We also presented the derivations by writing the equations of models used for regression analysis. To assess the effects of climate change on economic growth and income inequality using panel data and time-series data from Pakistan, we employed the ARDL technique. On one hand, this technique, minimizes the econometric issues related to the estimation process, while on the other hand, this technique divides the effects into two periods e.g., the short run and the long run. To cover the effects of climate change on agricultural production, we used linear panel data regression i.e., fixed effect method and random effect method.

Chapter 5

Results and Discussions

5.1 Introduction

This chapter includes the estimation results and their interpretations. It starts with summary statistics of the variables. It also includes the results of different unit root tests and panel cointegration tests which are shown in Tables 5.2 and 5.3, respectively. After these tests, the estimation results of climate change and economic growth, climate change and food production, climate change and crop production, and climate change and income inequality are presented, respectively. It also includes the estimation results and their interpretation of the issue of climate change and its impact on food and crop production in Pakistan.

5.2 Summary Statistics

The descriptive statistics of the study variables are presented in Table 5.1. The statistics indicate that the mean GDP per capita is 12.3518 thousand dollar during this range of study period at the global level for the 179 countries. The mean real GDP per capita varies significantly across developed and developing countries[11]. The global mean temperature hovered around 18.48°C during the examined period. The average level of precipitation for this period has remained around 97.67 millimeters. There is also a significant variation in the level of precipitation which remained at 416.64 as the maximum and 0.77 millimeters as the minimum during the study period. Similarly, the mean value of the average minimum and maximum temperature remained at 11.6C and 24.6C, respectively. The mean sea level pressure and hourly sunshine were recorded as 425.60 millibars and 88 hours, respectively. The statistics indicate that the mean

[11] Base year for the computation of GDP per capita and real GDP is 2015.

food price index, crop production index, and Gini coefficient are 78.4, 78.1, and 37.85, respectively during this range of study period at the global level for 179 countries[12].

Table 5.1: Descriptive statistics of the variables

Variables	Observations	Mean	S.D	Min	Max
RGDP($10bl)	7339	3080	11441.98	0.2144	173486.3
GDPPC($K)	7339	12.3518	20.4296	0.1642	195.88
FPI	7339	78.4009	52.5638	0	1097.43
CPI	7339	78.10355	46.23894	0	405.27
TEMP	7339	18.4823	8.7609	0.041	29.5411
PRCP	7339	97.6766	71.0858	0.7729	416.6405
MSLP	7339	425.60	499.08	0	1014
SS	7339	87.66	111.8922	0	665.5
GFCF($10bl)	7339	52.51	224.89	0.0374	3808.57
MINT	7339	11.59	13.00	-31.72	28.43
MAXT	7339	24.6079	5.6278	-4.09	37.55
MINP	7339	25.75	35.27	2.483	260.63
MAXP	7339	214.06	151.86	3.16	1136.15
GFCF($10bl)	7339	52.51	224.89	0.0374	3808.57
MREX($10bl)	7339	468.74	1629.36	0.02	25902.21
FAFD($10bl)	7339	36.16	77.15	-108.04	2455.22
TMPA	7339	13.25	80.64	0	2798.19
GINI	5549	37.85	9.1360	16.23	74.3
COEM	5549	4.6842	6.2735	0.011	70.13
TUP	5549	15.05	40.1978	2278	823.83
EMAG	7339	31.29	23.4320	0.125	92.557
UPOT	7339	50.51621	25.85171	0	100
AGLD	7339	40.19	21.3597	0.4487	86.1673

Source: authors' own calculations

To evaluate the order of integration, we apply panel unit root tests of different forms. In addition, to assess the long-run relationship among the study variables, this study intends to conduct panel cointegration tests. However, to start the empirical analysis, the study presents scatter plots of climate indicators and real GDP as a precursor to preview the nature of their relationships. Figure 5.1 plots the temperature against real GDP which exhibits a somewhat negative relationship between the variables. It indicates the effect of temperature on economic growth is detrimental. Few outlier observations show that negative values of temperature are associated with low real GDP. Further, the relationship between real GDP and precipitation is negative as in the preview of the scatter plot in Figure 5.2.

[12] Base years for the computation of FPI and CPI are 2014-2016.

Figure 5.1: Scatter plot of real GDP and Temperature

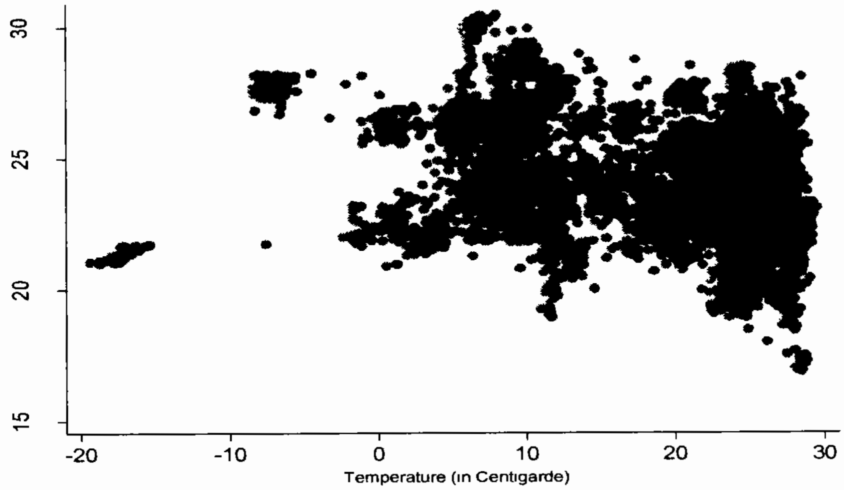
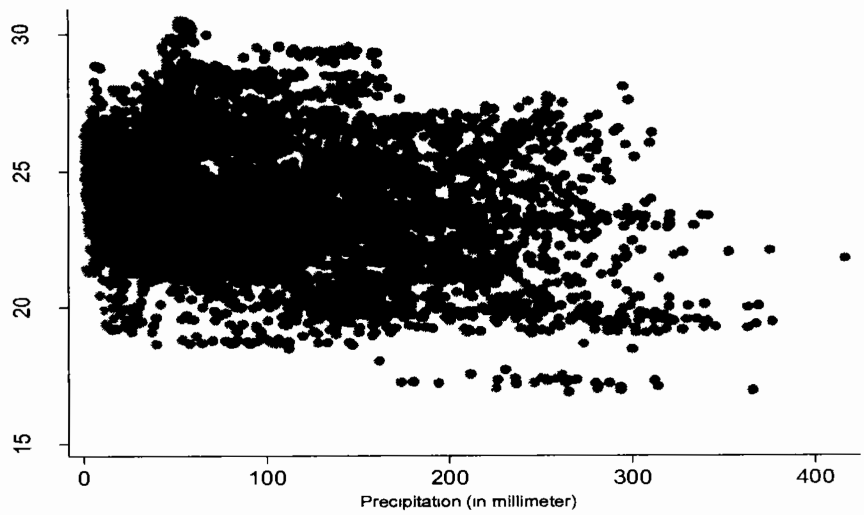


Figure 5.2: Scatter plot of real GDP and Precipitation



Source: authors' own creation

5.3 Results of Unit Root Tests

Several authors have introduced different unit root tests in order to ensure the stationarity of different variables. These tests include Levin-Lin Chu's (LLC)t*-state, Hadri's z-state, Breitung't-state, Im-Pesaran-Shin's W-t-bar state, and ADF Fisher's $\chi2$ statistic[13]. Three of these tests are based on the assumption of a common unit root process which exhibits that autocorrelation coefficients of the study variables are identical across cross-sections. The other two, Im-Pesaran-Shin's W-t-bar state and ADF-Fisher χ^2 tests depend upon the individual unit process with the assumption that autocorrelation coefficients vary across cross-sections. To avoid the problem of cross-section dependence, cross-sectional means for some of the tests are subtracted. A deterministic time trend is included for most of the variables. This study uses Schwarz Bayesian Information Criterion (SBIC) to determine the suitable lag length for empirical models. Spectral estimation is undertaken by the HAC options of Bartlett kernel with the HAC (Newey-West) bandwidth selection algorithm.

The results of unit root tests are presented in Table 5.2. In general, all the tests show that the majority of the variables are non-stationary at levels.[14] Nevertheless, they appear stationary at the first difference. For example, Levin-Lin Chu (LLC) test indicates that all the study variables are stationary.[15] Similarly, the IPS test also shows similar results as all the study variables are stationary. The results of the Breitung test somewhat indicate that not all the variables are significant as some of them possess insignificant p-value indicating the existence of non-stationarity in the case of real GDP per capita, and foreign aid and financial development. The remaining variables, i.e., real GDP, temperature, precipitation, and international trade are stationary. The result of the Hadri test does not support the assumption of stationarity for the variables of the study. According to this test, null is rejected that all panels are stationary, which

[13] For more info, see Maddala and Wu (1999), Im, Pesaran, and Shin (2003), Breitung (2000), and Hadri (2000).

[14] Literature on panel data mostly uses these tests. Our study follows the norms of existing literature and applies these tests to assess the stationarity of the variables.

[15] See LLC and Chu (2002).

indicates that some of the panels have a unit root problem. Lastly, the results of the ADF-Fisher $\chi 2$ tests provide evidence of the existence of stationarity of all the variables of the study by

Table 5.2: The results of panel unit root tests (At First difference)

	Tests assuming a common unit root process			Tests assuming individual unit root	
Series Name	**LLC t*-State**	**Breitung t-sate**	**Hadri z-state**	**IPS W-t-bar state**	**ADF-Fisher KS**
LNRGDP	-7.9697***	-3.3441***	228.6353***	-3.232***	16.8496***
	-0.0000	0.0004	0.0000	0.0006	0.0000
LNGDPPC	-3.5004***	3.7068	208.249***	-73.144***	12.805***
	-0.0000	0.9999	0.0000	0.0000	0.0000
LNTEMP	-24.9184***	-20.204***	12.40***	-21.0117***	82.969***
	-0.0000	0.0000	0.0000	0.0000	0.0000
LNPRCP	-32.3145***	-9.2205***	77.385***	-36.323***	101.375***
	-0.00001	0.0000	0.0000	0.0000	0.0000
LNMSLP	-	-	-	-	42.489***
	-	-	-	-	0.0000
LNSS	-	-	15.5026***	-	22.988***
	-	-	0.0000	-	0.0000
LNFAFD	-4.8254***	23.9305	84.738***	-3.956***	8.4765***
	-0.0000	1.00001	0.0000	0.0000	0.0000
LNGFCF	-6.8254***	-4.6654***	55.8014***	-12.2254***	8.2123***
	-0.0000	-0.0000	0.0000	-0.0000	0.0000
LNMREX	-2.4222*	-8.2342***	103.3225***	-5.7523***	9.5203***
	0.0769	0.0000	0.0000	0.0000	0.0000
LNTMPA	-3.3145***	-4.2205***	77.3849***	-36.3234***	101.375***
	-0.0000	0.0000	0.0000	0.0000	0.0000
FP1	-8.3468***	-5.4617***	123.87***	-7.3587***	17.6127***
	0.00001	0.00001	0.0000	0.0000	0.0000
CPI	-3.8146***	-8.2885***	101.9879***	-18.1620***	20.6260***
	-0.0000	0.0000	0.0000	0.0000	0.0000
EMAG	-11.0430***	-10.897***	190.085***	-2.2581***	23.65***
	0.0000	0.0000	0.0000	0.0000	0.0000
UPOT	-12.0982***	-29.567***	2.4670***	-22.7935***	193.83***
	0.0000	0.0000	0.0068	0.0000	0.0000
AGLD	-7.4477***	-5.3857***	102.30***	2.4844	-9.7519***
	0.0000	0.0000	0.0000	0.9935	1.0000
GINI	-14.3016***	-11.7823***	77.6353***	-20.2325***	79.8496***
	-0.0000	0.0000	0.0000	0.0000	0.0000
LNCOEM	-12.5156***	-7.7903***	49.7634***	3.5649***	19.4566***
	0.0000	0.0000	0.0000	0.0000	0.0000
LNGFCF	-12.8254***	-7.9305***	44.7384***	-30.8821***	70.4765***
	0.0000	0.0000	0.0000	0.0000	0.0000
LNTUP	-26.3145***	-40.2205***	2.5984**	-41.3234***	113.3752***
	-0.0000	0.0000	0.0047	0.0000	0.0000

Note: ***,** and * show statistical significance at the 1%,5% and 10% levels, respectively. The results on MSLP and SS for LLC, Breitung, and Hadri are not in the table as these tests require a strongly balanced dataset. As some of the countries do not possess the data on these variables, so, the concerned Organizations are not in a position to report the data on these variables for some or the whole years of the study of some countries.

rejecting the null hypothesis that all the panels have unit roots. For this study, we followed the proposed unit root process by using all these tests in the research work of Alagidede *et al* (2015).

5.4 Results of Panel Cointegration Tests

It is customary to use the panel cointegration tests to judge the long-run relationship among the variables. The results of three major panel cointegration tests e.g., Pedroni, Kao, and Westerlund are presented in Table 5.3.[16] The results of Pedroni's cointegration test provide evidence of cointegration among the variables. All the test statistics are statistically significant when considering auto-regression parameters to be the same while all of them strongly support the rationale for cointegration. For example, the result of Kao's cointegration strongly supports the case for the presence of cointegration among variables when AR parameters are considered

Table 5.3: Panel cointegration results

Pedroni test for cointegration (when AR parameters are the same)		
	Test statistics	P-Value
Modified variance ratio	-15.1662	0.0000
Modified Phillips-Parron t	13.7202	0.0000
Phillips-Parron t	1.6243	0.0520
Augmented-Dicky-Fuller t	2.3414	0.0096
Pedroni test for cointegration (when AR parameters are panel specific)		
Modified Phillips-Parron t	18.1637	0.0000
Phillips-Parron t	4.9152	0.0000
Augmented-Dicky-Fuller t	6.1882	0.0000
Kao's residual cointegration test		
Modified Dicky-Fuller t	4.1536	0.0000
Dicky-Fuller t	4.4881	0.0000
Augmented-Dicky-Fuller t	-1.8562	0.0317
Westerlund test for cointegration (when AR parameters are the same)		
Variance ratio	17.0272	0.0000
Westerlund test for cointegration (when AR parameters are panel specific)		
Variance ratio	19.6355	0.0000

Note: All the test's null hypothesis assumes that the panel exhibits no cointegration with the alternative hypothesis showing some or all the panels to be co-integrated. For Kao's residual test, there is no deterministic trend and its lag length is based on the (AIC) with a maximum length of 3.

to be panel-specific. Lastly, the Westerlund test for cointegration also strongly supports the existence of cointegration for the case when AR parameters are the same as well as when AR parameters are panel-specific.

[16]For more detail, see Pedroni (1995), Kao (1999), and Westerlund (2008).

5.5 Estimation Results and their interpretations

To estimate the impact of changes in climate on economic growth, this study applies a unit root test to assess the stationarity of the study variables and panel cointegration tests to ascertain the long-run relationship among the variables. Most of the tests confirm that variables are stationary at the first difference while three cointegration tests also show the presence of long-run relationships among them. Besides, in this study, two different tests are used to check the issue of misspecification bias in models i.e., the LM test and the Ramsey RESET test. For most of the models, our test results are acceptable. However, the Ramsey RESET test in the case of the climate-growth model is not significant. Overall, on the basis of these results, it can be inferred that the models of the study are reliable and are expressing acceptable relationships.

Pooled Mean Group (PMG) and Mean Group (MG) strategies are reported in Table 5.4. The estimation procedure uses both real GDP and GDP per capita to capture the climate change impact on the economic growth of 179 countries. For the long-run relationship of variables, error correction terms of both MG and PMG estimators are expected to be negative and significantly consistent. The coefficients of the error correction term have negative and significant values. The convergence coefficients of the two estimates indicate that a model does not immediately return to its state of equilibrium after a shock moves it away from the steady state. The study presents results by using three dimensions e.g., (i) using mean values of major climate indicators as regressors and (ii) using the extreme values (average minimum and maximum) of major climate indicators, and (iii) positive and negative mean deviations from their mean values of two major climate indicators as independent variables to capture the impact of changes in climate on economic growth (real GDP and real GDP per capita).

This study uses two specifications for each dimension to assess the effects of changes in climate on the economy. The first specification uses only the climatic indicators while the second includes all indicators e.g., climatic and non-climatic indicators to form a full model. In the first dimension, the results of the first specification exhibit elasticities as all the variables are in their logarithmic form in Table 5.4. The effects of mean temperature, precipitation, and dummy variable used for flood, drought, and storm are detrimental to real gross domestic product (GDP) that significantly reduce economic growth in the long run. The resultant coefficient of temperature shows that a percent increase in temperature significantly reduces the global GDP on average by 0.85%, ceteris paribus.

Temperature rise can potentially affect the economic performance either by affecting the yield of the agriculture sector or by affecting the institutions or investments which can affect the growth ability of an economy. Temperature rise may have both level as well as growth effects on the global economic system. It can also bring devastation to the industrial sector. Hot and humid conditions affect the production of the industrial sector. Further, it can negatively affect the health of humans in general and of laborers in particular which in turn reduces labor productivity. Climate changes increase mortality, and conflict (Acevedo, 2018; Hsiang, 2010; Dell and Olkan, 2010; Kalkhul and Wenz, 2020; Schlenker and Auffhammer, 2018).

Mean sea level pressure which works as an opposite indicator of mean sea level rise exerts positive effects on real GDP while the duration of sunshine reduces it but the effect in a later case is insignificant. Rising sea level causes devastation to countries an economic output that comes from coastal areas. Sea-level pressure or air pressure at sea level can either raise or lower the level of the sea through the Barometric effect. It's due to the reason that when low pressure is in place over the ocean, less weight (and thus, less force) is exerted downward, causing the water level to rise. Sea-level rise is a result of melting glaciers and ice sheets combined with seawater thermal expansion which is primarily caused by rising temperatures.

Mean sea level pressure is used as an indicator in place of sea level rise. Sea level pressure is an inferential indicator used to indirectly show the influence of sea level rise on economic activities. Sea level does not directly affect the economic outcomes in most cases rather its effects are indirect. It causes the sea level to either rise or fall. In our case, it is falling which provides us justification that the sea level is rising as per the definition of the barometric effect. The rise in sea level may result in coastal inundation, and loss of wetlands, beaches, and coastal ecosystems such as salt marshes, mangroves, tidal flats, and fisheries (Stern, 2007; Nicholls *et al.*, 2007; IPCC, 2007b). These losses can hamper the economic performance of a country.

The results, in the short run, also show almost similar effects for real GDP but with smaller coefficients. For instance, temperature, precipitation, and sunshine duration adversely affect economic growth, whereas, sea-level pressure enhances it. The reason that sunshine's impact is significant in the short run compared to the long run is that its impact is not significant in the long run which might be due to adaptation. In the long run, adaptation may not only reduce the adverse impact of climate change on economic growth but also reduces the adverse impacts of other climate change indicators. Natural disasters are more likely to adversely affect the economic growth of developing compared to developed economies. The control variables e.g., gross fixed capital formation, and merchandise exports enhances economic growth, while financial assistance and financial development, as well as trademark and patent applications, assert positive impacts on economic performance but their effect in insignificant.

In specification 2, the results for climatic indicators are similar to that of specification 1 with minor changes in the values of coefficients in the long run. However, the effects of non-climatic indicators i.e., foreign aid and financial development and trademark and patent applications assert a positive and significant influence on real GDP while gross fixed capital formation exerts a positive and significant effect on real GDP. For instance, the estimated value of the coefficient suggests that a 1% increase in foreign aid and financial development causes a rise of 0.31% in real GDP while a similar 1% increase in trademark and patent applications enhances real GDP by 0.1%. This paper also considers GDP per capita as the dependent variable. The estimation results for the long run for specification 1 indicate that climate change indicators like temperature, disasters' dummy, and sunshine duration exert damaging effects on GDP per capita. All these effects are significant except for mean precipitation, whereas, mean sea level pressure exerts positive effects on GDP per capita. However, in the short run, the effects change marginally as the coefficient of precipitation also becomes significant and negative.

The second specification shows the results of the full model where the effects of most of the climate change indicators are significantly detrimental except for sunshine duration while mean sea level pressure again shows its positive effect on GDP per capita. The estimation output of specification 2, shows semi-elasticities where the signs of coefficients are similar to that of what was observed in specification 1. However, the magnitudes of coefficients are smaller as we have included other non-climatic indicators. The results of the first dimension are following the nature of the theory as temperature according to the majority of the literature hurts the economic well-being of the masses. Similarly, results follow the theory in the case of precipitation which provides the justification that changes in patterns of precipitation may enhance as well as assert detrimental effects on economic activities. Disasters always bring a downfall to economic

Table 5.4: Long-run and short-run estimation results

Independent Variables	Real GDP as Dependent Variable				GDP per capita as Dependent Variable			
	Specification 1		Specification 2		Specification 1		Specification 2	
	MG	PMG	MG	PMG	MG	PMG	MG	PMG
Panel A: Long-run estimates								
Cointeq	-0.012***	-0.011***	-0.017***	-0.015***	-0.018***	-0 016***	-0 010***	-0.013***
TEMP	-0.86***	-0.82***	-0 85***	-0 84***	-0.076**	-0.079**	-0.55***	-0.62***
	(0.2514)	(0.232)	(0.2422)	(0.2231)	(0.039)	(0.041)	(0.25)	(0.33)
PRCP	-0.32***	-0.45***	-0 33***	-0.34***	-0.01	-0.02*	-0.042*	-0.054*
	(0.1405)	(0.1424)	(0.1187)	(0.1190)	(0.017)	(0.015)	(0.037)	(0.046)
FDS	-0.62**	-0.60**	-0.62**	-0.64**	-0.028**	-0 038**	-0.14***	-0.074**
	(0.2714)	(0.2985)	(0.3006)	(0.3210)	(0.028)	(0.052)	(0.047)	(0.043)
MSLP	0.03**	0.04*	0.022**	0.032**	0.13*	0.15*	0.03**	0 02*
	(0.012)	(0.011)	(0.62)	(0.69)	(0 102)	(0.104)	(0.025)	(0.015)
SS	-0.06	-0.052	-0.47	-0.60	-0.10*	-0.11	-0.12**	0.24**
	(0.071)	(0.062)	(0.60)	(0.64)	(0.054)	(0.075)	(0.050)	(0.042)
GFCF			0.22**	0 24*			0.12*	0.19**
			(0.993)	(0.824)			(0.704)	(0.764)
FAFD			0.31***	0.23***			0.014*	0.017***
			(0.1975)	(0.1775)			(0.011)	(0.012)
MREX			0.67***	0.58***			0.022	0.034*
			(0.928)	(0.962)			(0.04)	(0.03)
TMPA			0.096***	0.071***			0.004**	0 003**
			(0 051)	(0.0244)			(0.001)	(0.002)
Panel B: Short-run estimates								
ΔTEMP	-0.16***	-0.15***	-0.15***	-0.10**	-0.15***	-0.14**	-0.14***	-0.17**
	(0.0467)	(0.0471)	(0.0607)	(0.0541)	(0.0477)	(0.044)	(0.014)	(0.012)
ΔPRCP	-0.007*	-0.006**	-0.009*	-0.007	-0.007*	-0.006**	-0.002*	-0.004*
	(0.08)	(0.07)	(0.06)	(0.07)	(0.008)	(0.007)	(0.031)	(0.024)
ΔFDS	-0.15**	-0.13**	-0.22**	-0.19**	-0.15**	-0.21*	-0.013***	-0.014**
	(0.0861)	(0.0798)	(0.102)	(0.1212)	(0.0861)	(0.0671)	(0.002)	(0.001)
ΔMSLP	0.005**	0.004**	0.005**	0.004	0.005**	0.004**	0.001**	0 001*
	(0 002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.001)	(0.001)
ΔSS	-0.001	-0.002	-0.02**	-0.02**	-0 001	-0.001	-0.001	-0.001
	(0.007)	(0.006)	(0.013)	(0.012)	(0.007)	(0.006)	(0.002)	0.003
ΔGFCF			0.052***	0.054**			0.025**	0.027*
			(0.038)	(0.045)			(0.016)	(0.017)
ΔFAFD			0.001	0.002			-0.001***	-0.001***
			(0.002)	(0.001)			(0.001)	(0.001)
ΔMREX			0.073***	0.080**			0.030***	0.024***
			(0.048)	(0.037)			(0.045)	(0.040)
ΔTMPA			0.001	0.001			0.001***	0.002**
			(0.001)	(0.001)			(0.001)	(0.002)
Hausman test χ^2	79.4(0.002)	78.2(0.000)	77.3(0.000)	77.6.2(0.000)	69.2(0.012)	70 5(0.000)	68 4.2(0.000)	72.6(0.000)
No. of countries	179	179	179	179	179	179	179	179
Year Effects	No	No	Yes	Yes	No	No	Yes	Yes
Country Effects	No	No	Yes	Yes	No	No	Yes	Yes
No. of obs	7339	7339	7339	7339	7339	7339	7339	7339

Note: Real GDP and GDP per capita are the dependent variables The values in parenthesis are standard errors. ***, **,* show significance at the 1%, 5% and 10% levels, respectively. Model 1 only considers the climatic indicators while Model 2 represents the full model which includes both climate and non-climate indicators, respectively. In model 1 on both left and right sides, climatic variables are in logarithmic form and hence need to interpret as elasticities while in model 2 on the left side, temperature, precipitation, and foreign aid and financial development are in logarithmic form and are interpreted as semi-elasticities. The coefficients of the remaining variables and model 2 on the right side of the table need to interpret as semi-elasticities.

prosperity. These hazards most likely affect the poor economies relative to rich economies which can be due to the reasons that the former have less capacity to cope with disastrous situations.

All the non-climatic indicators positively contribute to GDP per capita in the long run. In the case of the short run, the effects change in terms of signs and significance, especially of non-climatic indicators. For instance, the impacts of temperature, precipitation, and sunshine duration are adverse for GDP per capita though the magnitudes of the coefficients become smaller compared to the long-run coefficients. Natural disasters are again more likely to reduce the per capita GDP of developing compared to developed economies. Foreign aid and financial development reduces GDP per capita which might be due to the reason that this type of assistance takes time to exert its positive implications on economies. The remaining control variables e.g., gross fixed capital, merchandise exports, and trademark and patent applications boost economic growth.

There are numerous channels through which climate change affects economic performance. Integrated Assessment Models (IAMs) are an important approach used extensively in literature pertinent to climate change that models the climate-economy relationship (Dell *et al.*,2012). Climate change literature, based on Integrated Assessment Models, at the micro level, exhibits a wide range of potential effects of temperature on economic growth including impacts on the productivity of the agriculture sector, physical performance, mortality, cognitive performance, social unrest, crime, and others.[17] Similarly, an increase in temperature can lead to political instability which can impede productivity growth and factor accumulation (Dell *et al.*,

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[17] For instance, on labor income, see, e.g., Dell *et al.* (2009); on agriculture, see, e.g., Schlenker and Roberts (2006); Adam *et al.* (1990); Deschenes and Greenstone (2007); Mendelsohn, Dinar, and Saughi (2001); and Guiteras (2007), on agricultural and industrial value-added, see, e.g., Dell *et al.* (2012); Dell & Olkans (2010).On health, see, e.g., Deschenes and Moratti (2009); Curriero *et al.* (2002); Deschenes and Greenstone (2007); Sachs and Malaney (2002); Gallup and Sachs (2001); and on soil quality, water tables, and health, see, e.g., Meehl *et al.* (2004). On human well-being (Deschenes, 2014; Hsiang *et al.*, 2013; Patz *et al.*, 2005). On ecosystem functioning (IPCC, 2014; Hoegh-Gulberg & Bruno, 2010), human capital (Graff Zivin *et al.*, 2018; Graff Zivin & Neidell, 2014), crop yield(Chenet *et al.*, 2016; Schlenker & Roberts, 2009). Similarly, on the productivity of labor, see, e.g., Zivine and Neidell (2010); Huntington (1915); Meese *et al.* (1982); Kalkuhl & Wenz 2020). On social unrest and crime, see, e.g., Jacob *et al.* (2007); Field (1992); and Miguel *et al.* (2004). Many other possible channels through which climate change can impact economic growth are discussed in the 4[th] assessment report of IPCC(2007).

2012). Empirical evidence shows that political instability leads to lower economic performance (Alesina, 1996). Warm weather is more likely to become a cause of protest and riots (Carlsmith & Anderson, 1979; US Riot Commission 1968; Boyanowsky, 1999). The higher temperature might provoke the dissatisfied public to seek an institutional change (Bruckner and Ciccone, 2011; Burke & Leigh 2010).

Table 5.5 presents the results based on extreme values of major climate indicators using the model setting of the first dimension[18]. This dimension uses the extreme values (minimum and maximum) of two major climate change indicators e.g., temperature and precipitation to assess whether these extreme changes also affect economic growth or not. The long-run estimates in Panel A of Table 5 show that minimum temperature, maximum precipitation, and disaster dummy negatively and significantly reduce the real GDP while minimum precipitation and mean sea level pressure exert positive effects on real GDP. The estimated value of the coefficient indicated that a 1% increase in minimum temperature (more cold weather conditions) reduces real GDP by 0.84%. The effect of maximum temperature and sunshine duration is insignificant. The short-run estimates are almost similar effects in terms of sign and significance but their magnitudes are much smaller as compared to that of the long-run estimates. The results of the full model show similar effects of changes in climate indicators. However, non-climatic indicators like foreign aid and financial development, gross fixed capital formation, and trademark and patent applications have positive impacts on the real GDP. The short-run estimates differ compared to the long-run estimates of sunshine duration which marginally reduces the real GDP.

[18] This study tries to cover the average, asymmetric, and extreme effects of climate change. To accomplish this task, we say, the first dimension covers the average effects, the second dimension focuses on extreme effects; while the third covers the asymmetric effects.

Minimum temperature, minimum precipitation, and disasters dummy negatively and significantly related to GDP per capita, whereas, maximum precipitation and mean sea level pressure influence the GDP per capita positively in the long run. The short-run estimation output reveals almost similar effects of climate indicators. In specification 2, under the pooled mean strategy, the results of the full model postulate that the coefficients of climate indicators need to interpret as semi-elasticities as these indicators are without logarithmic form while non-climatic indicators are in their logarithmic form so need to interpret as elasticities. The effects of minimum temperature, maximum temperature, and disaster dummy are detrimental to GDP per capita in the long run. For instance, colder weather or an increase in minimum temperature reduces GDP per capita by 0.47% on average, ceteris paribus. Maximum precipitation and mean sea level are positively related to GDP per capita. Non-climatic factors like merchandize exports and trademark and patent application enhance GDP per capita while foreign aid and financial development reduce it significantly. In the short run, minimum temperature and flood, drought, storm, and storm dummy significantly reduce GDP per capita. The effect of minimum precipitation is marginally positive on economic growth, whereas, other climatic indicators are insignificant. Control variables e.g., gross fixed capital formation, merchandise exports, and trademark and patent application enhance economic performance, while foreign assistance and financial development reduce it.

A few channels through which climate extremes could affect GDP include labor supply responses, damages to the stock of capital, and investment behavior fluctuations (Lecocq & Shalizi, 2007; Moore & Diaz, 2015; Fankhauser & Tol, 2005), output loss including damages on capital and labor productivity loss (Piontek *et al.*, 2019). Rising temperatures can affect the health of the public and reduce educational attainment which can lead to a long-term slowdown

Table 5.5:Long-run and short-run estimation results

Independent Variables	Real GDP as Dependent Variable				GDP per capita as Dependent Variable			
	Specification 1		Specification 2		Specification 1		Specification 2	
	MG	PMG	MG	PMG	MG	PMG	MG	PMG
Panel A: Long-run estimates								
Cointeq	-0.07***	-0.06***	-0.10***	-0.09***	-0.012***	-0.017***	-0 01***	-0 02***
MINT	-1.11***	-1.25***	-0.84***	-0.93***	-0.15***	-0.14***	-0.47***	-0.65***
	(0.4215)	(0.4110)	(0.3231)	(0.3155)	(0.45)	(0.40)	(0.25)	(0.30)
MAXT	1.06	1.05	1 44	1.47	0.16	0.16	-0.14***	-0.20***
	(0.9271)	(0.8866)	(0.9745)	(0.9785)	(0 1542)	(0.1560)	(0.04)	(0.03)
MINP	0.18***	0.19***	0.25***	0.27***	-0.30*	-0.42*	0.09**	0.08**
	(0.0517)	(0.0611)	(0.067)	(0.058)	(0.16)	(0.13)	(0.037)	(0.048)
MAXP	-0.61***	-0.59***	-0 57***	-0.61***	0.16***	0.13***	-0.15	-0.19
	(0.1491)	(0.1405)	(0.2412)	(0.2310)	(0.64)	(0.71)	(0.01)	(0.01)
FDS	-0 051*	-0.046**	-0.13*	-0 14*	-0.10*	-0.14*	-0.77**	-0.76**
	(0.3271)	(0.3068)	(0.4094)	(0.4144)	(0.11)	(0.08)	(0.44)	(0.39)
MSLP	1 14***	1.21***	1.02**	1 04**	0 24**	0.26**	0 01	0 02
	(0.9512)	(0.9498)	(0.8010)	(0.8210)	(0.1303)	(0.1471)	(0.012)	(0.014)
SS	-0.35	-0.31	-0.54	-0.58	-0.13	-0.11	-0.43*	-0.38*
	(0.8935)	(0.8814)	(0.7162)	(0.7074)	(0.1372)	(0.1410)	(0.34)	(0.41)
GFCF			0.23**	0.34*			0.22*	0.25**
			(0.998)	(0.941)			(0.721)	(0.864)
FAFD			0.21**	0.23**			-0.23***	-0.26***
			(0.10)	(0.09)			(0.10)	(0.09)
MREX			0.72***	0.62***			0.032	0.037*
			(0.879)	(0.794)			(0.04)	(0.03)
TMPA			0.015***	0.018***			0.36***	0.33***
			(0.025)	(0.023)			(0.10)	(0.12)
Panel B: Short-run estimates								
ΔMINT	-0.26***	-0.17***	-0.37***	-0 44***	-0.03***	-0.02***	-0.03**	-0.03**
	(0.031)	(0 034)	(0.044)	(0.043)	(0.05)	(0.04)	(0.03)	(0.05)
ΔMAXT	0.08	0.09	0.14	0.11	0.021	0.03	-0 012	-0.02
	(0.071)	(0 069)	(0.098)	(0.088)	(0.022)	(0.01)	(0.013)	(0.01)
ΔMINP	0.015***	0.011***	0.022***	0.021***	-0.021**	-0 03**	0.014*	0.012*
	(0.004)	(0.005)	(0.005)	(0.004)	(0.026)	(0.021)	(0.014)	(0 021)
ΔMAXP	-0.06***	-0.06***	-0.056***	-0 053***	0.023***	0.026***	0.013	0.021
	(0.017)	(0.015)	(0.0218)	(0.0211)	(0.061)	(0.05)	(0.014)	(0.016)
ΔFDS	-0.142*	-0.139*	-0.151*	-0.154**	-0.15***	-0.14***	-0.092***	-0.12***
	(0.093)	(0.089)	(0.1223)	(0.1202)	(0.04)	(0.03)	(0.06)	(0.05)
ΔMSLP	0.162***	0.17***	0 19**	0.20**	0 003*	0.002*	-0.01	-0.012
	(0.068)	(0.061)	(0.089)	(0.089)	(0.02)	(0.04)	(0.01)	(0.015)
ΔSS	-0.026	-0.022	-0.051*	-0.052*	-0.02	-0.03	-0.01	-0.01
	(0.049)	(0.043)	(0.066)	(0.057)	(0.04)	(0.03)	(0.014)	(0.012)
ΔGFCF			0.063***	0.047**			0.026**	0 033*
			(0.044)	(0.040)			(0.0210	(0.022)
ΔFAFD			0.02**	0.01**			-0.05***	-0.04***
			(0.009)	(0.009)			(0.02)	(0.03)
ΔMREX			0.063***	0.087**			0.021***	0.026***
			(0.042)	(0.037)			(0.045)	(0.040)
ΔTMPA			0.025***	0.021***			0.04***	0.03***
			(0.006)	(0.005)			(0.01)	(0.02)
Hausman test χ^2	78.2(0.000)	76.2(0.000)	73 6(0.000)	70.8(0.000)	78.2(0.000)	73 1(0.0045)	74 4(0.000)	77.1 (0 0064)
No. of countries	179	179	179	179	179	179	179	179
Year Effects	No	No	Yes	Yes	No	No	Yes	Yes
Country Effects	No	No	Yes	Yes	No	No	Yes	Yes
No. of obs	7339	7339	7339	7339	7339	7339	7339	7339

Note: Real GDP and GDP per capita are the dependent variables. The values in parenthesis are standard errors. ***, **,* show significance at 1%, 5% and 10% levels, respectively. Model 1 only considers the climatic indicators while Model 2 represents the full model which includes both climate and non-climate indicators, respectively. In model 1 on both the left and right sides, climatic variables are in logarithmic form and hence need to interpret as elasticities while in model 2 on the left side, variables are in logarithmic form and are interpreted as semi-elasticities. The coefficients of model 2 on the right side of the table need to interpret as semi-elasticities of economic performance. Labor productivity decline and investment level can also decrease as a result of lower sales or profitability (Cavallo, 2020). Similarly, higher temperatures affect educational attainment. It can reduce scores on tests and learning (Goodman *et al.*, 2020; Park, 2020).

Thirdly, this study assesses the said effect of climate changes on economic growth by using the positive and negative changes occurring to the average level of temperature and precipitation above and below their historical mean levels, respectively[19]. The estimation output in Table 5.6 is based on the mean group (MG) strategy. In the long run, shows that positive deviations in temperature above its historical mean level and negative deviations below its historical levels of temperature and precipitation hurt the real GDP. The dummy variable of natural disasters is likely to exert a detrimental effect on the real GDP of developing countries as compared to their developed counterparts. The remaining climate indicators have insignificant effects on real GDP except for mean sea level pressure which marginally enhances it. In the short-run, effects change, as positive deviations do not cause real GDP to decrease while the effects of other indicators are the same in terms of signs and significance except for magnitudes when compared to the long-run estimates. Gross fixed capital formation, Foreign aid and financial development, merchandise exports, and trademark and patent applications contribute positively to real GDP in the long run. The short-run estimates, in this case, differ compared to the long run in the case of sunshine duration which marginally damages the real GDP. This might be due to the reason that in the long run, countries try to minimize the adverse impacts of climate hazards by opting for adaptation.

[19] This mean is the overall mean of a respective country stretched over the period 1980-2020.

Table 5.6: Long-run and short-run estimation results

Independent Variables	Real GDP as Dependent Variable				GDP per capita as Dependent Variable			
	Specification 1		Specification 2		Specification 1		Specification 2	
	MG	PMG	MG	PMG	MG	PMG	MG	PMG
Panel A: Long-run estimates								
CointEq	-0.015**	-0 018**	-0.02**	-0.03**	-0.006***	-0.017***	-0.005***	-0.013***
POST	-5.21***	-06.31***	-0.62***	-0.39***	-0.83***	-0.80***	-0.73**	-0.76***
	(0.017)	(0.015)	(0.24)	(0.43)	(0.43)	(0.45)	(0.55)	(0.47)
NEGT	-5.14**	-4.81**	-0.44**	-0.58**	-1.95***	-1.57***	-1 61***	-1.57*
	(0.029)	(0.031)	(0.37)	(0 34)	(0.041)	(0.0229)	(0.67)	(0.61)
POSP	0.30	0.42	0 06	0.04	0 11*	0.42**	0.13*	0.16**
	(0.006)	(0.005)	(0.06)	(0.05)	(0.16)	(0.25)	(0.06)	(0.04)
NEGP	-1.41**	-0.12**	-0.11**	-0.12**	-0.022	-0.35	-0.27	0.18
	(0.71)	(0.83)	(0.06)	(0.08)	(0.019)	(0.51)	(0.12)	(0.09)
FDS	-0.55**	-0.52**	-0.85***	-0.97***	-0.92***	-0.96***	-0.83***	-0.88***
	(0.2316)	(0.2065)	(0.278)	(0.289)	(0.266)	(0.279)	(0.2654)	(0.2528)
MSLP	0.20*	0.32*	0.11*	0.09*	0.015	0.017	0.018	0.01
	(0.01)	(0.02)	(0.12)	(0.14)	(0.051)	(0.061)	(0.06)	(0.05)
SS	-0.05	-0.04	-0.55	-0.48	0.12	-0.16**	0.23	-0.028*
	(0.07)	(0.05)	(0.74)	(0.82)	(0.052)	(0.054)	(0.52)	(0.42)
GFCF			0.22**	0.36*			0.17**	0.25*
			(0.998)	(1.05)			(0.845)	(0.885)
FAFD			0.001***	0.002***			0.12*	0.14
			(0.001)	(0.001)			(0.13)	(0.21)
MREX			0.61***	0.55***			0.25***	0 30***
			(0.872)	(0.763)			(0.71)	(0 64)
TMPA			0.02***	0.01***			0.13**	0 18***
			(0.001)	(0.001)			(0.17)	(0.15)
Panel B: Short-run estimates								
ΔPOST	-0.13	-0.21	-0.02	-0.01	-0.05**	-0.03**	-0.052**	-0.034*
	(0.015)	(0.014)	(0.01)	(0.01)	(0.02)	(0 03)	(0.02)	(0.03)
ΔNEGT	-0.44***	-0.50***	-0.33**	-0.44**	-0.36*	-0.24***	-0.36*	-0.33***
	(0.012)	(0.010)	(0.12)	(0.10)	(0.023)	(0.05)	(0.024)	(0.03)
ΔPOSP	0.014	0.021	0.001	0.001	0.014*	0 012***	0.017*	0.018**
	(0.015)	(0.017)	(0.001)	(0.001)	(0.03)	(0 01)	(0.032)	(0.025)
ΔNEGP	-0.035**	-0.044**	-0.003**	-0.004**	-0.002	-0.003	-0.001	0.001
	(0.02)	(0.03)	(0.001)	(0.001)	(0.01)	(0.01)	(0.017)	(0.015)
ΔFDS	-0.31***	-0.26***	-0.23***	-0 26***	-0.090***	-0.093***	-0 14***	-0.16***
	(0.088)	(0.081)	(0.089)	(0.085)	(0.024)	(0.021)	(0.026)	(0.023)
ΔMSLP	0 004***	0.003**	0.04***	0.03***	0.001	-0.001	0.018	0.016
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0 012)	(0.015)
ΔSS	-0.015	-0.014	-0.015*	-0.013*	0.002*	0.005	0.041	-0.06
	(0.01)	(0.012)	(0.014)	(0.012)	(0.01)	(0.015)	(0.033)	(0.022)
ΔGFCF			0.069***	0.056**			0.034***	0.041***
			(0.047)	(0.043)			(0.034)	(0.032)
ΔFAFD			0.001	0.001			0.014**	-0.011**
			(0.001)	(0.001)			(0.015)	(0.013)
ΔMREX			0.057***	0.045**			0.021***	0 016**
			(0.042)	(0.038)			(0.022)	(0.027)
ΔTMPA			0.001	0.001			0.012**	0.016***
			(0.001)	(0.001)			(0.018)	(0.012)
Hausman test χ^2	68.2(0.000)	70.2(0.000)	66.4(0.000)	69.2(0.000)	68.2(0.000)	64.4(0.000)	65.3(0.000)	63.6 (0.000)
No. of countries	179	179	179	179	179	179	179	179
Year Effects	No	No	Yes	Yes	No	No	Yes	Yes
Country Effects	No	No	Yes	Yes	No	No	Yes	Yes
No. of obs	7339	7339	7339	7339	7339	7339	7339	7339

Note: Real GDP and GDP per capita are the dependent variables. The values in parenthesis are standard errors. ***, **,* show significance at 1%, 5% and 10% levels, respectively. Model 1 only considers the climatic indicators while Model 2 represents the full model which includes both climate and non-climate indicators, respectively. In specifications 1 and 2 on the left and right sides, variables are not in logarithmic form and hence need to interpret as semi-elasticities.

The estimation results of GDP per capita reveal that positive deviations in temperature and negative deviations in precipitation above and below their historical means and disasters' dummy significantly reduce the GDP per capita. Contrary to this, positive deviations in precipitation exert a positive effect on GDP per capita. The magnitudes of short-run coefficients are smaller as compared to the magnitudes of coefficients in the long run. Full model estimates reveal that most of the effects of climate-related indicators are damaging except for positive deviations in precipitation which marginally enhances the GDP per capita in the long run. Non-climatic indicators e.g., gross fixed capital formation, foreign aid and financial development, merchandise exports, and trademark and patent applications of the residents contribute positively to GDP per capita. However, this decline reduces in the short run as the coefficients have smaller magnitudes as compared to the magnitudes in the long run.

The results also indicate that there is no asymmetric effect of temperature both in the short run and the long run. However, asymmetry is found in the case of precipitation as negative changes negatively while positive changes positively affect economic performance. Kahn *et al.* (2019) showed that climate change deviating from their historical norms causes sectoral-level impacts. It affects GDP, the productivity of labor, and employment as well as the growth of output in different sectors of the economy (such as agriculture, manufacturing, construction, services, wholesale, and retail trade).

5.6 Effects of Climate Change on Economic Growth in Continents

Climate change is a global issue. Yet, its effects may change between continents and regions of the world as the climate varies worldwide. To investigate this asymmetry, this study divides the full sample continently. Further, this study randomly takes three regions e.g., South Asia, Central Europe, and Western Africa out of 3 major continents i.e., Asia, Europe, and Africa to assess the regional asymmetric effects of climate change too. The results in Table 5.7 indicate that temperature significantly exerts a positive effect on the real GDP of Europe and Africa, whereas, its effects are significantly negative for North and South America. Similarly, precipitation exerts

Table 5.7: Long-run and short-run estimation results (Average Changes only)

Independent Variables	Real GDP as Dependent Variable		
	Specification 1 (Asia)	**Specification 2 (Europe)**	**Specification 3 (Africa)**
Panel A: Long-run estimates			
Cointeq	-0.088***(0.011)	-0.004***(0.013)	-0.091***(0.137)
TEMP	1.18(0.192)	0.25*(0 154)	2.77***(0.336)
PRCP	-0.12(0.154)	0.21(0.361)	-0 66***(0.62)
MSLP	0.36***(0.321)	-0.574(3.31)	0.82*(0 239)
SS	-0.46*(0.621)	-1.18*(0.712)	-0.77*(0.227)
GFCF	0.25**(0.143)	0 82(0.124)	0.15***(0 22)
FAFD	1.70***(0.224)	0 27(0.451)	2.16**(1 51)
MEXP	0.12*(0.157)	0.34**(0.181)	0.47***(0 212)
TMPA	0.43***(0.161)	0.184*(0.137)	0.38***(0.42)
Panel B: Short-run estimates			
ΔTEMP	0.11(0.022)	0.028(0.031)	-0.54**(0.147)
ΔPRCP	-0 09*(0 073)	0.022(0.043)	0.33*(0.131)
ΔMSLP	0.021***(0.012)	-0.065(0.048)	-0.089*(0.163)
ΔSS	0.089**(0.031)	-0 014**(0 063)	-0.12**(0.221)
ΔGFCF	0.11***(0.013)	0.104***(0.013)	0.28**(0.06)
ΔFAFD	-0 073(0.074)	-0.04(0.105)	-0.049(0.062)
ΔMEXP	0.071***(0.011)	0.004*(0 003)	-0 064(0.017)
ΔTMPA	0.046**(0.012)	0.003*(0.002)	-0.002(0.044)
F-Statistics	10.56***	5.87***	6 89***
Adj R-Square	0.49	0.46	0 95
DW-Statistics	1.80	1.83	2.36
No. of countries	44	45	50
No. of obs	1804	1845	2050

Note: Real GDP is the dependent variable. The values in parenthesis are standard errors. ***, **, and * show significance at the 1%, 5% and 10% levels, respectively. Specifications 1, 2, and 3 represent the world, developing, and developed countries, respectively. All the variables are in logarithmic form and hence need to interpret as elasticities.

significantly damaging effects on the economic growth of Africa and North America. The effects of temperature and precipitation are mixed and insignificant for other continents. The results also show that asymmetric effects exist in the case of sunshine duration and sea-level pressure. Sunshine duration asserts negative effects, whereas, sea-level pressure poses a positive and significant effect on the economic performances of almost all the continents except Australia. Moreover, this study also finds asymmetry in effects in the short run and the long run. Temperature reduces the real GDP of Africa and North America in the short run, whereas, precipitation causes a reduction in the economic performance of Asia and South America. Gross fixed capital formation, value merchandise exports, and trademark and patent applications of the residents boost the economic performance of most of the continents both in the short run and

Table 5.8: Long-run and short-run estimation results (Average Changes only)

Independent Variables	Real GDP as Dependent Variable		
	Specification 1 (Central and North America)	Specification 2 (South American)	Specification 3 (Australia)
Panel A: Long-run estimates			
Cointeq	-0.014***(0.021)	-0 005***(0.003)	-0.091***(0 137)
TEMP	-0.92*(0.545)	-1.56*(0.88)	0 31(0.164)
PRCP	0.45*(0.372)	-0.84(0.984)	-0.52(0.574)
MSLP	0.25(0.667)	1.36*(0.674)	-0.75*(0.478)
SS	0.46(0.653)	-1.02*(0.481)	-0 869(0.351)
GFCF	0.73***(0.171)	0.11*(0.105)	0.54**(0.23)
FAFD	1.36*(0.129)	-1.32(1.87)	-0.55(0 281)
MEXP	0.25*(0.192)	1.60**(0 446)	1.12**(0.316)
TMPA	-0.022(0.91)	-1.66*(0.696)	-0.19(0.223)
Panel B: Short-run estimates			
ΔTEMP	-0.13*(0.013)	0.011(0 131)	0.018*(0.012)
ΔPRCP	0.06*(0.004)	-0.13**(0.034)	-0 031(0.036)
ΔMSLP	0.032(0.065)	1.08(0.072)	-0 050(0.059)
ΔSS	0 064(0.074)	-0.019(0.079)	-0.051(0.020)
ΔGFCF	0.053**(0.013)	0.34**(0.081)	0.057***(0 013)
ΔFAFD	-0.131(0 028)	0.04(0 383)	0 014(0 066)
ΔMEXP	0.044***(0.011)	0.22***(0.054)	0.039***(0.006)
ΔTMPA	-0.002(0.003)	0.008(0.019)	-0.011(0 096)
F-Statistics	13.28***	2.69**	1 92***
Adj R-Square	0.78	0.47	0.39
DW-Statistics	1.63	2.02	1.91
No. of countries	11	17	12
No. of obs	451	697	492

Note: Real GDP is the dependent variable. The values in parenthesis are standard errors. ***, **, and * show significance at the 1%, 5% and 10% levels, respectively. Specifications 1, 2, and 3 represent the world, developing, and developed countries, respectively. All the variables are in logarithmic form and hence need to interpret as elasticities.

the long run. The effects of foreign aid and financial development are positive and significant for Asia, Africa, and South America in the long run, whereas, its effects are negative for South America in the short run.

Our analysis further shows that the effects of climate change differ regionally though the effects are not significant for the randomly selected three regions. Temperature insignificantly reduces the economic performance of South Asia and Western Africa, whereas, it marginally boosts the real GDP of Central Europe. However, precipitation significantly reduces the economic growth of Central Europe. Sea-level pressure causes an increase in the economic performance of South Asia and Central Europe.

Table 5.9: Long-run and short-run estimation results (Average Changes only)			
Panel A: Long-run estimates			
Independent Variables	**Real GDP as Dependent Variable**		
	Specification 1 (South Asia)	**Specification 2 (Central Europe)**	**Specification 3 (Western Africa)**
Cointeq	-0.017***(0.098)	-0.028***(0.054)	-0.077***(0.015)
TEMP	-0.51(0.477)	1.67*(0.783)	-0.86(2.76)
PRCP	-0.19(1.12)	-2.19**(1.03)	-0.20(0.661)
MSLP	1.26**(0.673)	1.64***(0.614)	-0.91(1.80)
SS	1.91(0 495)	0.20*(2.42)	4.21*(2.81)
GFCF	1.05*(1.745)	0.82***(0.257)	0.76*(0.49)
FAFD	-0.63(0.248)	0.54(0.814)	1.59*(1 02)
MREX	0.71***(1.02)	-0.65(0 245)	-0.087(0.474)
TMPA	1.69*(1.07)	0.93***(0.287)	0.86***(0.756)
Panel B: Short-run estimates			
ΔTEMP	-0.173(0.098)	0.66(0.075)	-0.066(0 043)
ΔPRCP	0.033(0.272)	0.15(1.10)	-0.015(0.032)
ΔMSLP	0.22*(0.141)	1.15(1.86)	-0 07(0.013)
ΔSS	0.33(0.123)	0.063(0.209)	-0.07(0.013)
ΔGFCF	0.183*(0.251)	0.058**(0.318)	0.067(0.078)
ΔFAFD	-0.011(0.061)	-0 038(0.011)	0.016**(0.071)
ΔMREX	0.12***(0.128)	0.093***(0.088)	-0 041***(0.072)
ΔTMPA	0.29**(0.137)	0.017***(0.054)	0.026**(0.056)
F-Statistics	34.12***	10.36**	3.12***
Adj R-Square	0.42	0.53	0.35
DW-Statistics	2.15	1.83	1 86
No. of countries	07	09	15
No. of obs	243	369	615

Note: Real GDP is the dependent variable. The values in parenthesis are standard errors. ***, **, and * show significance at the 1%, 5% and 10% levels, respectively. Specifications 1, 2, and 3 represent the world, developing, and developed countries, respectively. All the variables are in logarithmic form and hence need to interpret as elasticities.

5.7 Empirical Estimates of Climate-Agricultural Relationship

In this part, we present the estimation results related to the relationship between climate change and agricultural production. The estimation results are presented in a threefold manner: first, we discuss the impact of climate change on agriculture production by using the average climate indicators as independent variables. We used both food production and crop production as dependent variables. The reason to use both of them is that the former is a raw good and the latter is a finished good. How climate change affects agriculture production in raw form and the finished product is the basic reason behind the intention. In the first dimension, we use the food production index (FPI) as a proxy variable for agriculture production.

The results in Table 5.10 show that the impact of the average temperature on food production is negative and significant for the complete sample. This effect is also detrimental for developing economies where higher temperature damages food production while the effect is also negative for developed economies but it is insignificant. The effect of precipitation on a complete set of countries and developing economies' food production is positive and significant,

Table 5.10: Climate Change and Food Production (Average Effects) Dependent Variable= Food Production Index

Independent Variables	World			Developing			Developed		
	Coefficient	T-value	S.E	Coefficient	T-value	S.E	Coefficient	T-value	S.E
TEMP	-0.065***	-3.47	(0.049)	-0.079***	-3.91	(0.051)	-0.010	-0 38	(0.123)
PRCP	0.032***	2.97	(0.044)	0.071***	5.82	(0.048)	-0.059***	-2.80	(0 082)
SS	-0 003*	-1.79	(0.005)	-0.005**	-2.26	(0.006)	0.001	0.56	(0.009)
EMAG	0.0015***	2.44	(0.001)	0.001***	2.02	(0.001)	0.008*	1.84	(0.017)
UPOP	-0.001***	-3.55	(0.0005)	-0.0002	-1.04	(0.0006)	-0.001***	-4.04	(0.001)
AGLD	0.09***	89.70	(0.003)	0.087***	65.93	(0.003)	0.089***	48.02	(0.005)
CONS	0.83***	35.24	(0.225)	0.62***	16.87	(0 011)	1.19***	11.45	(0.516)
Observations	7339			5043			2296		
R-square (within)	0.75			0.78			0.70		
F Test value	2549.59***	P=0.0000		2094.74***	P=0.0000		614.60***	P=0.0000	
Hausman Test Chi^2	193 65***	P=0.0000		113.03***	P=0.0000		83.11***	P=0.0000	
Auto. (F-statistics)	21.53***	P=0.0000		22.16***	P=0.0000		20.35***	P=0.0000	
Wald hetero. (chi2)	20297.9***	P=0.0000		16778.43***	P=0.0000		4843 98***	P=0.0000	
FE	Yes	------	------	Yes	------	-------	Yes	------	------

Note: ***, **, and * show the level of significance at 1%, 5%, and 10%, respectively. The Hausman test rejects the null hypothesis that the fixed effect model is appropriate as compared to the random effect model for all models. Heteroscedasticity in error terms is shown by the Wald test which is partially addressed by using robust standard errors and obtaining the transformation of independent variables of the study.

respectively, whereas, this effect is adverse and significant for developed economies. The effect of sunshine duration is negative as it affects food production adversely both in the world and developing countries but its effect is positive and insignificant in the case of developed economies. This might be due to the reason that developed countries have more resources to cope with the surging issue of climate change, whereas, developing economies face financial constraints. The non-climatic indicators like employment in the agriculture sector and agricultural land are positively related to the food production of the global economy, and developing and developed economies, respectively. Similarly, the effect of urbanization on food production for the global economy as a whole is negative and significant but after the separation of the sample into developing and developed economies, its impacts changes as urbanization affects the food production of developed countries negatively and significantly but this effect is not too detrimental for developing countries although it is negative.

Our results in the first specification indicate that a rise in temperature positively, whereas an increase in precipitation negatively affects food production. One of the studies showed that climate change is most likely to affect the security of food at the local, regional, and global levels. Climate change can reduce access to food, disrupt food availability, and affect food quality (Brown *et al.* (2014). For instance, projected jumps in temperatures, changes in patterns of precipitation, events of extreme weather changes, and declines in water availability may all result in a reduction in agricultural productivity. Increases in the severity and frequency of extreme weather events may also interrupt food delivery and resulting hikes in food prices. Rising temperatures may contribute to contamination and spoilage. Climate change has direct implications for agricultural production. There are various other channels through which climate change affects economic outcomes. The most important channel is reducing economic activities by affecting agricultural output. In the agriculture sector, precipitation and temperature are considered direct inputs in the production of crops. However, over the years, climate change impacts become broadened which include the impacts on the productivity of labor, health of the public, mortality, and conflict.[20]

The second dimension of the climate-agricultural relationship includes extreme values (minimum and maximum) of two major climate change indicators (temperature and precipitation). The estimation results in Table 5.11 show that at the global level, maximum temperature and precipitation effects are damaging as food production reduces by 0.26% and 0.012%, due to an increase in the average maximum level of temperature and precipitation, respectively. The impact of average minimum temperature is negative but insignificant, whereas, the effect of average maximum precipitation is positive and significant on food production. It is worth mentioning that when the sample is separated into developing and developed countries, the

[20] See Heal and Park (2016); Carleton and Hsiang (2016); and Dell, Jones, and Olkan (2014) for literature reviews. Climate shocks affect economic activities through their effects on third markets.

results changed between divisions[21]. These effects are almost similar when observed in the case of developing economies with slighter changes in the magnitudes of the coefficients. For developed economies, the effects of average maximum and average minimum precipitation are

Table 5.11: Climate Change and Food Production (Extreme Effects) **Dependent Variable= Food Production Index**

Independent Variables	World			Developing			Developed		
	Coefficient	T-value	S.E	Coefficient	T-value	S.E	Coefficient	T-value	S.E
MINT	-0.002	-0.39	(0.028)	-0.002	-0.36	(0.031)	0.011	.0.76	(0 061)
MAXT	-0.261***	-5.25	(0.093)	-0.188***	-3.71	(0.093)	-0.522***	-3.87	(0.461)
MINP	-0.012***	-3.78	(0.013)	-0.008***	-2.38	(0.010)	-0.02***	-3.03	(0.025)
MAXP	0.064***	5.42	(0.052)	0.081***	6.08	(0.056)	0 019	0.79	(0.102)
MHSS	-0.003***	-1.73	(0.005)	-0.005**	-2.26	(0.006)	0.003	0.61	(0.012)
EMAG	0.002**	2 93	(0.001)	0.001***	2.64	(0.001)	0 009**	2.00	(0.016)
UPOP	-0.0005***	-3.28	(0.0005)	-0.0001	-0.77	(0.001)	-0.001***	-4.06	(0.001)
AGLD	0.087***	31 88	(0 003)	0.087***	28.65	(0.003)	0 08***	17.76	(0.005)
CONS	0.46*	1.72	(0.347)	0.136***	23.45	(0.3621)	2.75*	1.80	(1.53)
Observations	7339			5043			2296		
R-square	0.61			0.79			0.57		
F Test value	2025.27***	P=0.0000		1684.44***	P=0.0000		496 83***	P=0.0000	
Chi^2 of Hausman Test	197.65***	P=0.0000		112.26***	P=0 0000		63.35***	P=0.0000	
Auto.(F-statistics)	21.41***	P=0.0000		22.14***	P=0.0000		20.17***	P=0.0000	
Wald hetero (chi2)	30396.06***	P=0.0000		16855.61***	P=0.0000		4898.12***	P=0.0000	
FE	Yes	------	------	Yes	------	-------	Yes	------	------

Note: ***, **, and * show the level of significance at 1%, 5%, and 10%, respectively. The Hausman test rejects the null hypothesis that the fixed effect model is appropriate as compared to the random effect model for all models. Heteroscedasticity in error terms is shown by the Wald test which is partially addressed by using robust standard errors and obtaining the transformation of independent variables of the study.

detrimental to food production. The level of maximum precipitation exerts positive but insignificant effects on food production. The duration of sunshine hours positively but insignificantly relates to food production.

The control variables like employment in the agriculture sector and agriculture land effects are positive and significant, respectively as both of them boost food production activities around the globe, developing and developed economies. Urbanization has a negative and significant effect on food production at the global level as well as in developed countries, respectively; on the other hand, its impact on developing economies is insignificant though negative. More extreme precipitation and temperature can prevent different crops from growing. Extreme climate change events, especially droughts, and floods, can reduce yields and harm

[21] Full sample, developing, and developed countries.

crops. For instance, high temperatures at nighttime affected yields of corn across the USA (Pryor, 2012).

In the third and last dimension of the climate-agriculture relationship, this study uses positive changes above the mean level of temperature and precipitation and negative changes below their mean deviations. The results in Table 5.12 indicate that positive changes above the mean deviation in temperature affect food production positively not only in the global economy but also in developed and developing economies. For instance, food production increases by 2.8% approximately due to an increase in the average level of positive changes in temperature by 1% for the global economy. Similarly, negative changes below the mean deviation of precipitation also enhance food production at a 1% level of significance for all of the three divisions. The effects of negative changes in temperature below and positive changes in precipitation above their respective mean deviations damage food production for all of the three divisions. However, in the case of developing economies, the effect of negative changes in temperature becomes insignificant. The duration of sunshine negatively affects food production

Table 5.12: Climate Change and Food Production (asymmetric effects) **Dependent Variable= Food Production Index**

Independent Variables	World			Developing			Developed		
	Coefficient	T-value	S.E	Coefficient	T-value	S.E	Coefficient	T-value	S.E
POST	0.028***	7.60	(0.037)	0.004***	4.85	(0.022)	0.284***	14.28	(0.056)
NEGT	-0.021***	-3 67	(0.026)	-0.0004	-0.17	(0.039)	-0.072***	-7.37	(0.030)
POSP	-0.001***	-4.58	(0.001)	-0.001***	-3.74	(0.001)	-0.001***	-3.41	(0.001)
NEGP	0.002***	6.85	(0.0013)	0.003***	7.47	(0.002)	0.002***	2.45	(0.002)
MHSS	-0.003	-1.27	(0.0052)	-0.005**	-2.27	(0.006)	0.004	1.11	(0.008)
EMAG	0.002***	2.57	(0.001)	0.0012***	2.15	(0.001)	0.010**	2.38	(0.017)
UPOP	-0 001***	-3.67	(0.0005)	-0.0002***	-1.20	(0.001)	-0.001***	-4.20	(0.001)
AGLD	0.081***	32.42	(0.003)	0.081***	28.85	(0.003)	0.081***	17.19	(0.005)
CONS	0.619***	2.91	(0.213)	0.6848***	3.69	(0.1856)	-0 555*	-1.68	(0.331)
Observations	7339			5043			2296		
R-square	0.75			0.78			0.72		
F Test value	2080.35***	P=0.0000		1705.17***	P=0.0000		565.58***	P=0.0000	
Chi^2 of Hausman Test	1175.84***	P=0.0000		902.05***	P=0.0000		710.15***	P=0.0000	
Auto.(F-statistics)	21.28***	P=0.0000		22.04***	P=0.0000		15 90***	P=0.0000	
Wald hetero test (chi2)	20696.6***	P=0.0000		17070.8***	P=0.0000		5572 18***	P=0.0000	
FE	Yes	------	------	Yes	------	-------	Yes	--------	------

Note: ***, **, and * show the level of significance at 1%, 5%, and 10%, respectively. The Hausman test rejects the null hypothesis that the fixed effect model is appropriate as compared to the random effect model for all models. Heteroscedasticity in error terms is shown by the Wald test which is partially addressed by using robust standard errors and obtaining the transformation of independent variables of the study in only developing economies. Lastly, the effects of employment in the agriculture sector and agricultural land are positive while urbanization asserts a negative effect on food production, respectively.

This study also used the crop production index as a dependent variable for agriculture production. The results in Table 5.13 reveal that climate change in the form of average temperature significantly reduces crop production. The crop production at the global level and in developing economies declined by 0.084% and 0.093% on average due to a 1% rise in average temperature, respectively, whereas, this decline is not significant in the case of developed economies though negative. The impact of average precipitation on food production differs across three divisions as it significantly increases crop production global as well as developing

Table 5.13 Climate Change and Crop Production (Average Effects) **Dependent Variable= Crop Production Index**

Independent Variables	World			Developing			Developed		
	Coefficient	T-value	S.E	Coefficient	T-value	S.E	Coefficient	T-value	S.E
TEMP	-0.084***	-3.65	(0.062)	-0.093***	-3.65	(0.067)	-0.048	-1.00	(0.148)
PRCP	0.03**	2.28	(0.069)	0.066***	4.36	(0.062)	-0.053**	-2.13	(0.151)
MHSS	-0.001	-0.41	(0.008)	-0.001	-0.25	(0 010)	-0.002	-0.41	(0.011)
EMAG	0.001*	1.73	(0.003)	0.006***	2.25	(0.003)	0.009*	1.72	(0.017)
UPOP	-0.001***	-2.83	(0.001)	0.006***	6.35	(0 001)	-0.001***	-3.40	(0.007)
AGLD	0.066***	17.80	(0.004)	0.079***	88.80	(0.005)	0.081***	51.68	(0.005)
CONS	1.12***	3.03	(0.368)	0.896**	2.20	(0.407)	1.46***	48.02	(0 749)
Observations	7339			5043			2296		
R-square (within)	0.61			0.63			0.57		
F Test value	1332.88***	P=0.0000		1037.03***	P=0.0000		355.04***	P=0.0000	
Hausman Test Chi^2	1310.22***	P=0.0000		1005.6***	P=0.0000		839.67***	P=0.0000	
Auto.(F-statistics)	6.87***	P=0.0000		6.14***	P=0.0000		8.88***	P=0.0000	
Wald hetero. (chi2)	10066.9***	P=0.0000		7842.26***	P=0.0000		2675.31***	P=0 0000	
FE	Yes	------	------	Yes	------	-------	Yes	------	------

Note: ***, **, and * show the level of significance at 1%, 5%, and 10%, respectively. The Hausman test rejects the null hypothesis that the fixed effect model is appropriate as compared to the random effect model for all models. Heteroscedasticity in error terms is shown by the Wald test which is partially addressed by using robust standard errors and obtaining the transformation of independent variables of the study.

countries but its effects are significantly detrimental to developed economies. However, sunshine duration exerts negative but insignificant effects on crop production when the sample is divided into two parts e-g., developing and developed. The level of employment in the agriculture sector is marginally significant and positive for the global economy as well as developed economies while it is highly significant for developing countries. Contrary to this, the influence of more agricultural land exerts a positive effect on crop production for all three segmentations. Lastly, urbanization hurts crop production of both developed and world economies significantly but its effect on developing economies is insignificant.

The results of the extreme effects are shown in Table 5.14. The extreme values in the form of maximum temperature and minimum precipitation reduce crop production, whereas, an increase in minimum temperature does not cause any damage to crop production of all three divisions. Maximum precipitation enhances crop production at the global level and in developing countries

Table 5.14: Climate Change and Crop Production (Extreme Effects) **Dependent Variable= Crop Production Index**

Independent Variables	World			Developing			Developed		
	Coefficient	T-value	S.E	Coefficient	T-value	S.E	Coefficient	T-value	S.E
MINT	0.001	0.13	(0.042)	-0.002	-0.19	(0.047)	0.018	0.96	(0.087)
MAXT	-0.354***	-5.64	(0.10)	-0.262***	-3.93	(0.103)	-0 69***	-4.36	(0 485)
MINP	-0 012***	-2.60	(0.013)	-0.008*	-1.75	(0.014)	-0 012*	-1.73	(0.029)
MAXP	0.054***	3.81	(0.082)	0.0076***	4 62	(0.069)	0.001	0 12	(0.189)
MHSS	-0.0004	-0 16	(0.008)	-0.001	-0.20	(0.011)	0.0001	0.14	(0.011)
EMAG	0.007***	2 87	(0 003)	0.007***	2.58	(0.003)	0.01*	1.85	(0.016)
UPOP	0 004***	6.46	(0.001)	0.006***	6.50	(0.001)	-0.001***	-3.50	(0.001)
AGLD	0 066***	17.85	(0.004)	0.064***	13.48	(0.005)	0.08**	12.55	(0.005)
CONS	1.05**	2.26	(0.463)	0.784*	1.70	(0.495)	2.53**	2 40	(1.55)
Observations	7339			5043			2296		
R-square	0.31			0.36			0.29		
F Test value	1072 3***	P=0.0000		834.47***	P=0 0000		288 04***	P=0.0000	
Hausman Test (Chi^2)	26.52***	P=0.0000		21.45***	P=0.0000		16.41***	P=0.0000	
Auto.(F-statistics)	6.88***	0.0000		6.12***	P=0.0000		8.71***	P=0.0000	
Wald hetero test (chi2)	10114.8***	0.0000		7882.02***	0.0000		848.79***	0.0000	
FE	Yes	------	------	Yes	--------	-------	Yes	--------	------

Note: ***, **, and * show the level of significance at 1%, 5%, and 10%, respectively. The Hausman test rejects the null hypothesis that the fixed effect model is appropriate as compared to the random effect model for all models. Heteroscedasticity in error terms is shown by the Wald test which is partially addressed by using robust standard errors and obtaining the transformation of independent variables of the study.

but it does not affect crop production in developed countries. The sunshine duration exerts native effects on crop production but these remain insignificant for the first two divisions while its effect is positive but insignificant for the crop production of developed countries. The effects of all other non-climate indicators are positive and significant except for urbanization which exhibits that an increase in urbanization leads to a decline in crop production in developed economies.

Finally, Table 5.15 shows the estimation results of the third dimension, it is worth mentioning that all the results are almost similar in signs and significance at par with the output obtained in the case of the food production index for the same strategy except for the magnitudes of the coefficients. The only difference in result is for employment in the agriculture sector where its effect on crop production is marginally significant though positive for the world and developed countries while for developing economies, its effect is positive but insignificant.

Table 5.15: Climate Change and Crop Production (asymmetric effects) **Dependent Variable= Crop Production Index**

Independent Variables	World			Developing			Developed		
	Coefficient	T-value	S.E	Coefficient	T-value	S.E	Coefficient	T-value	S.E
POST	0.027***	6.01	(0.043)	0.018***	4 15	(0.030)	0.245***	10.14	(0.063)
NEGT	-0.037***	-5.21	(0.028)	-0.019**	-2.08	(0.039)	-0.080***	-6.90	(0.033)
POSP	-0.001***	-3.75	(0.001)	-0.001***	-2.98	(0.001)	-0.001***	-2.97	(0.002)
NEGP	0.002***	5.41	(0.002)	0.003***	5.40	(0.002)	0.002***	2.60	(0.004)
MHSS	-0.0002***	-0.16	(0.008)	-0.003	-0.36	(0.011)	0.002	0.35	(0.012)
EMAG	0.0013*	1 74	(0.003)	0.001	1.24	(0 003)	0 011*	1.86	(0.021)
UPOP	-0.001***	-2.90	(0.001)	-0.0001	-0.64	(0.001)	-0.001***	-3.50	(0.001)
AGLD	0.065***	17.16	(0.004)	0.064***	13.49	(0.005)	0.071***	11.37	(0.006)
CONS	0.762***	3.33	(0.229)	0.927***	4.27	(0.217)	-0.528**	-1.84	(0.287)
Observations	7339			5043			2296		
R-square	0.61			0.64			0.73		
F Test value	1085.76***	P=0.0000		840.42***	P=0.0000		314.29***	P=0.0000	
Chi^2 of Hausman Test	1158.29***	P=0.0000		911.20***	P=0.0000		719.83***	P=0.0000	
Auto (F-statistics)	6.87***	P=0.0000		6.18***	P=0.0000		6.65***	P=0.0000	
Wald hetero test (chi2)	10252.4***	P=0.0000		7946.48***	P=0 0000		2971.54***	P=0.0000	
FE	Yes	------	------	Yes	------	-------	Yes	--------	------

Note: ***, **, and * show the level of significance at 1%, 5%, and 10%, respectively. The Hausman test rejects the null hypothesis that the fixed effect model is appropriate as compared to the random effect model for all models. Heteroscedasticity in error terms is shown by the Wald test which is partially addressed by using robust standard errors and obtaining the transformation of independent variables of the study.

Summing up, estimation results exhibit that climate change is very much influential in both food and crop production. On one hand, few indicators enhance food and crop production, whereas, on the other hand, they exert adverse effects. Similarly, the effects are different too for three different divisions. Developed countries are less prone to climate change even though they emit more GHGs into the atmosphere. They have ample resources to tackle this hazard. The mitigation and adaptation policies prove useful in combating the adverse impacts of climate change hazards. Contrary to this, developing nations which are more vulnerable to climate change have fewer resources to reduce the devastations posed by climate change. Overall, climate change effects are surging around the globe. It affects the global economy in one way or the other. So, its influences and implications cannot be denied for the global economic system in general and the agriculture sector in particular.

5.8 Results and Discussions (Pakistan Economy)

5.8.1 Summary Statistics

The descriptive statistics of the study variables are presented in Table 5.16. The results indicate that the mean, maximum, and minimum temperature during the period 1960-2020 in Pakistan remained at 20.64, 27.63, and 13.69 centigrade whereas the same statistics of precipitation were 298, 72.58, and 2.96 millimeters, respectively. Similarly, the mean levels of the food production index and crop production index are 25.5 and 59.3, respectively. The mean hourly sunshine per month is 196 hours. We also report the mean, median, standard deviation, kurtosis, and skewness of the study variables in Table 5.16.

5.8.2 Estimation Results and Interpretations

To check the stationarity of the variables, this study employs the Dicky-Fuller test of a unit root. The results of the test are shown in Table 5.17. The output test indicates that few variables are stationary at levels whereas others are not. However, after applying the first difference, almost all the variables become stationary. Though ARDL bound testing approach confirms the presence of cointegration among variables which is also validated by having significant F-test values. Yet, to check the presence of cointegration among variables, we employed the Johansen cointegration analysis. The results of the Johansen cointegration approach in Table 5.18 indicate that two integrating vectors validate the presence of the long-run relationship between the study variables. This entails and assures the reliability and robustness of ARDL cointegration analysis.

The results of linear and non-linear models are presented in Table 5.19. The study uses Hannan-Quinn criteria (HQ) as a model selection method with HAC standard errors and covariance (Newey-West) as a coefficient covariance matrix. The automated lag selection criteria are used which selected 4 lags as an appropriate lag length. The estimates of linear models are reported in the upper part of Table 5.19 which shows the short-run and the long-run estimates of the linear model. Temperature does not affect food production at zero lag however further lags pose significant implications to food production whereas; precipitation and sunshine duration significantly enhance food production in the short run. The dummy variable used for natural disasters[22] affects food production negatively but insignificantly. Contrary to this, temperature and natural disasters dummy reduce food production in the long run which is also backed by the theory that rising temperatures and the occurrence of disasters damage the economic outputs, especially of the agriculture sector. The increase in precipitation and sunshine duration has favorable effects on food production in the long run.

In general, most crops during their growth process require a considerable amount of rainfall although some crops are less dependent on rainfall. Plants absorb an ample quantity of water through their roots and it is natural that they evaporate that water into the air. It's a cycle and for the completion of this natural cycle, it is imperative that crops must be provided ample water for their growth process. Similarly, sunshine is an important source of energy that plants require to convert water and carbon dioxide into oxygen and carbohydrates. The carbohydrates produced by photosynthesis are a source of reproductive and vegetative growth. It also increases crop biomass.[23] Sunshine is also used by plants to produce their own food through the

[22] A natural disaster is a dummy variable used in place of floods, droughts, storms, and sea-level rise.
[23] Biomass is known as a plant-based material that is used as fuel for the production of electricity and heat. For instance, agricultural residues, wood and wood residues, and energy crops.

photosynthesis process. Simply, sunshine is important for plant growth because the light and the heat required by all the growing plants are provided by solar radiation which shows that sunshine most enhances crop production in the agriculture sector.

By comparing, it is evident that the short-run effects last in the long run too though their implication for food production differs in the two periods. Negative changes damage food production more compared to the damages of positive changes in temperature which indicate asymmetric effects of temperature in terms of their magnitudes in the long run. Besides, both gross fixed capital formation and urbanization enhance food production. The result in the case of urbanization is positive which can be interpreted as urbanization may lessen the pressure from the land of the rural area which can be used more for cultivation rather than for residential purposes. Similarly, an increase in agricultural land reduces food production which may be due to the reason that often the agriculture sector in developing economies experiences diminishing returns as more inputs like land and labor are employed for cultivation. The negative and significant value of ECM exhibits that variables are co-integrated. The estimation results of the linear model also reveal that long-run effects on food production are more significant compared to the short-run effects.

We also applied CUSUM and CUSUMSQ tests to validate the stability of the linear model estimates. Both tests confirm the stability of the estimates which is shown in Figure 5.3. The lower part of Table 5.19 presents the estimation output of the non-linear model. Most of

Table 5.16: Summary Statistics of variables (For Pakistan)

	FPI	CPI	TEMP	MINT	MAXT	PRCP	MINP	MAXP	SS	AGLD	UPOP	GFCG
Mean	52.51246	59.26918	20.63590	13.68885	27.62754	298.0028	2.956877	72.58400	195.7582	3.6260	37.3643	27.294
Median	45.76000	54.37000	20.67000	13.70000	27.66000	304.7400	2.733930	71.59480	205.0000	3.6172	32.9144	27.2546
Maximum	108.1400	106.7800	21.82000	14.86000	28.82000	396.8300	9.284690	148.1210	277.5000	3.8509	82.0946	28.3724
Minimum	15.32000	18.78000	19.71000	12.66000	26.72000	190.7500	0.161850	34.22670	41.00000	3.5206	9.9443	25.7045
Std. Dev.	29.48751	27.29841	0.548241	0.583513	0.527752	57.09386	2.191270	23.43505	55.82618	0.0693	21.8242	0.6542
Skewness	0.456309	0.200648	0.215468	0.168521	0.205162	-0.104509	1.081896	0.601220	-0.797518	0.6667	0.4747	-0.2982
Kurtosis	1.894859	1.736376	2.093468	1.944230	2.231216	1.934001	4.130902	3.288330	2.859456	3.3375	1.9629	2.0123
Obs	61	61	61	61	61	61	61	61	61	61	61	61

Note: agricultural land and urbanization are in acre lac and million rupees, respectively. Std Dev is the standard deviation.
Source: Authors' own calculation

Table 5.17: Unit Root test result (Augmented Dickey-Fuller test)

		FPI	CPI	TEMP	MINT	MAXT	PRCP	MINP	MAXP	SS	AGLD	UPOP	GFCF
With Constant	Level	2.40(10)	1.52(8)	-0.18(7)	-0.237(7)	-0.251(7)	-7.76(0)***	-8.20(0)***	-7.95(0)***	-2.54(0)	-4.98(10)***	2.16(2)	1.47(7)
With Constant and Trend	First Difference	-7.14(10)***	-2.87(8)**	-6.27(6)***	-6.09(6)***	-6.19(6)***	-9.11(1)***	-10.1(1)***	-6.15(3)***	-7.29(1)***	-4.3(10)***	0.47(2)***	-5.34(5)***
With Constant	Level	-1.89(10)	-3.86(8)**	-6.55(0)***	-6.45(0)***	-6.53(0)***	-7.86(0)***	-8.13(0)***	-7.96(0)***	-2.84(4)	-5.5(10)***	0.57(2)	-2.30(4)
With Constant and Trend	First Difference	-8.0(10)***	-10.4(6)**	-6.21(6)***	-6.02(6)***	-6.14(6)***	-9.04(1)***	-9.98(1)***	-6.45(3)***	-10.4(0)***	-4.21(10)***	-4.5(0)***	-5.47(6)***

Note: *** and ** statistical significance at 1% and 5%, respectively. Agricultural land (AGLD) is in acre lacs and urban population (UPOP) is in million. The numbers in parenthesis are the selected lags by AIC.
Source: Authors' own construction

Table 5.18 Results of the Johansen cointegration approach

Hypothesis	Trace statistics	Maximum eigenvalue
R = 0	153.0621*	98.5315*
R ≤ 1	62.3548*	47.3645*
R ≤ 2	23.1685	13.7315
R ≤ 3	3.5621	3.5621

* indicates significance at 1%

Table 5.19 Full-information estimates when the food production index used as a dependent variable

I. Linear ARDL model	Panel A: Short-run coefficient estimates								
Lag order	0	1	2	3	4	5	6	7	8
ΔlnFPI									
ΔlnTEMP	0.04(0.81)[1]	0.44(0.13)	0.68(0.13)	0.58(0.18)					
ΔlnPRCP	0.03**(0.042)								
ΔlnSS	0.03***(0.01)								
ΔND	-0.04(0.48)	0.027(0.001)	0.01(0.26)						
ΔlnAGLD	-0.41(0.012)	-0.60(0.02)	0.43(0.002)	0.63(0.019)					
ΔlnGFCF	0.11(0.002)	0.05(0.32)	0.012(0.77)	-0.10(0.001)					
ΔlnUPOP	8.4(0.03)	-9.1(0 007)							
Panel B: Long-run coefficient estimates									
Constant	lnTEMP	lnPRCP	lnSS	lnND	lnGFCF	lnAGLD	lnUPOP		
14.62^{*}(8.74)	-4.1^{***}(1.61)	0.20^{*}(0.101)	0.07^{**}(0.03)	-0.13^{**}(0.06)	0.27^{*}(0.16)	-1.6^{***}(0.57)	0.76^{***}(0.13)		
Panel C: Diagnostics									
F-test[2]	ECM[3]$_{t-1}$	LM[4]	RESET[5]	$\bar{R}^2$	CUSUM(CUSUM^2)				
3251.9^{***}	-0.39^{***}(0.12)	2.43(0.11)	0.46(0.504)	0.99	Stable				
II. Non-linear ARDL model	Panel A: Short-run coefficient estimates								
ΔlnFPI									
ΔPOST	0.07(0.01)[1]	0.042^{***}(0.012)							
ΔNEGT	0.013(0.011)	-0.01(0.011)	0.03^{**}(0.014)						
ΔPOSP	0.014(0.001)	-0.02(0.001)	-0.03(0.001)						
ΔNEGP	-0.012(0.001)	0.01(0.001)	-0.02^{***}(0.001)						
ΔND	-0.06(0.010	0.02^{***}(0.012)							
ΔlnSS	0.014^{***}(0.006)								
ΔlnAGLD	-0.27^{*}(0.14)	-0.12(0.41)	0.76^{***}(0.14)						
ΔlnGFCF	0.08^{**}(0.04)	-0.013(0 063)	-0.07^{**}(0.04)						
ΔlnUPOP	-1.92^{***}(0.56)								
Panel B: Long-run coefficient estimates									
Constant	POST	NEGT	POSP	NEGP	ND	lnSS	lnAGLD	lnGFCF	lnUPOP
7.45(15.06)**	-0.91^{*}(0.042)	-1.13^{**}(0.051)	0.025^{***}(0.001)	-0.012(0.001)	-0.82^{**}(0.032)	0.05^{**}(0.02)	$-1\ 09^{***}$(0.065)	0.13^{***}(0.051)	0.82^{***}(0.06)
Panel C: Diagnostics									
F-test[2]	ECM[3]$_{t-1}$	LM[4]	RESET[5]	$\bar{R}^2$	CUSUM(CUSUM^2)	Wald-SR[6]	Wald-LR		
$3591\ 1^{***}$	-0.36^{***}(0.036)	1.18(0.32)	0.023(0.88)	0.99	Stable	$8\ 87^{**}$	10.39^{**}		

Note: [1] The values inside the parenthesis are standard errors. [2] The upper bound critical value for cointegration of the F-test while using 9 exogenous variables is 2.99, 3.30, and 3.97 at the 10%, 5%, and 1% significance levels, respectively. These critical values are determined by Pesaran, Shin, and Smith (2001. Table C1.iii: Case-III).[3]The critical values that determine the long-run relationship of ECM_{t-1} are -4.23, -4.54, and -5.19 when using k=9 whereas is -4.56, -4.88, and -5.54 when k=7 at the 10%, 5%, and 1% significance level, respectively These critical values are determined by Pesaran, Shin, and Smith (2001, Table C2.iii: Case-III).[4]LM is the test which is based on chi-square distribution used for the detection of autocorrelation whose critical value is 2.70, 3.84, and 6.64 at the 10%, 5%, and 1% level of significance.[5]RESET is tested for misspecification by Ramsey having chi-square distribution which has the critical value 2.70. 3.84, and 6.64 at the 10%, 5%, and 1%. *, **, and *** represent 10%, 5%, and 1% significance levels, respectively. [6] The critical values based on chi-square distribution for both Wald tests are 2.70, 3.84, and 6.64 at 10%, 5%, and 1%, respectively.

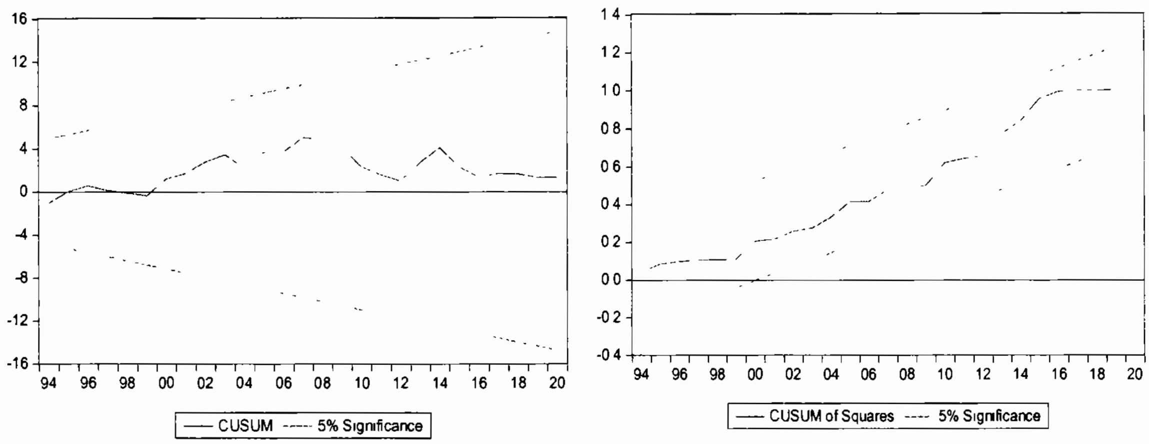

Figure 5.3: The plot of CUSUM and CUSUMSQ tests to check the stability of the linear ARDL model

the variables in the short run do not affect food production at zero lag except sunshine duration which enhances food production and few lag values of the climate indicators. However, the long-run estimates exhibit that both positive and negative changes in temperature significantly reduce food production. Yet, we do not find any asymmetry as both the changes affect negatively which is also evident from the short-run estimates.

Besides, the effects of changes in the level of precipitation are also asymmetric as positive changes in the level of precipitation enhance food production, whereas, negative changes negatively though insignificantly affect the production of food. For precipitation, there exists a long-run asymmetry which is also evident from the output of the Wald test denoted by Wald-SR and Wald-LR in Table 5.19. Panel C of Table 5.19 presents the different diagnostic tests used for cointegration, autocorrelation, misspecification of model, and stability. The existence of cointegration is assured by negative and significant ECM, whereas a significant value of the F-test shows the overall significance of the model. The residuals of the non-linear model are autocorrelation-free as LM tests show an insignificant value based on the chi-square distribution.

The estimation output of the linear model in the case when crop production is considered a variable of interest is shown in the upper part of Table 5.20. The short-run estimates reveal that most of the climate indicators significantly affect crop production except temperature and natural disasters when they are at zero lag. The short-run effects of precipitation and sunshine duration are positive for crop production as both these factors enhance the production of crops in a short period. However, in the long run, temperature and natural disasters significantly reduce crop production whereas precipitation and sunshine duration pose favorable effects on crop production. F-test and ECM support the existence of cointegration as both of them have significant values. The residuals of the linear model are not serially correlated and the model is correctly specified and stable as per the outcome of the LM test, RESET test, CUSUM, and CUSUMSQ tests of stability.

From the estimation output, it is evident that there is an asymmetry relationship between temperature and crop production, whereas, precipitation has no significant asymmetric effects on crop production. The lower part of Table 5.20 shows the estimation results of the non-linear model. The short-run effects are not significant for most of the climate change indicators at lag zero. However, the effects are somewhat significant in the second and third lags. The negative changes in temperature and sunshine duration boost crop production in the short run. The positive changes in temperature and duration of sunshine increase whereas natural disasters hurt crop production in the long run. The effects of negative and positive changes in precipitation are positive but insignificant. The diagnostic test results are somewhat similar to that of the linear model. So, most of the effects are significant in the long run, yet the effects are not asymmetric.

Climate changes in the form of extreme temperature and precipitation (maximum and minimum) changes affect the productivity of the agriculture sector.

Table 5.20 Full-information estimates when crop production index used as a dependent variable

I. Linear ARDL model				Panel A: Short-run coefficient estimates					
Lag order	0	1	2	3	4	5	6	7	8
ΔlnCPI	-----	------	------	------					
ΔlnTEMP	-0.13(0.14)[1]	0.55**(0.25)	0.78***(0.27)	0.88***(0.29)					
ΔlnPRCP	0.033**(0.017)								
ΔlnSS	0.06***(0.011)	-0.03***(0.01)	0.04***(0.01)						
ΔND	-0.01(0.011)	0.05***(0.01)							
ΔlnGFCF	-0.052(0.04)								
ΔlnUPOP	3.68(7.34)	-18.91(8.32)	22.41**(6.23)	-4.73**(3 06)					
ΔlnAGLD	-0.87***(0.31)	-1.33***(0.46)	0.48*(0.27)	1.06***(0.41)					

Panel B: Long-run coefficient estimates

Constant	lnTEMP	lnPRCP	lnSS	ND	LnGFCF	LnUPOP	LnAGLD
14.2(12.96)**	-5.13***(1.66)	2.4**(0.11)	0.72**(0.032)	-1.42**(0.06)	-1.41(0.073)	1.01***(0.092)	-0.81(0.89)

Panel C: Diagnostics

F-test[2]	ECM^3_{t-1}	LM[4]	RESET[5]	$\bar{R}^2$	CUSUM (CUSUM²)
594.8***	-0.47(0.13)	1.87(0.17)	2.21(0.15)	0.99	Stable

II. Non-linear ARDL model Panel A: Short-run coefficient estimates			
ΔlnCPI			
ΔPOST	0.04(0.20)	0.07***(0.021)	
ΔNEGT	0.035*(0.021)	-0.022(0.021)	0.065***(0.03)
ΔPOSP	0.01(0.002)		
ΔNEGP	0.03(0.002)		
ΔND	-0.12(0.014)	0.035***(0.011)	
ΔlnSS	0.031***(0 013)		
ΔlnAGLD	-0.61*(0.37)	-0.60(0.41)	1.38***(0.29)
ΔlnGFCF	0.057(0.066)	0.14(0.12)	-0.16***(0.062)
ΔlnUPOP	0.27***(0 096)		

Panel B: Long-run coefficient estimates

Constant	POST	NEGT	POSP	NEGP	ND	lnSS	lnAGLD	lnGFCF	lnUPOP
-13.29*(7.59)	-1.61**(0.08)	-1.43(0.12)	0.04(0.002)	0.03(0.01)	-1.52***(0.60)	0..92**(0.04)	-0.97**(0.12)	0.63(0.12)	0.79***(0.14)

Panel C: Diagnostics

F-test	ECM_{t-1}	LM	RESET	$\bar{R}^2$	CUSUM(CUSUM²)	Wald-SR[6]	Wald-LR
551.3***	-0.34***(0.087)	1.43(0.26)	0.011(0.92)	0.99	Stable	8.25**	6.64**

Note: [1] The values inside the parenthesis are standard errors [2] The upper bound critical value for cointegration of the F-test while using 9 exogenous variables is 2 99, 3 30, and 3 97 at the 10%, 5%, and 1% significance levels, respectively These critical values are determined by Pesaran, Shin, and Smith (2001, Table C1 in Case-III) [3]The critical values that determine the long-run relationship of ECM_{t-1} are -4 23, -4 54, and -5 19 when using k=9 whereas is -4 56, -4 88, and -5 54 when k=7 at the 10%, 5%, and 1% significance level, respectively These critical values are determined by Pesaran, Shin, and Smith (2001, Table C2 in Case-III) [4]LM is the test which is based on chi-square distribution used for the detection of autocorrelation whose critical value is 2 70, 3 84, and 6 64 at the 10%, 5%, and 1% level of significance [5]RESET is tested for misspecification by Ramsey having chi-square distribution which has the critical value 2 70, 3 84, and 6 64 at the 10%, 5%, and 1% *, **, and *** represent 10%, 5%, and 1% significance levels, respectively [6] The critical values based on chi-square distribution for both Wald tests are 2 70, 3 84, and 6 64 at 10%, 5%, and 1%, respectively

The upper part of Table 5.21 shows the linear model estimation output. At lag zero, most climate change indicators do not affect food production except sunshine duration which boosts food production in the short run. However, further lags of coefficients show their positive effect on food production for most of the climate change indicators. Maximum and minimum temperature effects are asymmetric but insignificant in the short run. Maximum temperature positively and significantly enhances food production, whereas, the minimum temperature does not affect it significantly in the long run. This shows an asymmetric relationship between the maximum and the minimum temperature in the long run. The asymmetric relationship also exists in the case of precipitation as maximum precipitation significantly boosts food production whereas minimum precipitation does insignificantly reduce it. Natural disasters hurt food production while sunshine duration enhances food production significantly in the long run. The diagnostic tests are also acceptable for this model.

The lower part of Table 5.21 presents the estimation results for crop production as an independent variable. The results reveal that significant asymmetric effects exist in the case of both maximum and minimum temperature, respectively in the short run. The significance is similar for both variables; however, signs work in opposite directions. Similar is the case of

precipitation but results are marginally significant for minimum precipitation. Minimum and maximum temperature damage crop production but their effects are insignificant. However, minimum and maximum both enhance crop production though the magnitude of the latter is larger compared to the former. The duration of sunshine enhances crop production. The output of diagnostic tests is quite similar to that of what was observed in the case of food production as a variable of interest.

Table 5.21: Full-information estimates (Extreme Effects)

I. Linear Model for Food Production Index (FPI)			Panel A: Short-run coefficient estimates						
Lag order	0	1	2	3	4	5	6	7	8
ΔlnFPI									
ΔMAXT	0.12(0.02)[1]	0.02**(0.01)	0.03***(0.01)	0.03***(0.005)					
ΔMINT	-0.13(0.03)								
ΔMAXP	0.014(0.0001)								
ΔMINP	0.027(0.001)	-0.015(0.0010	0.02**(0.001)	0.05***(0.005)					
ΔND	0.41(0.007)	0.32***(0.007)	0.14(0.005)	0.13**(0.006)					
ΔlnSS	0.21***(0.006)	-0.035***(0.01)							
ΔlnAGLD	-0.59***(0.19)	-0.72***(0.17)	0.27**(0.11)	0.58***(0.15)					
ΔlnGFCF	-0.016(0.026)								
ΔUPOP	-3.02***(0.93)								
Panel B: Long-run coefficient estimates									
Constant	MAXT	MINT	MAXP	MINP	ND	lnSS	lnAGLD	lnGFCF	lnUPOP
-8.20**	-3.2***(0.087)	1.14(0.075)	0.024**(0.001)	-0.05(0.012)	-1.23***(0.035)	1.62***(0.038)	-0.57(0.52)	-0.03(0.06)	1.01***(0.06)
Panel C: Diagnostics									
F-test[2]	ECM^3_{t-1}	LM[4]	RESET[5]	$\bar{R}^2$	CUSUM(CUSUM²)				
3545 4***	-0.40***(0.062)	0.091(0.913)	0.57(0.46)	0.99	Stable				
II. Linear Model for Crop Production Index (CPI)			**Panel A: Short-run coefficient estimates**						
ΔlnCPI									
ΔMAXT	0.13**(0.051)	-0.02(0.053)	-0.03(0.044)	0.17***(0.036)					
ΔMINT	-0.12**(0.053)	0.055(0.063)	0.08*(0.087)	-0.11***(0.038)					
ΔMAXP	-0.012(0.002)	-0.014*(0.003)	-0.03(0.003)	-0.04**(0.003)					
ΔMINP	0.01*(0.004)	-0.01***(0.002)	-0.002(0.003)	0.01***(0.003)					
ΔND	0.02(0.015)	0.043***(0.011)	0.001(0.011)	0.033**(0.013)					
ΔlnSS	0.044***(0.011)	-0.06**(0.025)							
ΔlnAGLD	-1.36***(0.46)	-1.62***(0.35)	-0.60*(0.33)	0.81***(0.25)					
ΔlnGFCF	-0.12***(0.045)								
ΔlnUPOP	-2.67(8.27)	-28.8*(18.21)	32.3***(6.69)	-12.7**(2.44)					
Panel B: Long-run coefficient estimates									
Constant	MAXT	MINT	MAXP	MINP	ND	lnSS	lnAGLD	lnGFCF	LnUPOP
-9.21(6.89)*	-1.43(0.72)	-1.141(0.11)	0.022**(0.004)	0.21***(0.004)	-0.34(0.04)	0.82***(0.023)	2.8(0.60)	-0.14***(0 04)	0.96***(0.05)
Panel C: Diagnostics									
F-test	ECM_{t-1}	LM	RESET	$\bar{R}^2$	CUSUM(CUSUM²)				
780.2***	-0.91***(0.19)	1.66(0.20)	0.23(0.64)	0.99	Stable				

Note: [1] The values inside the parenthesis are standard errors. [2] The upper bound critical value for cointegration of the F-test while using 7 exogenous variables is 3.06, 3.39, and 4.26 at the 10%, 5%, and 1% significance levels, respectively. These critical values are determined by Pesaran, Shin, and Smith (2001, Table C1.iii: Case-III).[3]The critical values that determine the long-run relationship of ECM_{t-1} are -4.23, -4.54, and -5.19 at the 10%, 5%, and 1% level when using k=7. These critical values are determined by Pesaran, Shin, and Smith (2001, Table C2.iii: Case-III).[4]LM is the test used for the detection of autocorrelation whose critical value is 2.70, 3.84, and 6.64 at the 10%, 5%, and 1% level of significance.[5]RESET is tested for misspecification by Ramsey having chi-square distribution which has the critical value 2.70, 3.84, and 6.64 at the 10%, 5%, and 1%. *, **, and *** represent 10%, 5%, and 1% significance level, respectively.

5.9 Estimation Results of Climate-Inequality Nexus

To estimate the long-run and short-run relationship between climate changes and income inequality, we test the stationarity and the long-run relationship among the study variables using unit root and panel cointegration tests. For the long-run causal relationship, we estimate the error correction term (ECT) for each of the models, where, statistically significant and negative values provide the justifications that variables have a long-run relationship. The error correction term (ECT) also equips the evidence that if a shock occurs to these variables, it drives the study variables back to their equilibrium positions. We present the empirical results of the study in the following way. First, the average response of climate change indicators on income inequality is assessed. The results of this empirical analysis for a linear model are presented in Table 5.22. This is valuable to mention that we also separate the sample into two divisions i.e., developing and developed countries. This exercise is done to compare the effects of climate change on the two divisions. The variables are not expressed in a natural logarithm. Hence, parameters are interpreted as semi-elasticities.

The short-run and the long-run estimates in Table 5.22 show that an increase in temperature causes an increase in income inequality. For instance, a 1^{O}C Celsius increase in temperature exacerbates the Gini coefficient by 3.96 units, on average, in the long run, whereas, in the short run, this rise reduces to 0.33 units. Climate change affects crops which leads to lower productivity and high cost of production, losses of income to farmers, a raised seasonal unemployment rate, and a rise in the level of poverty (Alam *et al.*, 2017). According to the report of the Inter-American Development Bank (IDB), there are three main reasons that climate change and natural disasters increase inequality. First, poor people are more vulnerable and exposed to climate change than their rich counterparts. Second, they lose their limited resources when climate hazards hit their belongings. Third, they have fewer resources to cope with the adverse effects of climate change (IDB, 2020). These three calculations are based on Burke *et al.* (2015) analysis which also showed a negative relationship between temperature and GDP per capita. Rising temperature reduces economic growth across countries, especially in developing economies. It is estimated that global warming causes a gap of 25% between the top and bottom income deciles (Diffenbaugh & Burke, 2019; Cavallo 2020).

Similarly, an increase in the level of precipitation leads to a marginal increase in the Gini coefficient. For example, a 1-millimeter increase in precipitation results in a rise of 2.9 units in

Table 5.22: Long-run and Short-run Estimation Results on Climate-Inequality Nexus (Average Effects)

Independent Variables	**GINI Coefficient as Dependent Variable**		
Panel A: Long-run estimates			
	Specification 1 (World)	**Specification 2 (Developing)**	**Specification 1 (Developed)**
Cointeq	-0.033***(0.022)	-0.092***(0.013)	-0.091***(0.137)
TEMP	3.96***(0.138)	5.67***(0.838)	4.9**(0.651)
PRCP	2.9***(0.224)	4.42***(0.261)	0.36(0.352)
ND	0.67***(2.904)	------------	-----------------
MSLP	0.72*(0.068)	0.11*(0.12)	0.17*(0.115)
SS	-0.351(0.314)	-0.71(0.372)	-0.27(0.521)
GFCF	0.94***(0.231)	0.71***(0.25)	0.26(0.23)
ITRD	1.47***(0.275)	1.73***(0.334)	1.03***(0.37)
TUP	0.812**(0.42)	1.35***(0.42)	0.21(0.72)
Panel B: Short-run estimates			
ΔTEMP	0.33***(0.0.11)	0.52***(0.15)	0.45**(0.23)
ΔPRCP	0.24*(0.024)	0.43***(0.34)	0.04(0.035)
ΔND	0.72***(0.25)	-----------	-----------------
ΔMSLP	0.13*(0.065)	0.13*(0.12)	0.02*(0.015)
ΔSS	-0.037(0.036)	-0.31(0.42)	-0.024(0.051)
ΔGFCF	0.083**(0.042)	0.075***(0.047)	0.024(0.021)
ΔITRD	0.12***(0.30)	0.16***(0.036)	0.13***(0.044)
ΔTUP	0.36**(0.042)	0.12***(0.053)	0.023(0.071)
F-Statistics	15.89***	14.55**	5.92***
Adj R-Square	0.69	0.67	0.68
DW-Statistics	2.05	1.99	1.91
No. of countries	179	179	179
No. of obs	5549	3813	1736

Note: GINI coefficient is the dependent variable. The values in parenthesis are standard errors. ***, **, and * show significance at the 1%, 5% and 10% levels, respectively. Specifications 1, 2, and 3 represent the world, developing, and developed countries, respectively. All the variables are not in logarithmic form and hence need to interpret as semi-elasticities.

the Gini coefficient in the long run. However, this effect is not significantly harmonious for developed countries. The impacts of mean sea level pressure and sunshine duration are positive and negative, respectively; though insignificant except for developed countries where mean sea level pressure marginally increases income inequality. Natural disasters are perilous for the Gini coefficient for all three divisions e.g., world, developing, and developed. The control variables gross fixed capital formation, openness to international trade, and urbanization cause the Gini coefficient to aggravate significantly.

Second, Table 5.23 shows the results of positive and negative deviations in major climate indicators (temperature and precipitation) from their overall mean levels for the study period. Both negative changes in temperature and precipitation cause a reduction in the Gini coefficient, whereas, positive changes in temperature insignificantly increase it. Positive changes in precipitation significantly exacerbate the Gini coefficient. For instance, negative changes in temperature of 1^{o}C cause the Gini coefficient to go down by 5.11 units, whereas, 1^{o}C change in negative changes below the mean deviation also causes a decline in the Gini coefficient. It is worthwhile to mention that positive changes in temperature above the mean deviation significantly push the Gini coefficient upward in developed countries only. The other results almost follow the same analogy as observed in the first dimension. There is an asymmetric relationship between climate change and income inequality which is evident from the estimates of the linear and non-linear models.

Third, the estimated parameters of the extreme climate changes for 179 countries are shown in Table 5.24. The results indicate that minimum temperature and maximum precipitation have a positive relationship with income inequality both in the short run and the long run. For both in the short run as well as in the long run. The rise in emissions leads to more income

Table 5.23: Long-run and short-run estimation results (Asymmetric Changes)			
Panel A: Long-run estimates			
Independent Variables	**GINI Coefficient as Dependent Variable**		
	Specification 1 (World)	**Specification 2 (Developing)**	**Specification 1 (Developed)**
Cointeq	-0.032***(0.023)	-0.085***(0.012)	-0.107***(0.014)
POST	2.10(0.40)	2.29(0.403)	1.32*(0.86)
NEGT	-5.11**(0.247)	-1.69(0.331)	1.22***(0.34)
POSP	6.11(0.342)	1.18***(0.384)	0.37(0.71)
NEGP	-1.85***(0.483)	-2.22***(0.59)	-1.12(0.91)
ND	9.74***(2.86)	-------------	------------
MSLP	0.71(0.82)	1.10(1.22)	0.92(0.11)
SS	-2.74(0.34)	-0.37(0.43)	-1.21(0.24)
GFCF	0.93***(.242)	0.72**(0.29)	1.56(1.94)
ITRD	1.48***(0.26)	1.91***(0.382)	0.91***(0.321)
TUP	0.82**(0.41)	1.44***(0.045)	0.11(0.62)
Panel B: Short-run estimates			
ΔPOST	0.18(0.041)	0.21(2.55)	0.14*(0.101)
ΔNEGT	-0.43**(0.044)	-0.14(0.344)	-0.13***(0.048)
ΔPOSP	0.52(0.036)	0.11***(0.041)	0.031(0.064)
ΔNEGP	-0.16***(0.053)	-0.19***(0.062)	-0.12*(0.114)
ΔND	0.83***(0.261)	---------------	------------
ΔMSLP	0.06(0.064)	0.11(0.13)	0.12(0.11)
ΔSS	-0.22(0.033)	-0.32(0.41)	-0.002(0.005)
ΔGFCF	0.071**(.045)	0.062*(.045)	0.022(0.021)
ΔITRD	0.13***(0.047)	0.16***(0.047)	0.11***(0.042)
ΔTUP	0.07**(0.41)	0.13**(0.53)	0.012(0.045)
F-Statistics	13.26***	15.25***	5.52***
Adj R-Square	0.69	0.67	0.68
DW-Statistics	2.05	1.99	1.91
No. of countries	179	179	179
No. of obs	5549	3813	1736

Note: GINI coefficient is the dependent variable. The values in parenthesis are standard errors. ***, **,* show significance at the 1%, 5% and 10% levels, respectively. Specifications 1, 2, and 3 represent the world, developing, and developed countries, respectively. All the variables are not in logarithmic form and hence need to interpret as semi-elasticities.

inequality around the globe. For example, both in the long run and short run, a unit instance, a 1°C rise in minimum temperature results in an increase of the Gini coefficient by 2.2 units, on average in the long run. Similarly, a 1-millimeter increase in maximum precipitation causes an increase in the Gini coefficient by 0.20 units. For this dimension, the effects of natural disasters remain to exacerbate the Gini coefficient both in the short run and the long run. The remaining parameters e.g., maximum temperature, minimum precipitation, and sunshine duration do not significantly cause income inequality. These results remain present in the developing countries except for maximum temperature which marginally increases the Gini coefficient. However, in

Table 5.24: Long-run and short-run estimation results (Extreme Effects)			
Panel A: Long-run estimates			
Independent Variables	**GINI Coefficient as Dependent Variable**		
	Specification 1 (World)	**Specification 2 (Developing)**	**Specification 1 (Developed)**
Cointeq	-0.03***(0.024)	-0.090***(0.011)	-0.091***(0.013)
MAXT	8.41(0.735)	1.39(1.31)	1.39**(0.758)
MINT	2.23**(1.132)	3.21***(1.34)	0.99(0.232)
MAXP	2.32**(1.14)	2.11**(1.12)	0.21(0.337)
MINP	4.81(.52)	5.12(0.52)	0.78(1.375)
ND	8.19***(2.88)	------------	--------------
MSLP	0.70*(0.068)	0.74(0.95)	0.15*(0.107)
SS	-0.241(0.314)	-0.19(0.38)	-0.13(0.52)
GFCF	0.91***(0.231)	0.72***(0.265)	2.75(0.627)
ITRD	1.41***(0.272)	1.76***(0.364)	0.93***(0.381)
TUP	0.84**(0.42)	1.37***(0.431)	0.27(0.718)
Panel B: Short-run estimates			
ΔMAXT	1.21(0.062)	0.13*(0.91)	0.13*(0.11)
ΔMINT	0.18**(1.101)	0.29***(0.12)	0.11(0.022)
ΔMAXP	2.01**(0.120)	0.022**(0.014)	0.02(0.031)
ΔMINP	0.042(.432)	0.52(0.56)	0.07(0.12)
ΔND	0.68***(0.259)	------------	-------------
ΔMSLP	0.11*(0.284)	0.11(0.13)	0.14*(0.112)
ΔSS	-0.21(0.032)	-0.022(0.042)	-0.015(0.046)
ΔGFCF	0.08***(0.04)	0.062*(0.041)	0.25(0.21)
ΔITRD	0.12***(0.033)	0.16***(0.036)	0.085**(0.041)
ΔTUP	0.074**(0.042)	0.12***(0.053)	0.032(0.074)
F-Statistics	15.63***	11.57***	4.79***
Adj R-Square	0.69	0.67	0.68
DW-Statistics	2.05	1.99	1.91
No. of countries	179	179	179
No. of obs	4829	3813	1736

Note: GINI coefficient is the dependent variable. The values in parenthesis are standard errors. ***, **, and * show significance at the 1%, 5% and 10% levels, respectively. Specifications 1, 2, and 3 represent the world, developing and developed countries, respectively. All the variables are not in logarithmic form and hence need to interpret as semi-elasticities.

In the case of developed countries, only maximum temperature and mean sea level pressure raises the Gini coefficient, whereas, other climate indicators do not influence income inequality. The effects of gross fixed capital, openness to international trade, and urbanization induce a rise in income inequality at the global level.

5.10 Empirical Results of Emission-Inequality Linkages

Finally, we present the estimation results of the symmetry and asymmetric effects of carbon emissions on income inequality. The results of the linear model on the left column of Table 5.25

show that carbon emissions have a positive and significant relationship with income inequality increase in carbon emissions results in the rise of the Gini coefficient by 6.72 and 0.48 units, respectively. We estimated a non-linear model to find whether there exist asymmetric effects of carbon emissions on income inequality or not. The results of the non-linear model are portrayed in the right column of Table 5.25. The results indicate that there is an asymmetric relationship between carbon emissions and income inequality.

Positive changes above the mean in carbon emissions raise the Gini coefficient, whereas, negative changes bring it down both in the short run and the long run. Natural disasters in the

Table 5.25: Long-run and short-run estimation results (Emission Scenario)

Panel A: Long-run estimates			
	GINI Coefficient as Dependent Variable		
Independent Variables	**Specification 1 (Average Changes)**	**Independent Variables**	**Specification 1 (Asymmetric Changes)**
Cointeq	-0.079***(0.013)	Cointeq	-0.079***(0.013)
COEM	6.72***(2.525)	POSC	0.98***(0.312)
		NEGC	-3.43***(0.81)
ND	13.36***(2.964)	ND	8.66***(2.91)
GFCF	1.14***(0.263)	GFCF	0.99***(0.91)
ITRD	1.93***(0.287)	ITRD	1.64***(0.275)
TUP	1.05**(0.482)	TUP	0.83***(0.452)
Panel B: Short-run estimates			
Δ COEM	0.48***(0.201)	ΔPOSC	0.07***(0.031)
----------	-----------	ΔNEGC	-0.271***(0.076)
ΔND	0.96***(0.24)	ΔND	0.69***(0.251)
ΔGFCF	0.082***(0.041)	ΔGFCF	0.08***(0.042)
ΔITRD	0.14***(0.034)	ΔITRD	0.013*(0.033)
ΔTUP	0.08**(0.043)	ΔTUP	0.07***(0.041)
F-Statistics	21.73***	F-Statistics	21.73***
Adj R-Square	0.68	Adj R-Square	0.68
DW-Statistics	2.05	DW-Statistics	2.05
No. of countries	179	No. of countries	179
No. of observations	5549	No. of observations	5549

Note: GINI coefficient is the dependent variable. The values in parenthesis are standard errors. ***, **, and * show significance at the 1%, 5% and 10% levels, respectively. Specifications 1, 2, and 3 represent the world, developing and developed countries, respectively. All the variables are not in logarithmic form and hence need to interpret as semi-elasticities.

form of floods, droughts, storms, and sea-level rise also increase income inequality. The effects of control variables on income inequality again remained positive for this dimension.

5.11 Robustness Checks

To assuage the reader of some misspecification concerns, we estimated different specifications of three main dimensions. First, we estimated a model for each specification using only climate change indicators. Second, we estimated the full model by controlling both time-fixed effects as well as country-specific effects. Before this, we also estimated our main three models without controlling any of these two effects i.e., time-fixed effects and country-fixed effects. Our estimation output indicates that the estimated models are correctly specified as the estimates of these models are almost insensitive to the inclusion of time-specific and country-specific effects. It is pertinent to mention that none of the indicators' coefficients showed any change in their significance and signs. However, the magnitudes of some indicators changed very slightly. Yet, this change was negligible. This shows that our estimation results are a little sensitive and stimulant to time-specific and country-specific effects. On the basis and inclusion of time and country-specific effects, our estimation results are robust and reliable in all the major cases. Finally, it is worthwhile to mention that as the sample size is divided into different continents and sub-regions having relatively smaller sizes, we assume based on an analogy drawn from main models that the results of these estimations are also robust.

Further, this study also presented two cases to check the robustness of our results. These additional analyses are presented in Appendix. We consider robustness to alternative panel specifications in which three new variables are introduced i.e., primary schooling, population density, and malaria prevalence. The introduction of these variables does not significantly impact the results of our initial models. These two additional specifications strengthen our results as their results are broadly consistent across these two additional panel specifications. However, population density showed significantly negative impacts on economic growth in the short run whereas its impact on growth is marginally negative in the long run. The impact of population density on income inequality is positive in the case of developing economies. Its impact on the full sample is marginally positive. Similarly, we have also catered to the issues of country-specific and time-specific effects for climate-agricultural and climate-inequality relationships. Our results showed robustness which indicates that the coefficient of our variables and their standard errors are less sensitive and stimulant to country and time-related effects.

Conclusions

6.1 Summary Findings

This study concludes by first presenting the findings of the climate-growth relationship. Second, it presents the summary findings of the relationship between climate change and agricultural production. Finally, it includes the summary of results found in the case of the climate-inequality nexus.

This study aimed at investigating the symmetric and asymmetric impacts of climate change on economic growth in 179 countries. The main results of the study are as follows. First, the average responses of climate change indicators reveal that temperature, precipitation, and dummy variable used for flood, drought, and storm hurt the economic performance in the long run while mean sea level pressure enhances it. The extended duration of sunshine also exerts negative effects on economic growth. The estimation output also reveals that non-climatic factors boost economic performance. These effects also persist in the short run. However, the adversity and intensity of these indicators decline. The estimation results while using GDP per capita show that average temperature, precipitation, sunshine duration, and disaster dummy significantly reduce the GDP per capita while mean sea level pressure enhances it in the long run. Non-climate indicators positively contribute to GDP per capita. In the short-run effects remain almost similar however, their magnitudes are reduced significantly. In the short run, foreign aid and financial development damages while gross fixed capital enhances GDP per capita.

Second, climatic indicators like minimum temperature, maximum precipitation, and natural disasters exert detrimental effects on the real GDP, whereas, minimum precipitation and mean sea level pressure enhance it in the long run. Minimum temperature, minimum precipitation, and disaster dummy exert damaging effects on GDP per capita while maximum precipitation and mean sea level boost it in the long run. The short-run effects vary in terms of magnitudes but not in terms of signs and significance in general.

Third, positive deviations in temperature above the historical mean level and negative changes in temperature and precipitation below their historical means reduce economic growth. The effect of these deviations also persists in the short run. Foreign aid and financial development and trademark and patent application also boost real GDP while the duration of sunshine marginally damages it. The estimation output in the case of GDP per capita reveals that most of the climate indicators reduce GDP per capita except for positive changes in precipitation above the mean level while non-climatic factors enhance it...

Finally, this study found asymmetric effects of climate change on economic growth when analyzing the impacts of climate change on the economic performance of 6 major continents e.g., Asia, Europe, Africa, North America, South America, and Australia, and 3 selected regions out of 6 contents e.g., South Asia, Central Europe, and Western Africa. The temperature rise exerts positive effects on the economic activities in Europe and Africa, whereas, its effects are adverse to the economic growth of North and South America. The effects of precipitation are negative for Africa and North America. Similarly, in most of the continents except Australia, sunshine duration negatively, whereas, sea-level pressure positively contributes to economic growth. Further, climate change effects are also asymmetric for 3 selected regions e.g., South Asia, Central Europe, and Western Africa out of 3 major continents of the world e.g., Asia, Europe, and Africa. The effects of temperature are insignificantly damaging for South Asia and Western Africa, whereas, it boosts the economic performance in Central Europe.

Precipitation significantly reduces economic growth in Central Europe while sea-level pressure boosts it in South Asia and Central Europe.

To sum up the effects of climate change on agricultural production, this study concludes that climate changes in the form of higher temperature and sunshine duration cause a decline in food production worldwide and in developing economies while their impacts are insignificant for developed economies. The average level of precipitation positively affects the food production of the first two divisions while its effects are detrimental to the last division. All the non-climatic indicators enhance food production except urbanization which causes a decrease in food production. Similarly, maximum temperature and minimum precipitation are also not beneficial for food production as these extreme values cause a reduction in food production. Unlike these two extremes, maximum precipitation enhances the production of food in the first two divisions but in the latter case, its effect is insignificant. Besides, negative and positive changes below and above the mean level of temperature and precipitation, respectively cause a reduction in the production of food for all three divisions of the study. However, positive and negative changes above and below the mean values of temperature and precipitation, respectively enhance food production. The duration of sunshine e.g., increased hours of sunshine causes a reduction in food production in developing economies.

Likewise, the first strategy higher temperature negatively while precipitation positively affects crop production. The effect of sunshine duration is insignificant though negative. Employment in the agriculture sector marginally enhances food production in the first and third divisions while in the case of developing economies, its effect is positive and significant. Urbanization retard crop production for the first and third division of the analysis but for developing economies, it enhances the production of crops. The effects of extreme changes on crop production are similar to that of food production in the first strategy except for changes in the magnitudes of their coefficients. However, urbanization unexpectedly enhances crop production of the first two divisions while its effect is damaging for developed economies. Similarly, the effects of asymmetric changes are almost at par with that observed in the case of the food production index with slighter changes in the magnitudes while sunshine duration does not significantly damage crop production in developing economies.

This study summarizes the outcome of the investigation on the (a)symmetric effects of climate changes on agriculture production in Pakistan for the period 1960 to 2020 in the following way. First, temperature changes in the short run do not affect food production whereas precipitation and sunshine duration enhance it. However, rising temperatures and repeated occurrences of natural disasters cause a decline whereas precipitation and duration of sunshine boost food production. Most of the short-run effects of the linear model last in the long run which indicates that there are no effect asymmetries between climate change indicators and food production. The results of the non-linear model reveal positive and negative changes in temperature damage food production in the long run. It is evident from the estimation results that asymmetric effects are present in terms of the magnitudes of the variables in the non-linear model. It is worth mentioning that asymmetry exists for the effects of precipitation as positive changes in precipitation enhance while negative changes reduce it though the effect in the latter case in food production is not significant. Similarly, sunshine enhances but natural disasters damage food production in the long run.

Second, temperature and natural disasters effects are negative and symmetric on crop production although their damages are prominent only in the long run. Precipitation and sunshine enhance crop production. The results of the non-linear model show an asymmetric relationship between both positive (negative) changes in temperature and crop production. Sunshine duration also enhances crop production.

Third, the effects of maximum and minimum temperatures are asymmetric as maximum temperatures positively but insignificantly enhance food production in the short run, on the other hand, it damages the production of food significantly in the long run. Similarly, maximum precipitation boosts food production only in the long term. The effects of natural disasters and sunshine duration are damaging and boosting, respectively. The findings reveal that an asymmetric relationship exists between maximum temperature as it significantly boosts crop production in the short run while its effects are negative but insignificant in the long run. Similarly, maximum precipitation causes an insignificant reduction in the short period while it enhances crop production in the long run which shows an asymmetric relationship between them.

Further, this study sums up the results aimed at investigating the symmetric and asymmetric impacts of climate changes and carbon emissions on income inequality in 179 countries. The main results of the study are as follows. First, most of the climatic change indicators in a linear relationship exacerbate income inequality except the duration of sunshine duration which insignificantly reduces inequality both in the short run and the long run. Second, we found an asymmetry effect of climate changes on income inequality as the effects of positive and negative changes above and below their mean deviations are different for income inequality. Third, extreme changes in climate change indicators exert mixed effects on income inequality. An increase in minimum temperature and maximum precipitation causes an increase in income inequality.

Fourth, the results show that an asymmetric relationship exists between carbon emissions and income equality. Carbon emissions positively and significantly increase income inequality.

However, positive and negative changes in carbon emissions above and below the mean deviations assert different effects on income inequality. Former exacerbate, whereas, later cause a reduction in income inequality. Besides, natural disasters bring more inequality in incomes for developing countries compared to developed countries. The non-climatic indicators also become a reason for the increase in income inequality. It is worthwhile to mention that most of the climate change effects fall more heavily on developing countries compared to developed countries.

6.2 Limitations of the Study

It is a challenging task to conduct a study on the climate-economy nexus, especially at the global level due to several issues. These challenges require greater attention to reach the desired level of outcome. Though this study tries to tackle and address the issues and concerns arising during the analysis there are some limitations that must be kept under consideration by the researchers. The limitations of the study include:

- The observations on some of the variables like mean sea level pressure and mean hourly sunshine etc. are missing. The data of these variables is unbalanced for analysis. Similarly, data on some other non-climatic variables i.e., gross fixed capital, real GDP, and GDP per capita is also missing for some countries.
- The time duration of the study spanned from 1980-2020 (41 years). However, the data is squeezed for the investigation of differential effects of climate change on income inequality as the data on the Gini coefficient falls too short before the 1990s.
- As there is no global data available on the variables like floods, droughts, storms, and sea-level rise, so, this study tries to incorporate the impacts of these variables by using dummy variables (natural disasters).

- Natural disaster data at the global level is not available. We have used dummy variables to investigate the impacts of disasters on the economic outcome.

6.3 Policy Recommendations

It is a need of time to put more effort into implementing and consolidating particularly those policies which are important to prevent the degradation of climate indicators. Investment in adaptation measures at the national and international levels can minimize the deleterious effects of this hazard. To promote sustainable development activities around the globe, the adaptive capacity of the people to climate change must be enhanced by improving access to resources, reducing inequalities of resources among groups, improving information and education, and improving the infrastructure, institutional capacity, efficiency, etc. Besides, mitigation policies in the form of the development of efficient renewable energy sources like solar, wind, and tidal can be adopted which reduce dependence on fossil fuels that are also major drivers of increasing the volume of carbon emissions worldwide.

In order to improve the climate conditions by lowering GHG emissions, there is a greater insurgency to reduce deforestation and forest degradation, especially in developing economies. To decrease the volume of GHG emissions, low-carbon technologies, and practices must be used and carbon taxes can also be levied to reduce environmental degradation. Moreover, following the measure and setting the target of temperature below 2 degrees Celsius during this century by the Paris Agreement can also be proven helpful for minimizing the detrimental effects of climate change.

To build the resilience of farmers, investment in adaptation measures can bring significant change and improvement in the production of the agriculture sector. For instance, farmers may use adaptation measures like growing crop varieties that are drought tolerant besides other sustainable farm management activities. Besides, land use and management need to be improved for enhanced crop production. Technologies that are climate-resilient, economically viable, and technically sound must be used to combat and mitigate the adversities of this hazard.

The Government of Pakistan must take necessary actions and measures by devising a proper policy to lower CO_2 emissions which is one of the prime causes of contamination and volatility of climate change indicators, especially temperature. The government should invest in acquiring modern technology which can assist the metrological experts to forecast the occurrence of floods, droughts, storms, sea-level rise, etc. accurately. The Govt can devise plans and policies accordingly to minimize the adversity of disasters. For improved agriculture production, new crop varieties can be used which resist and survive in the presence of harsh temperatures, changing patterns of rainfall, solar radiation, and other natural disasters. Credit facilities to the agriculture sector, the introduction of new farming techniques, and R&D can boost and rebuild the sustainable and resilient agriculture sector of Pakistan. The sunshine data before 1983 has the issue of reliability due to non-documentation. Besides, the usage of panel data especially at the Provincial level, in the case of Pakistan, can assist researchers to portray regional or provincial implications of asymmetric effects of climate change.

Policymakers should prioritize poverty and inequality reductions. It is mandatory to form and implement such policies which cause a reduction in inequalities in the distribution of and enhance access to resources. Besides, policies must focus on the solution to the surging issue of climate change and carbon emissions to reduce environmental degradation. Investment in adaptation measures at the international level in general and in developing economies, in particular, can mitigate adverse climate changes and emissions. Poor countries must be provided with credit facilities as they mostly remain unable to internalize the cost required to mitigate GHG emissions. To decrease the level of carbon emissions, low-carbon technologies and practices must be used and the imposition of carbon taxes can cause a reduction in environmental degradation.

6.4 Future Research Areas

Future research may consider the issues which focus on the establishment of a baseline relationship between climate and human health including mental health, livelihood, water resources, ecosystems, etc. Regional effects can also be focused on as the climate varies regionally. It may consider the issues about the establishment of a baseline relationship between climate and food prices, agricultural revenue, water availability, crop diseases, etc. Capturing and pin picture the regional impacts of this hazard may also prove beneficial. Future research must consider the asymmetric effects of climate change not only on the production of different food crops but also on their prices. Future studies may also consider and focus on income inequalities in different regions of the world. Sectoral inequalities due to climate change can also be focused on in future research. How climate change affects the labor productivity and income of the labor force working in different sectors of an economy can also be an interesting area for future research.

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Appendices

Appendix 1

Table No.23 Developing countries according to International Monetary Fund [edit]

The following are considered developing economies according to the International Monetary Fund's World Economic Outlook Database, October 2018.[83][84]

Afghanistan
Albania
Algeria
Angola
Antigua and Barbuda
Argentina
Armenia
Aruba
Azerbaijan
Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belize
Benin
Bhutan
Bolivia
Bosnia and Herzegovina
Botswana
Brazil
Brunei
Bulgaria
Burkina Faso
Burundi
Cambodia
Cameroon
Cape Verde
Central African Republic
Chad
China
Chile
Colombia
Comoros
Democratic Republic of the Congo
Republic of the Congo
Costa Rica
Côte d'Ivoire
Croatia
Djibouti
Dominica
Dominican Republic
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Eswatini (Swaziland)
Ethiopia
Fiji
Gabon
The Gambia
Georgia
Ghana
Grenada
Guatemala
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
Hungary
India
Indonesia
Iran
Iraq
Jamaica
Jordan
Kazakhstan
Kenya
Kiribati
Kosovo
Kuwait
Kyrgyzstan
Laos
Lebanon
Lesotho
Liberia
Libya
Madagascar
Malawi
Malaysia
Maldives
Mali
Marshall Islands
Mauritania
Mauritius
Mexico
Federated States of Micronesia
Moldova
Mongolia
Montenegro
Morocco
Mozambique
Myanmar
Namibia
Nauru
Nepal
Nicaragua
Niger
Nigeria
North Macedonia
Oman
Pakistan
Palau
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Qatar
Romania
Russia
Rwanda
Saint Kitts and Nevis
Saint Lucia
Saint Vincent and the Grenadines
Samoa
São Tomé and Príncipe
Saudi Arabia
Senegal
Serbia
Seychelles
Sierra Leone
Solomon Islands
Somalia
South Africa
South Sudan
Sri Lanka
Sudan
Suriname
Syria
Tajikistan
Tanzania
Thailand
Timor-Leste
Togo
Tonga
Trinidad and Tobago
Tunisia
Turkey
Turkmenistan
Tuvalu
Uganda
Ukraine
Uruguay
Uzbekistan
Vanuatu
Venezuela
Vietnam
Yemen
Zambia
Zimbabwe

Appendix 2

Table No. 24 Countries with very High Human Development

The 2018 Human Development Report by the **United Nations Development Programme** was released on 14 September 2018, and calculates HDI values based on estimates for 2017

2018 rankings [1]	Country	HDI 2018 rankings [1]	HDI Change from previous year [1]
1	Norway	0.953	0.002
2	Switzerland	0.944	0.001
3	Australia	0.939	0.001
4	Ireland	0.938	0.004
5	Germany	0.936	0.002
6	Iceland	0.935	0.002
7	Hong Kong	0.933	0.003
7	Sweden	0.933	0.001
9	Singapore	0.932	0.002
10	Netherlands	0.931	0.003
11	Denmark	0.929	0.001
12	Canada	0.926	0.004
13	United States	0.924	0.002
14	United Kingdom	0.922	0.002
15	Finland	0.920	0.002
16	New Zealand	0.917	0.002
17	Belgium	0.916	0.001

2018 rankings [1]	Country	HDI 2018 rankings [1]	HDI Change from previous year [1]
31	Greece	0.870	0.002
32	Cyprus	0.869	0.002
33	Poland	0.865	0.005
34	United Arab Emirates	0.863	0.001
35	Andorra	0.858	0.002
35	Lithuania	0.858	0.003
37	Qatar	0.856	0.001
38	Slovakia	0.855	0.002
39	Brunei	0.853	0.001
39	Saudi Arabia	0.853	0.001
41	Latvia	0.847	0.003
41	Portugal	0.847	0.002
43	Bahrain	0.846	
44	Chile	0.843	0.001
45	Hungary	0.838	0.003
46	Croatia	0.831	0.003
47	Argentina	0.825	0.003

17	Liechtenstein	0.916	0.001	48	Oman	0.821	0.001
19	Japan	0.909	0.002	49	Russia	0.816	0.001
20	Austria	0.908	0.002	50	Montenegro	0.814	0.004
21	Luxembourg	0.904	0.001	51	Bulgaria	0.813	0.003
22	Israel	0.903	0.001	52	Romania	0.811	0.004
22	South Korea	0.903	0.003	53	Belarus	0.808	0.003
24	France	0.901	0.002	54	Bahamas	0.807	0.001
25	Slovenia	0.896	0.002	55	Uruguay	0.804	0.002
26	Spain	0.891	0.002	56	Kuwait	0.803	0.001
27	Czech Republic	0.888	0.003	57	Malaysia	0.802	0.003
28	Italy	0.880	0.002	58	Barbados	0.800	0.001
29	Malta	0.878	0.003	58	Kazakhstan	0.800	0.003
30	Estonia	0.871	0.003				

Appendix 3 Additional specification for Robust Check

Table 25: Long-run and short-run estimation results

Independent Variables	Real GDP as Dependent Variable				GDP per capita as Dependent Variable			
	Specification 1		Specification 2		Specification 1		Specification 2	
	MG	PMG	MG	PMG	MG	PMG	MG	PMG
Panel A: Long-run estimates								
Cointeq	-0.012***	-0.011***	-0.017***	-0.015***	-0.018***	-0 016***	-0.010***	-0.013***
TEMP	-0.91***	-0.92***	-0.85***	-0.81***	-0.076**	-0.079**	-0.52***	-0 60***
	(0 2614)	(0.0000)	(0.2447)	(0 2311)	(0.039)	(0.041)	(0.23)	(0.31)
PRCP	-0.36***	-0.45***	-0 34***	-0.30***	-0.01	-0.02*	-0 04*	-0 05*
	(0.1415)	(0.1411)	(0.1204)	(0.1142)	(0.017)	(0.015)	(0.03)	(0.04)
FD5	-0.68**	-0.66**	-0 68**	-0.66**	-0.032**	-0.04**	-0.13***	-0.09**
	(0.3014)	(0.2985)	(0.3272)	(0.3310)	(0.031)	(0.054)	(0.041)	(0.047)
MSLP	0.03**	0.04*	0.02**	0.03**	0.13*	0.15*	0.03**	0.02*
	(0.011)	(0.015)	(0.64)	(0.59)	(0.106)	(0.109)	(0.013)	(0 01)
SS	-0.06	-0.056	-0.59	-0 73	-0.11*	-0.14	-0.11**	0.22**
	(0 074)	(0.06)	(0.61)	(0.54)	(0.074)	(0.085)	(0.042)	(0.03)
FAFD			0.35***	0.32***			0 01*	0 01***
			0.1945	0.1875			(0.011)	(0.01)
ITRD			-0.34	-0.31*			0.032	0.037*
			(0.42)	(0.52)			(0.04)	(0.03)
TMPA			0.013***	0.011***			0.004**	0.003**
			(0.021)	(0.03)			(0.001)	(0.002)
PRSC			-0.013	-0.011			-0.034	-0.038
			(0.013	(0.011)			(0.032)	(0.027)
POPD			0.014	0.012			-0.016*	-0.021*
			(0.027)	(0.035)			(0.016)	(0.017)
MLPR			-0.013	-0.015			-0.072*	-0.074*
			(0.014)	(0.011)			(0.013)	(0.016)
Panel B: Short-run estimates								
ΔTEMP	-0.19***	-0.17***	-0.15***	-0.11**	-0.19***	-0.17**	-0.12***	-0.15**
	(0.0477)	(0.0461)	(0.0602)	(0.0541)	(0 0477)	(0.044)	(0.01)	(0 01)
ΔPRCP	-0.007*	-0.006**	-0.007*	-0.005	-0.007*	-0.006**	-0.004*	-0.005*
	(0 08)	(0.07)	(0.05)	(0.06)	(0.008)	(0.007)	(0.03)	(0.02)
ΔFDS	-0.15**	-0.13**	-0.19**	-0.17**	-0.15**	-0.21*	-0.012***	-0.015**
	(0.0861)	(0.0798)	(0.102)	(0.1112)	(0.0861)	(0.0671)	(0.002)	(0.001)
ΔMSLP	0.005**	0.004**	0.005**	0.004	0.005**	0 004**	0.001**	0.001*
	(0.002)	(0.001)	(0 002)	(0 002)	(0.002)	(0.003)	(0 001)	(0.001)
ΔSS	-0.001	-0.002	-0.01**	-0.01**	-0.001	-0.001	-0 001	-0.001
	(0 007)	(0.006)	(0.01)	0.01	(0.007)	(0.006)	(0.002)	0.003
ΔFAFD			0 001	0.002			-0.001***	-0.001***
			(0.002)	(0.001)			(0.001)	(0.001)
ΔITRD			-0.012	-0.011			0 012***	0.02***
			0.001	0.001			(0.001)	(0.001)
ΔTMPA			0.001	0.001			0.001***	0.002**
			(0.001)	(0.001)			(0 001)	(0.002)
ΔPRSC			0.002	0.001			-0.0011	-0.0014
			(0.0013	(0.0011)			(0.003)	(0.0027)
ΔPOPD			0.001***	0 002**			-0.001***	-0.002***
			(0.002)	(0.003)			(0.0006)	(0.0007)
ΔMLPR			-0.0012*	-0.0015*			-0.0026*	-0.0023**
			(0.014)	(0.011)			(0.0013)	(0.0016)
Hausman test χ^2	79.4(0.002)	78.2(0.000)	77.3(0.000)	77.6.2(0.000)	69.2(0.012)	70.5(0.000)	68.4 2(0 000)	72.6(0.000)
No. of countries	179	179	179	179	179	179	179	179
No. of obs	7339	7339	7339	7339	7339	7339	7339	7339

Note: Real GDP and GDP per capita are the dependent variables. The values in parenthesis are standard errors. ***, **,* show significance at 1%, 5% and 10% levels, respectively. Models 1 only considers the climatic indicators while model 2 represents the full model which includes both climate and non-climate indicators, respectively. In model 1 on both left and right sides, climatic variables are in logarithmic form and hence need to interpret as elasticities while in model 2 on the left side, temperature, precipitation, and financial assistance, and financial development are in logarithmic form and are interpreted as semi-elasticities. The coefficients of the remaining variables and of model 2 on the right side of the table need to interpret as semi-elasticities.

Table 26: Long-run and Short-run Estimation results on Climate-Inequality Nexus (Average Effects)			
Panel A: Long-run estimates			
Independent Variables	**GINI Coefficient as Dependent Variable**		
	Specification 1 (World)	**Specification 2 (Developing)**	**Specification 1 (Developed)**
Cointeq	-0.033***(0.022)	-0.092***(0.013)	-0.091***(0.137)
TEMP	3.86***(0.138)	5.77***(0.838)	4.6**(0.651)
PRCP	2.78***(0.224)	4.22***(0.261)	0.37(0.352)
ND	0.69***(2.904)	------------	-----------------
MSLP	0.62*(0.068)	0.11*(0.12)	0.18*(0.115)
SS	-0.341(0.314)	-0.70(0.372)	-0.26(0.521)
GFCF	0.86***(0.231)	0.71***(0.25)	0.28(0.23)
ITRD	1.47***(0.275)	1.63***(0.334)	1.03***(0.37)
TUP	0.712**(0.42)	1.32***(0.42)	0.21(0.72)
PRSC	0.024(0.044)	0.020(0.040)	0.026(0.046)
POPD	0.068(0.045)	0.053**(0.045)	0.033(0.035)
MLPR	-0.069(0.013)	-0.032(0.013)	-0.022(0.015)
Panel B: Short-run estimates			
ΔTEMP	0.31***(0.0.11)	0.51***(0.15)	0.42**(0.23)
ΔPRCP	0.23*(0.024)	0.41***(0.34)	0.04(0.035)
ΔND	0.72***(0.25)	------------	-----------------
ΔMSLP	0.13*(0.065)	0.13*(0.12)	0.02*(0.015)
ΔSS	-0.037(0.036)	-0.31(0.42)	-0.024(0.051)
ΔGFCF	0.071**(0.042)	0.073***(0.047)	0.024(0.021)
ΔITRD	0.11***(0.30)	0.15***(0.036)	0.13***(0.044)
ΔTUP	0.33**(0.042)	0.14***(0.053)	0.023(0.071)
ΔPRSC	0.0026(0.0032)	0.0029(0.0037)	0.0018(0.0042)
ΔPOPD	0.0074*(0.0073)	0.0054***(0.0053)	0.0044(0.0042)
ΔMLPR	-0.075(0.0012)	-0.045(0.0014)	-0.039(0.0024)
F-Statistics	17.89***	15.55**	5.96***
Adj R-Square	0.74	0.69	0.71
DW-Statistics	2.01	1.99	1.91
No. of countries	179	179	179
No. of obs	5549	3813	1736

Note: GINI coefficient is the dependent variable. The values in parenthesis are standard errors. ***, **, and * show significance at the 1%, 5% and 10% levels, respectively. Specifications 1, 2, and 3 represent the world, developing, and developed countries, respectively. All the variables are not in logarithmic form and hence need to interpret as semi-elasticities.

Appendix 4 Results of misspecification tests

1. **Breusch-Godfrey Serial Correlation LM Test:**

➢ For Climate-Growth Model

F-statistic	0.113873	Prob. F(2,457)	0.8924
Obs*R-squared	0.244568	Prob. Chi-Square(2)	0.8849

➢ For Climate-Agricultural Model

F-statistic	1.288724	Prob. F(2,6600)	0.2757
Obs*R-squared	2.583858	Prob. Chi-Square(2)	0.2747

➢ For Climate-Inequality Model

F-statistic	1.135003	Prob. F(2,4107)	0.3215

Obs*R-squared	2.279799	Prob. Chi-Square(2)	0.3199

2. Ramsey RESET tests

- For Climate-Growth Model, the results are not significant.
- For Climate-Agricultural Model (when food production index is used as dependent variable)

	Value	df	Probability
t-statistic	0.575600	2019	0.5649
F-statistic	0.331315	(1, 2019)	0.5649
Likelihood ratio	0.332436	1	0.5642

- For Climate-Agricultural Model(when crop production index is used as dependent variab

	Value	df	Probability
t-statistic	1.203839	1944	0.2288
F-statistic	1.449228	(1, 1944)	0.2288
Likelihood ratio	1.454650	1	0.2278

- For Climate-Inequality Model

	Value	df	Probability
t-statistic	0.593553	6601	0.5528
F-statistic	0.352305	(1, 6601)	0.5528