IMPACT OF CLIMATE CHANGE ON AGRICULTURE

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31.03.2022

Abstract: *Ensuing climate change is one of the most defining problems of the 21st century. As per IPCC (AR6), the global average temperatures have already increased by 1.1 degree Celsius since pre-industrial era (1850-1900) along with an increase in the frequency and intensity of extreme weather events. The paper seeks to causatively identify the impact of climate change on agriculture gross value added using exogenous variation in weather outcomes over time within a given spatial area. Panel data on 150 countries over the period 1991-2016 is used for this purpose. Three distinct models have been built which aim to capture the non-linear impact of weather variables (temperature and precipitation), impact of extreme weather shocks on agriculture GVA and address potential reverse causality respectively. The results reported reveal that there are positive but diminishing returns to temperature and precipitation and a negative impact of weather shocks on agriculture gross value added. The negative weather shocks are exacerbated in countries which are already hot. The study underscores the importance of adaptation efforts at a local scale through harnessing youth innovation and indigenous knowledge and continued mitigation at a global scale through developing an effective carbon tax regime and improving means of global cooperation on this global public good problem.*

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"The Earth is what we all have in common"- Wendell Berry

INTRODUCTION

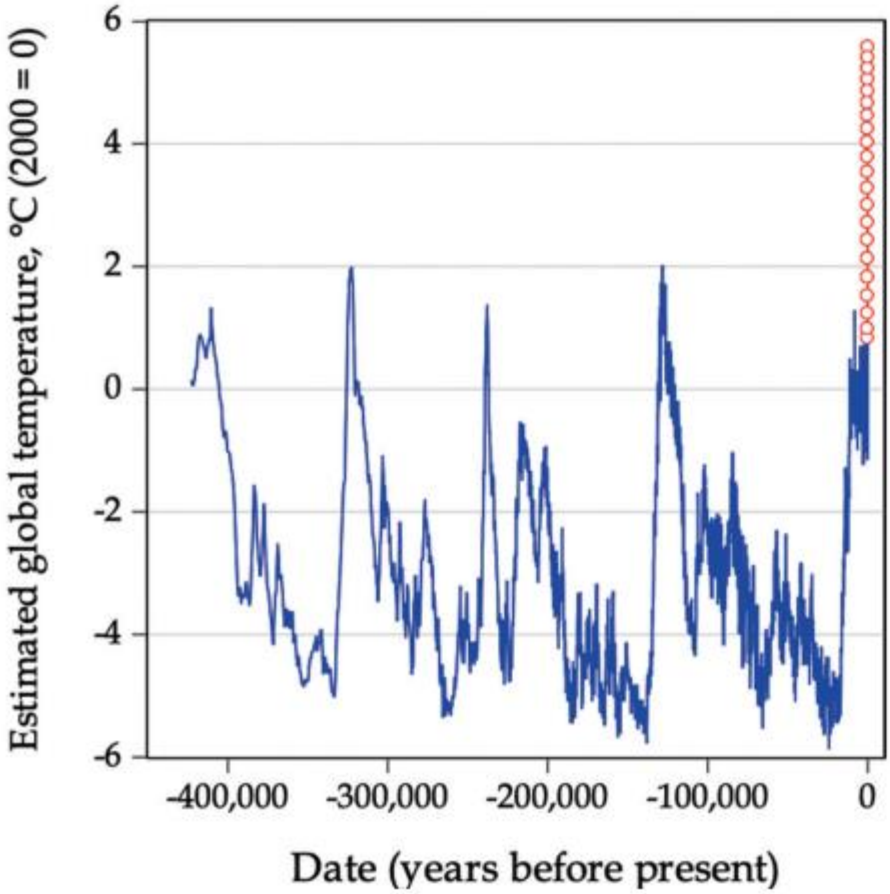
Ensuing climate change[2] is one of the most defining problems of the 21st century. Scientific evidence on climate science has been around since 1856, when Eunice Newton Foote published her paper on the greenhouse effects of CO2. With the technological improvements after the Second World War, the science of global warming became even more evident and since the 1980s the true threat of global warming has become apparent to those outside the scientific community. Today climate change is not just a scientific concern but has widespread implications for economies, sociology, geopolitics, national and local politics, law, health and global inequality to name a few.

According to IPCC's Sixth Assessment Report[3] anthropogenic emissions have resulted in a global temperature rise of 1.1 degree Celsius since 1850-1900. The report also states that unless there are immediate, rapid and collective reductions in greenhouse gas emissions, the curtailment of global temperature rise to 1.5 or even 2 degree Celsius will be beyond our reach. Since climate change is a *global public good*, individual nations lack incentive to take action to curtail their greenhouse gas emission as they enjoy only a small fraction of the benefits of their actions. This failure to take collective action has resulted in an observable increase in temperatures and rise in the frequency of extreme weather events such as droughts, floods and heat waves in the last half century. These changes in weather patterns are becoming evident in not just the low income developing countries but also developed nations. The summer monsoon precipitation over India has already declined by around 6% from 1951 to 2015, with significant decreases over the Indo- Gangetic plains and Western Ghats. [i] Glacial retreat in the Himalayas, compounding effects of sea-level rise and intense tropical cyclones leading to flooding and high heat stress are potent risks to India's weather stability as per IPCC.

Climate change is increasingly being viewed as an interdisciplinary theme rooted in natural sciences but also requiring action from economics, social and policy domains. Scientific rigour on the accumulation of greenhouse gases and its impact on global climate has increased manifold. Development in the last half century has enabled scientists to use Antarctic ice-core data to develop paleoclimatic records of CO2 concentration and temperatures for the last half million years. The figure below shows a reconstruction of global temperatures for the last half-million years with the present temperature being normalised to zero. The red dots show the projection of future temperatures if global warming persists unchecked. In the absence of collective policies to slow down greenhouse gases emissions, the global temperatures will soon surpass the historical maximum of the last half million years. [ii]

[2] IPCC (2014) defines climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer."

[3] Working Group 1 report which is the first instalment of IPCC's Sixth Assessment report (AR6) which will be completed in 2022



Estimated global temperature variations for the last 400,000 years based on Antartic ice core (blue line) along with model predictions for the next two centuries (red dotted line). Source: Nordhaus (2013a)

Policy making towards climate change requires the estimation of three distinct relationships. First environmental scientists need to study the relationship between carbon dioxide emissions and ambient carbon dioxide levels. Next atmospheric scientists study the relationship between ambient carbon dioxide concentrations and global temperatures (known as the climatic sensitivity parameter)[iii]. Lastly economist study the causal relationship between temperature levels and its impact on economic activity. This guides climate change policies such as carbon tax, cap and trade. Scientific rigour has strengthened our understanding of the first two relationships allowing economists to quantify the latter relationship and guide policymaking.

Economists have long been involved in assessing the macroeconomic impact of climate change. A persistent rise in temperature, erratic rainfall patterns and frequent extreme weather events can have a long term macroeconomic impact through adversely affecting labour productivity, agricultural yields and investments. Estimates of costs of climate change have been given by economists including the Stern Report, 2006[iv] which stated that under status quo the impacts of climate change could cost between 5% and 20% of world GDP every year and Nobel laureate Nordhaus who claims that a 4 degree Celsius increase in global temperature over pre-industrial levels would reduce GDP per capita between 2% and 4% [v] which is estimated through the Integrated Assessment Model (IAM).[4]

[4] The IAM approach relies on micro-evidence from climate- economy interaction and aggregates this effect into a net effect on national income. This evidence is used to compute a Social Cost of Carbon (SCC) which can guide policymakers on carbon tax.

Dell et al. (2012) estimate the impact of historical fluctuations in temperature on economic growth and level. They attempt to find the channel of influence through estimating the impact of weather shocks on agriculture, industrial output and political stability through a cross country analyses over a long time period. World Economic Outlook by IMF (2017) uses an impulse response function to see the effect of an increase in temperature on contemporaneous and future economic growth and find that in countries with high average temperatures, an increase in temperature dampens economic activity and in countries with low average temperature, an increase in temperature increases economic activity with the threshold temperature being between 13 – 15 degree Celsius. The results suggest highly uneven impacts of warming across the globe. As low income developing countries tend to have higher average temperatures, impact of increasing temperatures will be more acutely felt on the per capita income in these countries.

AGRICULTURE AND CLIMATE CHANGE

Dell et. al. (2012) in their study of impact channels find the most significant impact of climate change through the agriculture sector. The vulnerability of the agriculture sector to climate change is well documented and it is found to be one of the important channels through which climate change increases the susceptibility of low income developing countries which are highly dependent on agriculture. World Economic Outlook by IMF (2017) finds that a 1 degree Celsius increase in temperature, estimated at the median temperature prevailing in low-income developing countries, reduces agriculture gross value added and crop production. Production recovers somewhat in near future and remains depressed over the medium term.

Nordhaus, in his development of climate economics, classifies certain human and natural systems as ‘unmanageable’ which are highly vulnerable to the impacts of climate change. The most severe damages of climate change are likely to be concentrated in these vulnerable systems including rain-fed agriculture, coastal areas facing rising sea-level, river run-offs and forest fires in low-income and tropical regions like tropical Africa, Latin America and the Indian subcontinent. These systems operate at large scales with complexities that cannot be managed through human technologies. Scientists are especially concerned about significant and irreversible imbalances that can occur in these systems beyond a tipping point.

Hulme (1996) describes four ways through which climate changes can potentially affect agriculture. *Firstly* climate change induced changes in temperature and precipitation will alter the distribution of agro-climatic regions. Regions in higher latitudes will benefit from lengthening of growing seasons, shifting crop production pole-wards. However other factors such as changes in precipitation, irrigation use, and fertilizer inputs will also affect the final outcome. In contrast, regions in the lower latitudes, which are already at an optimal temperature for crop cultivation are likely to suffer from further increase in temperatures. *Secondly* rising carbon dioxide levels are expected to have a positive effect on yields of certain plants such as wheat, soybean and rice through increased water-use efficiency and photosynthesis. However, the net results might be moderated due to costly pests and weed infestation. Moreover the nutritional quality of crops is also lowered with high CO_2 concentration. *Third* agriculture in rain-fed areas is likely to suffer due to reduced water availability. This can put additional pressure on aquifer exploitation and put stress on competing water usage (industrial, municipal). Areas in semiarid tropical and subtropical regions will be most susceptible to changing rainfall patterns. *Lastly* increased frequency of extreme weather events such as droughts and floods, and higher variances in temperature and precipitation can exacerbate crop losses. Droughts can put pressure on water usage for crops while floods or increased

precipitation in other regions can lead to soil erosion, leaching of agricultural chemical into water bodies. The expected variability in temperature, precipitation, atmospheric carbon content and extreme weather events is going to have a profound effect on crop yields, soils, insects, water availability, pests, diseases and livestock.
The overall agriculture system is a complex one with climate affecting multiple facets of it. Backward and forward linkages from agriculture to poverty reduction, industries and food security make the assessment of potential impacts on agriculture even more crucial. According to IPCC, global crop and economic models predict a 1-29% increase in cereal prices in 2050 due to climate change, with low income consumers at especially high risk.

Another reason to focus on agriculture and land use as being tied with climate changes is that it is an important source of greenhouse gas emissions. As per IPCC (2019) [vi] an estimated 23% of total anthropogenic greenhouse gas emissions from 2007-2016 have resulted from agriculture, forestry and other land use. Land degradation and deforestation which accompany agriculture reduces the green-cover which further contributes to climate change.

Given the high degree of susceptibility of agriculture sector to climate change and climate variability, it is crucial to implement the right set of mitigation and adaptation to reduce the adverse impacts on agriculture productivity. As per studies agriculture sector is considerably adaptable given that resources, technological and management adaptations can be implemented fairly quickly. [vii]

Quantifying the economic impact of climate change on agriculture is receiving increasing attentions. There are two main models used to estimate the same: *structural models* and *spatial analogue models*. The structural models like *agro-economic simulation* models are models similar to experimentation where CO2 or other climatic variables of interest are varied and their impact on crop yield is estimated. Another similar technique is the *agro-ecological zone analysis* under which crops are assigned to certain agro-ecological zones and their predicted yields are measured which are then used in simulation that track the changes in climate in this agro-ecological zones. Farm management practices such as timing of field operations, crop choices and irrigation can be included in structural models. Economic impacts (e.g. changes in acreage, supply by crop and region as well as resulting changes in prices) are then estimated by incorporating yield estimation results from crop simulation models into economic models. The types of economic models that have been used with agronomic models include computable general equilibrium (CGE) models, partial equilibrium mathematical programming models and spatial equilibrium models of the agricultural sector.

Studies using *agronomic* approach including Parry et al. (1988)[viii] find that countries in higher latitudes are likely to gain from the lengthening of the growing season, higher evapotranspiration however is likely to have a perverse impact on crop yields. In India, Sinha and Swaminathan (1991)[ix] find that an increase in winter temperature can lead to a 10% reduction in wheat output in the northern states of Punjab, Uttar Pradesh and Haryana. A number of studies have focused on the vulnerability of African nations. For Kenya, Downing (1992)[x] states that the potential food production could increase with higher temperatures and increased precipitation, however communities in semiarid areas, who already have low crop yields could suffer further due to insufficient rainfall. Agronomic studies with adaptation also produce interesting results. For eg. Jin et al. (1994) find that adoption of new rice cultivars and changing plantation dates enhances the yields at several sites in southern China. Naylor et al. (2001) analyse the impact of El Nino and La Nina on rice production in Java, Indonesia and find that these events affect the timing of plantations and cause fluctuations in productions which in turn causes price instability in domestic markets causing hardships for low income groups spending a large portion of their incomes on food.

The *spatial analogue* approach is based on statistical and econometric methods which have been used to estimate the impacts of climate change on agricultural production in different regions by taking account of changes in farmer management practices and decisions in response to changing climatic conditions. The factors that can also affect crop production such as soil type and quality are integrated in the models estimated. The *Ricardian approach* automatically incorporates adaptation by farmers to climate change into the analyses so long as the costs and benefits of agricultural production have a market value.
Mendelsohn, Nordhaus and Shaw (1994)[xi], in their paper on the US economy differentiate between economic costs and advantages based on which time of the year climate change occurs and find a potential impact in the range of -5.8$ billion to 36.6$ billion depending upon which model and climate scenario is used. Kumar and Parikh (1998)[xii] use cross-sectional data from India and demonstrate that even with adaptation in inputs and timing of crop-plantation, losses from climate change would remain significant.

Climate change impact on *fisheries* has been brought out by IPCC, according to which anthropogenic carbon emission is leading to ocean warming, acidification, and oxygen loss resulting in loss of fish production with implications for food production and human communities.[xiii] A study by Lam et. al[xiv] shows using marine simulation models that global fisheries revenues could reduce by 35% more than the projected drop in catch by 2050s under the high CO2 emission scenarios. Regionally, the increase in catch in higher latitude regions might not translate into increase in revenue due to increase in prevalence of low value catch and also a reduction in catch from vessels in these countries operating in more severely affected distant areas. The regions most vulnerable to climate change induced changes in fisheries have been identified in Africa, north-western South America and Asia on the basis of their exposure to climate change, high dependence on fisheries in nation exports, employment and dietary requirements (protein intake) and low potential for adaptability. Loss of fishing revenue in these nations is likely to translate into economic hardship or missed opportunities of development in the absence of adaptability. [xv]

Climate Change impact on Agriculture Prices and Consumption
Nelson et al. (2009)[xvi] report that even with no climate change the prices of important crops like wheat, rice, soy, maize will increase between 2000 and 2050 due to population, income growth and demand for bio-fuels. With climate change the increase in prices will be even more profound due to supply side shocks with additional increase between 32 and 37 % for rice, 94 to 111% for wheat and 11 to 14% for soybeans. Through an increase in feed prices, the prices of meat is also expected to go up. For example beef prices would increase by 33% by 2050 with no climate change and by 60% with climate change. These rising prices would have a negative welfare effect on consumption on lower socio-economic groups. The authors also estimate that with climate change, calorie availability in 2050 will be even lower than in 2000 throughout the world with the effect being more profound in Sub-Saharan Africa and developing countries (6.9% and 4.4% respectively).

The rest of this paper is organized as follows, section 2 introduces readers to the methodology of estimation and includes a graphical representation of the data used. Section 3 includes the empirical results and finally section 4 concludes the paper.

DATA SOURCES AND GRAPHICAL EXPLORATION OF DATA

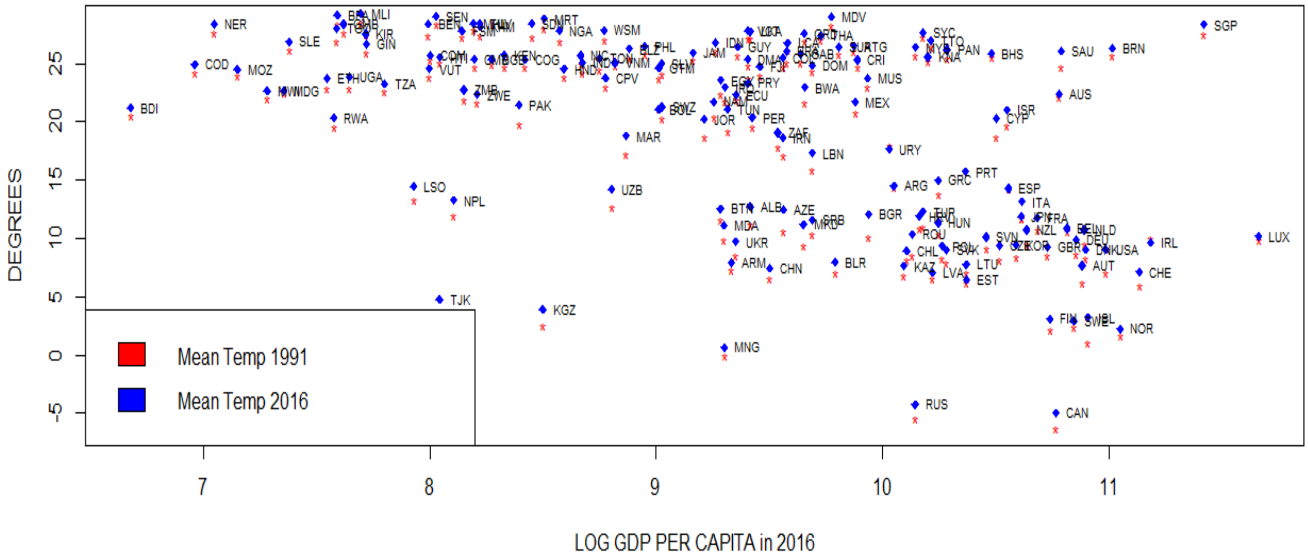
The study uses panel data estimation for 150 countries over the time-period 1991-2016 to capture the impact of climate change on agriculture gross value added. Due to the unavailability of data for certain years, some observations are missing and thus the panel data in the model is unbalanced. Climate change is being captured through change in temperature and precipitation over the period of analysis. The dependant variable is taken as the Log of agriculture value added per capita. The analysis is carried out through three models which will be described below along with the variables. All the plots in this section have been plotted on the R software.

Table 1: Variable definition and Sources:

INDICATOR	SERIES NAME	DEFINITION	SOURCE
Log of Agriculture Value Added Per Capita.	lnagri	Agriculture, forestry, and fishing corresponds to ISIC divisions 01-03 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs	Agriculture, forestry, and fishing, value added (constant 2010 US$) World Development Indicators Population - World Development Indicators
Average annual temperature (c)	temp	Mean annual temperature (degree Celsius per year)	World Bank Climate Change Knowledge Portal
Average annual rainfall (mm)	precp	Average rainfall is the long-term average in depth (over space and time) of annual precipitation in the country.	World Bank Climate Change Knowledge Portal
Latitude	latitude	Latitude of nation’s capital city	World Development Indicators
Longitude	longitude	Longitude of nation’s capital city	World Development Indicators
Log Employment in agriculture	lnemp	Employment in agriculture (% of total employment) (modelled ILO estimate)	World Development Indicators
Log Rural access to electricity	lnelec	Access to electricity, rural (% of rural population)	World Development Indicators
Log Irrigation	lnirri	Agricultural irrigated land (% of total agricultural land)	World Development Indicators
Log Agriculture mechanisation	lnmech	Agricultural machinery, tractors per 100 sq. km of arable land	World Development Indicators
Log fertilizer	lnfert	Fertilizer consumption (kilograms per hectare of arable land)	World Development Indicators
Log Area under agriculture land	lnagri_land	Agricultural land (% of land area)	World Development Indicators

The graph below shows the relationship of log of GDP per capita in 2016 against the mean temperature in two years, 1991 and 2016. In contemporary data the fact that poor countries tend to be hotter than rich countries is well captured. Dell et al. (2009) show through a cross section analysis that national income falls by 8.5% for a 1 degree celsius increase in temperature. However, authors such as Acemoglu et al. (2002) argue that this correlation might be driven by a spurious association between temperature and national characteristics like institutions.

Fig 1: Relation between Log GDP per capita in 2016 against annual average temperature



This relationship is also depicted in the above representation. The figure also shows that the average temperature across the nations has increased over this period with the blue triangles lying above the red crosses for almost all the countries. This warming is also depicted in the figure below:

Fig 2: Global annual average temperature change over the period 1991-2016

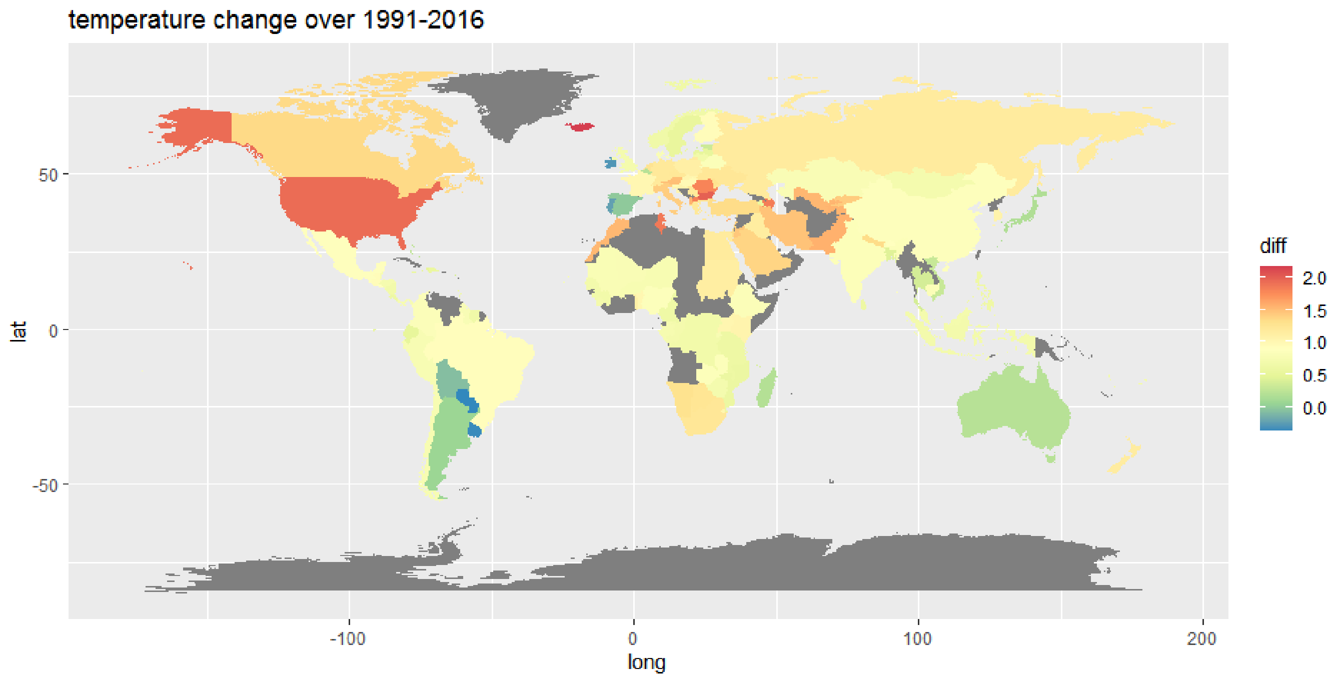
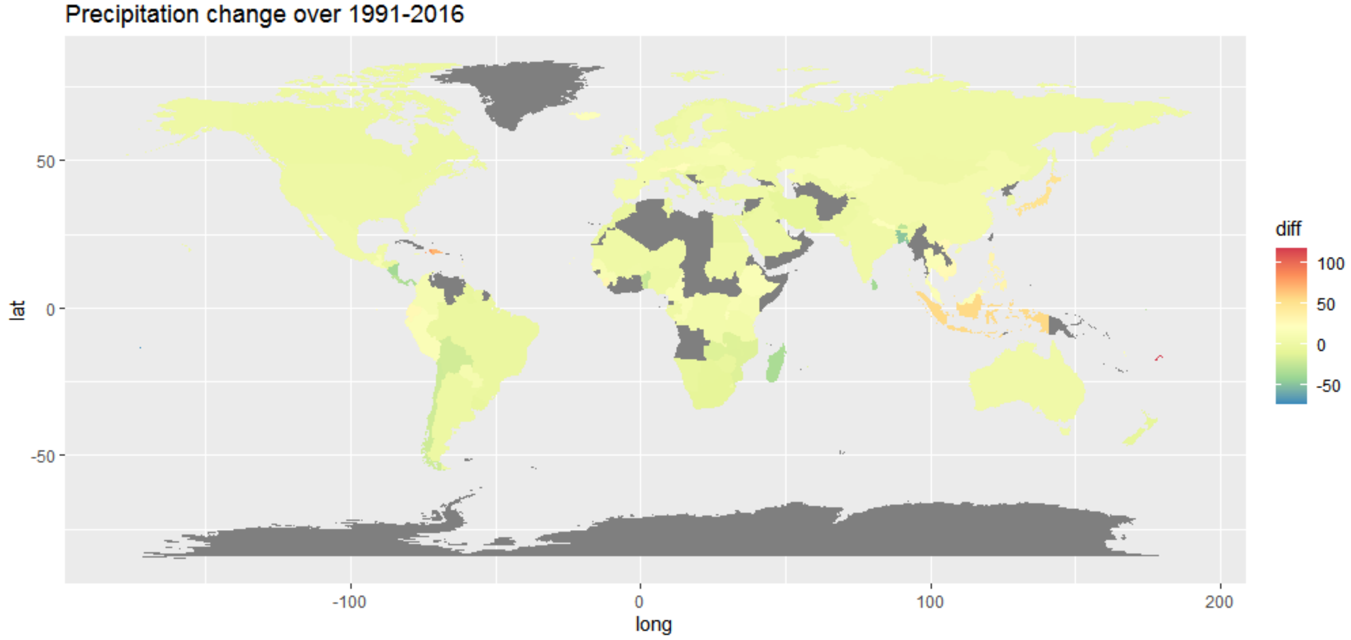


Fig 3: Global annual average precipitation change over 1991-2016



According to IPCC, warming has intensified over the last 40 years and the 10 warmest years on record have occurred since 2005. Temperature has increased at the rate of 0.18 degree Celsius every decade since 1981. Climate change is also projected to lead to an increase in precipitation over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and in limited areas of the tropics.
The boxplots below show the distribution of Log Agriculture Gross Value Added Per Capita across the regions over the years 1991 and 2016.

Fig 4: Regional Variation in Log of Agriculture Gross Value Added per capita 2016

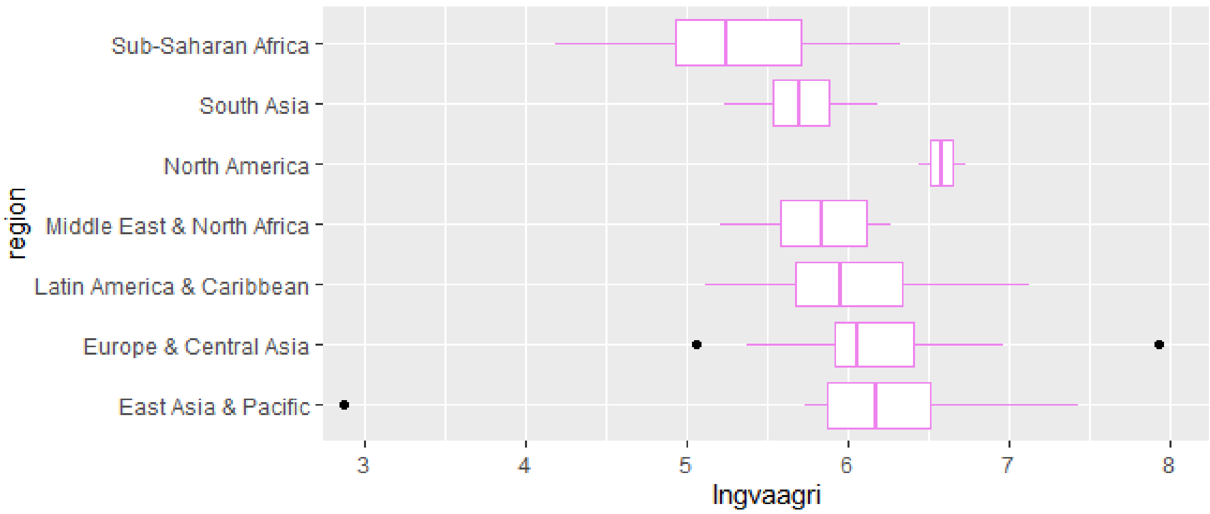
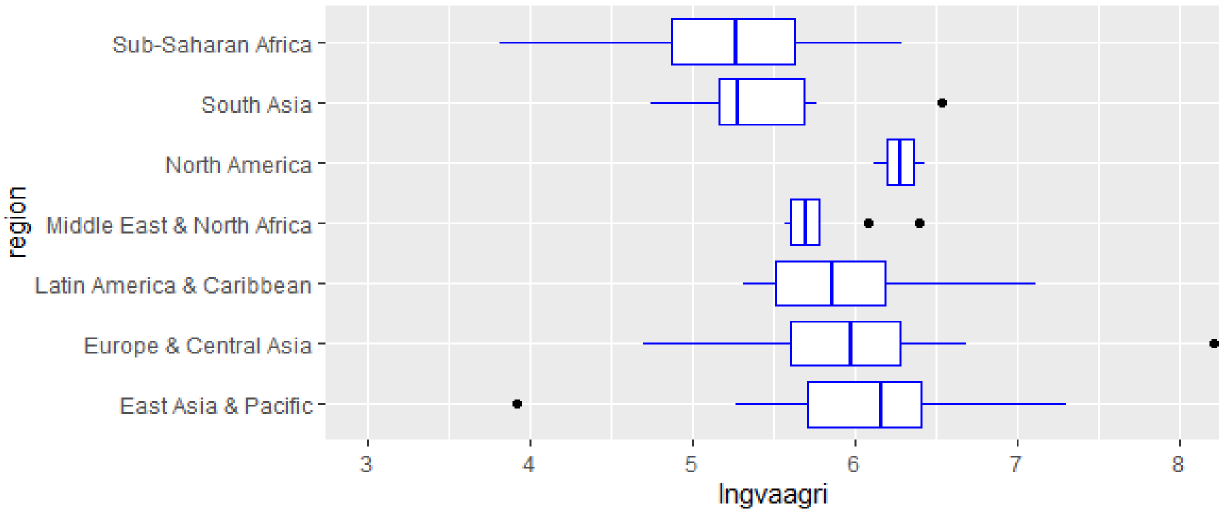


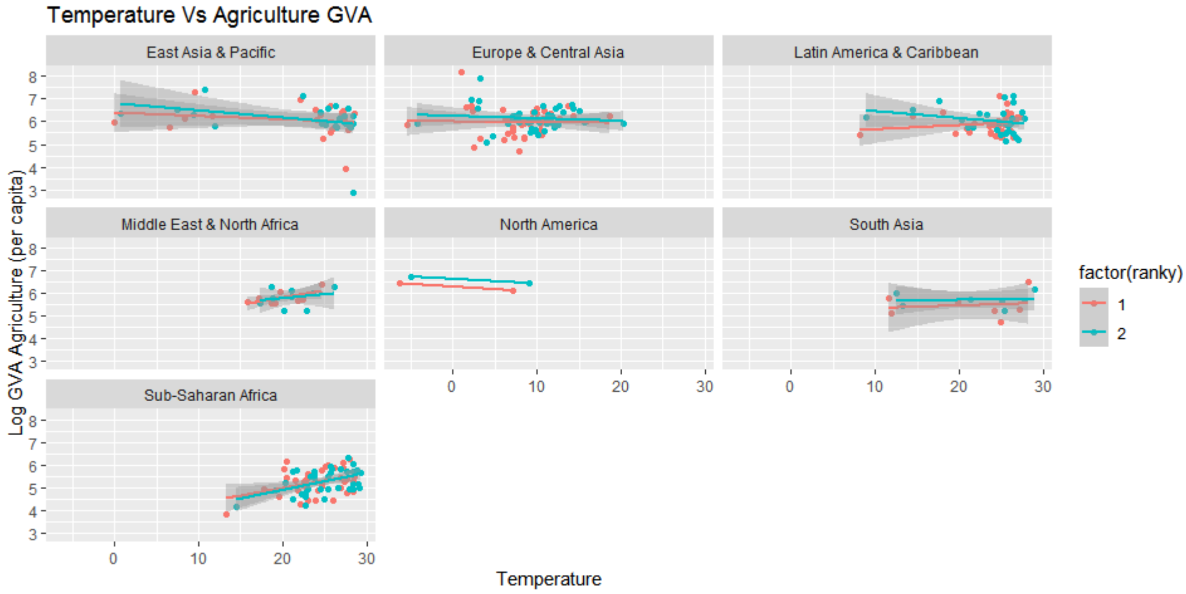
Fig 5: Regional Variation in Log of Agriculture Gross Value Added per capita 1991



Based on the boxplots, the median value for East Asia Pacific, Sub-Saharan Africa and Latin America has not changed from the beginning to the end of the sample. The median value for Europe and Central Asia, Middle East and North Africa, North America and South Asia has increased. As a region, Sub-Saharan Africa has the most variability in the distribution of GVA while North America and Middle East & North Africa have the least variability (due to lesser number of countries in these regions, hence lesser observations).

The scatterplot below show the cross-section relations between Temperature and Precipitation with LNGVA for the beginning and end of the sample. The cross- section relation can be seen as negative in some regions and positive in others.

Fig 6: Region-wise relation between temperature and Log of Agriculture GVA for 1991 and 2016



Year

Fig 7: Region-wise relation between Precipitation and Log of Agriculture GVA for 1991 and 2016

We see a lot of variation by region but the relation seems to be similar from the beginning to the end of the sample.

ECONOMETRIC METHODOLOGY

According to Dell at. Al (2014) there has been a surge in recent literature of panel data models that use exogenous variations in weather outcomes over time within a given spatial area to causatively identify effects on outcome of interest. The basic functional relationship of interest is given by:

$$y = f(\boldsymbol{C}, \boldsymbol{X})$$

$\boldsymbol{C}$- Climate variables

$\boldsymbol{X}$- Other Variables correlated $\boldsymbol{C}$ and affecting Outcome

A cross-section model utilises spatial variation to estimate this relationship. The authors state that reverse-causation is unlikely to be a major concern to the extent that weather variables are exogenously determined. A more likely concern is related to 'omitted variable bias' when trying to estimate the relationship using cross-section data. If the variables that potentially estimate the outcome of interest are not accounted for the estimates will be biased. At the same time, the authors warn that adding more controls will not necessarily produce a better estimate of coefficients if the Xs are themselves a function of the climate variables C. This may be the case with controls like GDP, population, institutional measures. This gives rise to the "over-controlling" problem as and can have the effect of partially eliminating the explanatory power of climate. The authors also point out that the cross-section model reflects a very long-run equilibrium. For instance if the cross-section results are showing a correlation between temperature and income that is based on a long historical process with intervening mechanisms like development of institutions, path of agricultural development or technological exchange.
Climatic studies today aim to study the functional relationship between climatic variables and economic outcomes to assess the potential impact of forecasted temperature changes over the next several decades. It would not make sense to incorporate these intervening mechanisms in

these models because these processes are too slow or they may include a historical process (colonialism) that will not repeat itself in the future.

Many of these issues can be addressed through using panel data models which use longitudinal data to investigate the effect of weather variables. Panel models use the exogenous variation in weather outcomes over time within a given spatial area to causatively identify effects on outcomes of interest. The equation of interest is given as follows:

$$y_{it} = \beta C_{it} + \gamma Z_{it} + \mu_i + \theta_t + \varepsilon_{it}$$

μ_i- Spatial fixed effects, θ_t- Time Fixed Effects Z_{it}-Time varying observables

Model 1

Following the illustration of panel model by Dell et al. the model the model is formulised at follows:

$$\boldsymbol{lnagri_{it} = \alpha_0 + \alpha_1 temp_{it} + \alpha_2 tempsq_{it} + \alpha_3 precp_{it} + \alpha_4 precpsq + \mu_t + \varepsilon_{it}}$$

Where t indexes time (year) and i indexes countries. In a panel data model, choice is between using Random Effects model and Fixed Effects model, however for this analysis fixed effects model is better suited for the following reasons:

1. It helps in controlling for country fixed effects such as soil type, soil quality, and geographic locations.
2. Helps in avoiding omitted variable bias from non-inclusion of time-fixed spatial characteristics, whether observed or unobserved that might affect the outcome of interest and thereby allows us to see the impact of weather variables on lnagri.
3. Random effects model assumes that the unobserved country specific effects are uncorrelated with each of the regressors included in the mode, which is unlikely to be true as climate variables are likely to be correlated with the country-specific effects of agriculture values added.

The Hausman Test is also carried out to test whether random effects model is more suited for the data at hand, however this is rejected based on a low p-value.

Time fixed effect is also included which helps in neutralizing common trends that change over time but are constant across entities and ensuring that the estimates capture the effect of weather variables.

Additional controls are not included in this model as variables like area under agriculture, share of employment under agriculture, fertilizer usage are likely to be dependent on climate and might of partially eliminate the explanatory power of climate. The weather variables are used in a non-linear formulation as the non-linear impact of climate change on economic activity is well documented, Burke et al. (2015)[xvii]

Results from this specification are provided below

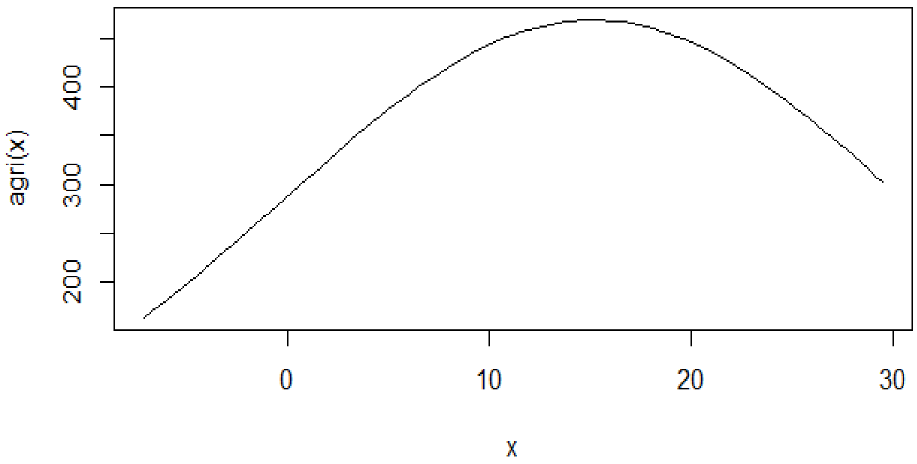
Table 2

Dependent variable lnagri		
Temp	0.0643***	(5.38)
Tempsq	-0.00212***	(-5.43)
Precp	0.00108**	(2.30)
Precpsq	-0.00000273**	(-2.38)
_cons	5.368***	(37.41)
Country Fixed effects	Yes	
Time Fixed effects	Yes	

N 3781
R^2 0.072
adj. R^2 0.026
t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

As per the results, the effect of temperature increase on lnagri is positive and significant at 1%. A 1 degree Celsius increase in temperature increase the agriculture value added by 6%. However, as the coefficient of tempsq is negative and significant at 1%, the impact of temperature on lnagri increases but at a diminishing rate. The impact of precipitation is positive and significant at 10%, the coefficient implies that a 100mm increase in precipitation increases the gross value added in agriculture by 0.1%. The negatively significant coefficient of precipitation once again implies that this effect increases at a diminishing rate and excess rainfall may be harmful to agriculture.
The plot below shows the predicted agriculture GVA per capita as temperature varies, holding other variables at mean value.

Fig 8: Predicted Agriculture GVA per capita (2010 US$) as temperature varies, holding other variables at mean value

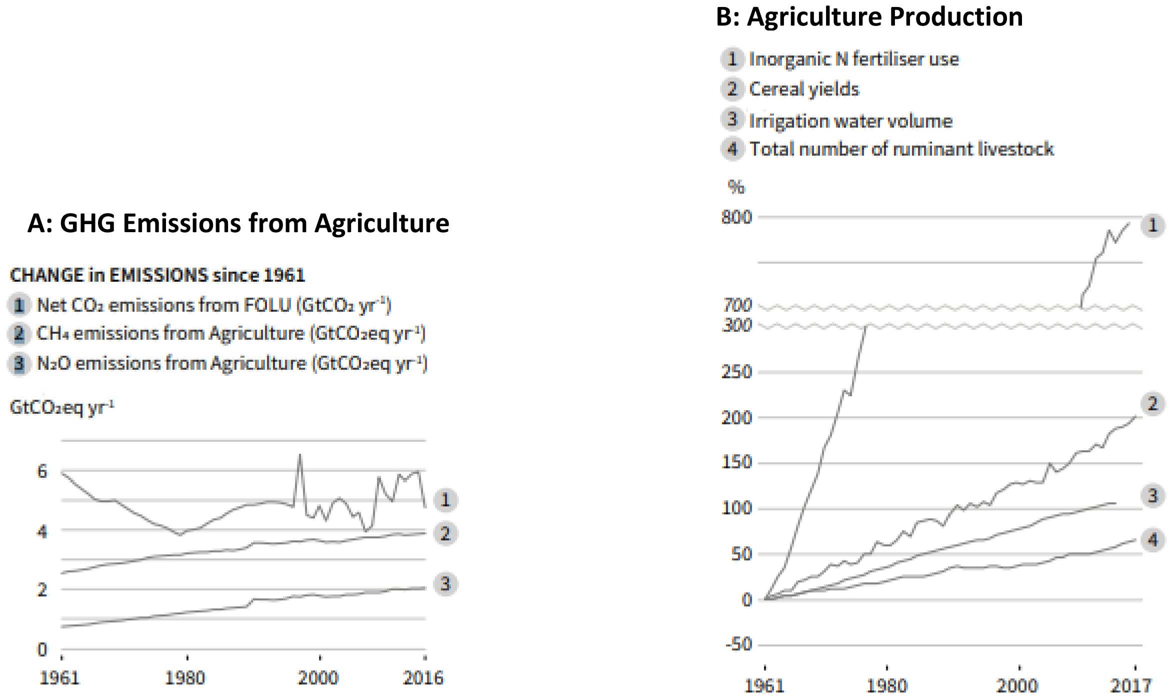


Model 2

A potential concern with the panel data model is that of reverse causality between agriculture value added and temperature. According to IPCC Special report on Climate Change and Land (2020)[xviii], an approximate 23% of greenhouse gas emission from anthropogenic activities between 2007 and 2016 derived from agriculture, forestry and other land use. Further, land use change and desertification associated with expanding agriculture also contributes to climate change. As shown in figure 9B below, since 1961, the production of cereal crops has increased by 240% (until 2017). This is attributable to both land area expansion and increasing yields. Paper by Husnain et. al. (2018)[xix] addresses the potential endogeneity due to reverse causality by the use of instrumental variables. Geographical variable- latitude is used as an instrumental variable for temperature. The method of IV-2SLS is used for this purpose.

Firstly the endogeneity test is carried out to check whether the variables are endogenous or exogenous. Basis the Durban score ($p < 1$percent), Wu-Hausman F- statistic ($p < 1$percent), the null hypothesis of ‘variables are exogenous’ is rejected in alternative specifications, making the 2SLS a plausible estimation technique for catering to the endogeneity.
The *relevance* of latitude as an Instrumental variables for temperature is checked by running the first stage regression. Results of this regression are reported in the appendix. It is found that the IV has the right sign and is significant, which means that it can be substituted as an instrument for temperature.

Fig 9A, 9B: Sources of GHG emisisons from Agriculture , Forestry and other land use. Source IPCC Special Report on Climate Change and Land (2020) and incresing agriculture production



The results of the second stage regression are reported below. The model is run accounting for country and year fixed effects.

Table 3

Dependent variable lnagri		
temp	-0.156***	(-28.51)
precp	-0.000117	(-0.72)
lnfert	0.0125***	(3.41)
lnirri	-0.0270***	(-4.37)
lnmech	0.00874*	(1.76)
lnagri_land	0.150***	(11.05)

lnemp	0.0113*	(1.77)
_cons	6.987***	(38.05)
Country fixed effects	Yes	
Year fixed effects	Yes	

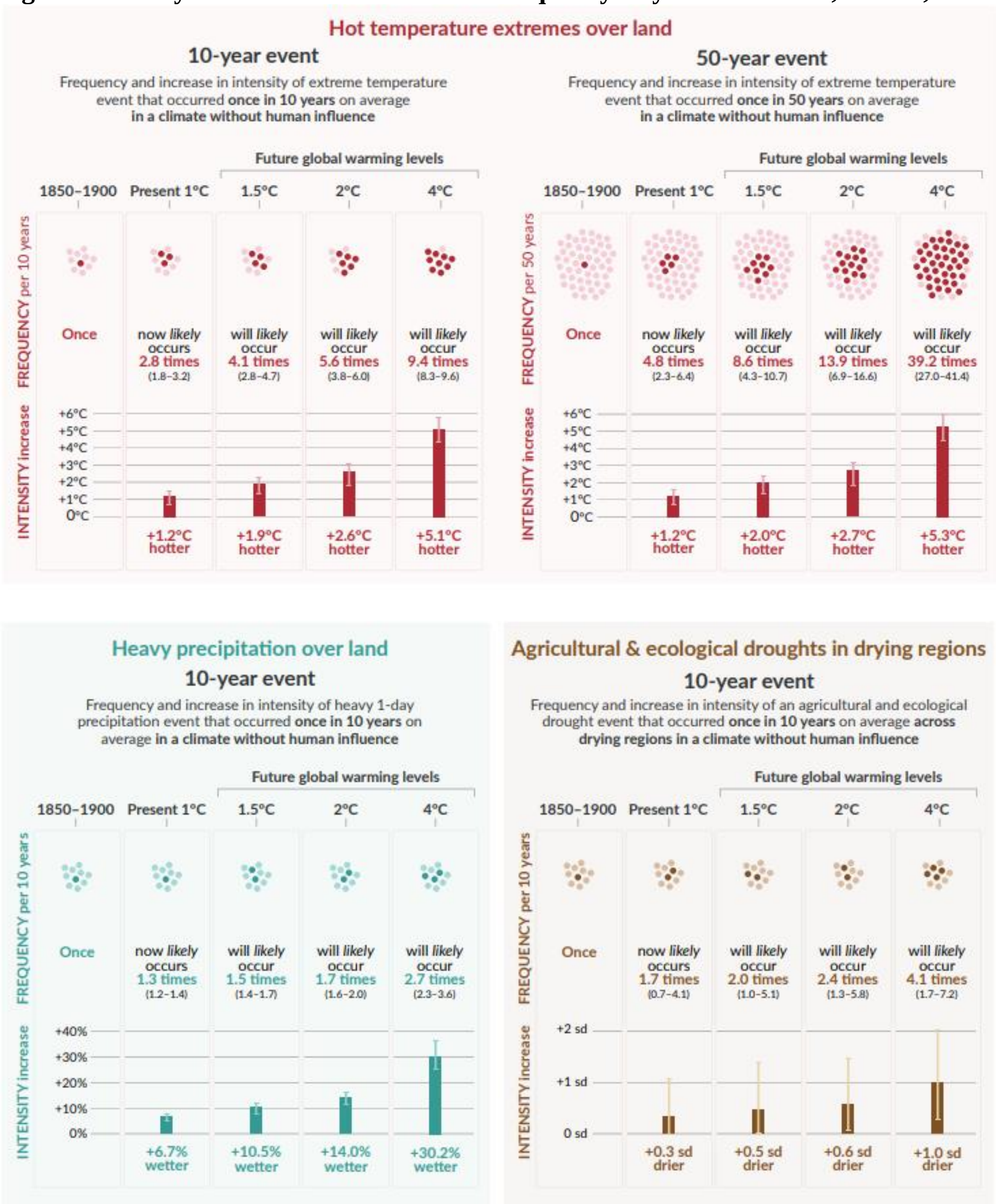
N 3781
t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The coefficient of temperature is negative and statistically significant at the 1 % level and signifies that a 1 degree increase in temperature reduces gross value added in agriculture by 15%. The coefficient of precipitation is however, found to be insignificant. The coefficient on fertiliser is positive and significant at the 1% level and implies that 1% increase in fertilizer per hectare of arable land increase agriculture gross value added by 0.01%. Surprisingly, the coefficient on lnirri is negative and significant at 1% indicating that a 1% increase in the percentage of irrigated area reduces gross value added in agriculture by 0.02%. This effect could possibly due to the fact that irrigation was already substantially expanded by 1990s and further are brought under irrigation might be land unsuitable for cultivation for the crops it is being used for leading to limited gains from irrigation. lnagri_land coefficient is positive and significant indicating that a 1% increase in area under agriculture increase agriculture gross value added by 0.15%. Coefficient on lnmech is positive and signitifcant at 10% indicating that a 1% increase in agricultural machinery, tractors per 100 sq. km of arable land increases agriculture GVA by 0.008%.

There are a few caveats that need to be kept in mind while interpreting the results of this model including the fact that the greenhouse gas emissions contribution to global warming and increase in temperature depends on the global stock of emissions which takes time to dissipate in the atmosphere. Therefore there is likely to be a lag between increase in emissions and increase in temperatures at a country levels.
Secondly some authors, like Deaton (2010)[xx] have written about the inappropriateness of geographical IVs in that they do not satisfy the 'exclusion restriction' of being uncorrelated with the disturbance term.

Model 3
The adverse impact of extreme temperatures on economic activity and especially agriculture is well documented. As per IPCC[xxi], "Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming". As per the figure below, extreme temperature events that occurred once in every 10 years on average in a climate without human influence are likely to occur 4.1 times with a warming of 1.5 degree Celsius. Similarly heavy 1-day precipitation events that occurred every 10 years are now likely to occur 1.5 times with a warming of 1.5 degree Celsius. Similarly extreme agricultural and ecological droughts that occurred once every 10 years across drying regions in a climate without human influence, are likely to occur twice as frequently.

Fig 10: Analysis of extreme events frequency by IPCC AR6, WG1, 2021



In a 2016 paper, Lesk et. al [xxii] show that over the time period 1964-2007, droughts and extreme heat significantly reduce national cereal production across the globe by 9-10%. Similarly a paper by Marmai et. al (2022)[xxiii] uses data on 6 different crops from 32 countries over the period 1961 to 2002 and establishes that per country and per crop the risk of yield reduction is above 90% when an extreme event occurs. The Indian Economic Survey 2017, analyses the impact of extreme weather on crop yield in India through construction of shock variables based on district wise rainfall and temperature distribution. A similar methodology is adopted for cross-country analysis in this paper. The variables used for the analysis are described below:

Table 4

INDICATOR	SERIES NAME	DEFINITION	SOURCE
Temperature Shock	hightemp	Dummy variable, which takes the value 1 if the temperature in country i in year t is in the top 10 percentiles of the country-specific temperature distribution.	Mean annual temperature- World bank climate change knowledge portal
Precipitation Shock	lowrain	Dummy variable which takes the value 1 if rainfall in country i in year t is in the bottom 10 percentile of the district specific rainfall distribution	Average of Rainfall- World Bank Climate Change Knowledge Portal
Poor Country Indicator	poor	Dummy variable which takes the value 1 if the GDP per capita of country i is below the median per capita income in the first year in which the country enters the sample	GDP per capita, PPP (constant 2017 international $)- World Development Indicators
Hot Country Indicator	hot	Dummy variable which takes the value 1 if mean temperature in country i is above the median temperature in the first year in which the country enters the sample	Mean Annual Temperature- World Bank Climate Change Knowledge Portal

Model used:

$$\begin{aligned} \boldsymbol{lnagri} = {} & \boldsymbol{\alpha_0 + \alpha_1 hightemp + \alpha_2 lowrain + \alpha_3 poor * hightemp + \alpha_4 poor} \\ & \boldsymbol{* \, lowrain + \alpha_5 hot * hightemp + \alpha_6 hot * lowrain + \alpha_7 lnfert_{it}} \\ & \boldsymbol{+ \alpha_8 lnirri_{it} + \alpha_9 lnmech_{it} + \alpha_{10} lnagri\_land_{it} + \alpha_9 lnemp_{it} + \mu_t} \\ & \boldsymbol{+ \varepsilon_{it}} \end{aligned}$$

A fixed effects model is used to carry out the analysis with country and year fixed effects. Results are shown below:

Table 5

Independent variable lnagri		
hightemp	-0.000544	(-0.03)
lowrain	-0.0246**	(-2.16)
poorhightemp	0.0586**	(2.54)

poorlowrain	-0.0326	(-1.42)
hothigtemp	-0.0631***	(-2.67)
hotlowrain	0.0616***	(2.65)
lnfert	0.0145**	(2.19)
lnirri	-0.0245*	(-1.82)
lnmech	0.00993	(0.91)
lnagri_land	0.162***	(3.55)
lnemp	0.00900	(0.58)
_cons	4.556***	(11.97)
Country fixed effects	Yes	
Time fixed effects	Yes	

N 3781
R^2 0.124
adj. R^2 0.116
t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

While the impact of a precipitation shock is significant at a 5% level on average (precipitation shock lowers the agricultural value added by 2% on average), the impact of a temperature shock is significantly negative in hot nations. In a hot nation, temperature shock lowers agriculture value added by 6% on average. In poor nations a temperature shock is significant and associated with an increase in agriculture value added. While farmers in developed countries have access to risk coping mechanism ex-ante, such as crop insurance, farmers in poor nations have greater incentive to adapt to weather shocks by changing cropping patterns, input use and adopting other forms of mitigation. A paper by Aragon et. al[xxiv] (2018), uses micro data from farming households in Peru 2007-2015 and finds that farmers respond to temperature shocks by increasing their land use and changing their crop mix away from cereals to tubers. This response offsets partially the loss in output from reduced yields. Moreover farmers also adopt coping mechanisms ex-post like migrations, disposal of livestock or off-farm labour. These effects can be seen as productive adaptations in the face of climate change.

CONCLUSION

The three models discussed in the paper bring out the impact of climate change on agriculture using different formulations. The first model establishes the non-linear impact of weather variables on agriculture GVA. While a rise in temperature increases the GVA, it happens at a decreasing rate with adverse impacts at high temperatures. Model 2 also highlights the impact of extreme temperature shocks and rainfall shocks in regions which are already hot. While modelling for the impact of climate change it is important to keep into consideration the non-linear impact of rising temperatures. According to IPCC, the rising of an additional 0.5 degree Celsius of temperature from present will be associated with a rise in extreme temperatures in many regions and increase in frequency, intensity and amount of heavy precipitation in several regions (high confidence). Moreover authors like Weitzman highlight the importance of considering extreme events which are non-negligible tail risks of low-probability catastrophic outcomes, ranging from “known unknown” tipping points to the “unknown unknowns” of black-swan bad-feedback events that we cannot even imagine today. These events can lead to entire ecosystem collapse to a point which is unimaginable today.

Since the impact of climate change on agriculture varies with region, the implications for food security, livelihood, and poverty reductions are marred with global inequality. Indigenous or other minority groups and small-scale producers, are often at higher risk of malnutrition, livelihood loss, rising costs and competition over resources. Adaptation options are available but often lack economic or institutional feasibility or limits on information. The urgency of the situation calls for immediate policy decisions that enhance effectiveness and feasibility of adaptation and mitigation at a global as well at a local scale. Financial barriers hinder the implementation of adaption in agriculture and aquaculture therefore significantly more public and private investment is required. At a local level, harnessing youth innovation, along with indigenous knowledge, urban and rural livelihood will support effective climate change adaptation that ensures resilient economies in food system. At the same time mitigation efforts at the national and global level need to continue unabated through a reduction in carbon emissions. Developing a carbon tax regime based on social cost of carbon, improving means of global cooperation and adhering to targets of decarbonisation are all means that need to be implemented by nations in a coordinated fashion.

Appendix

Checking suitability of latitude as an IV for temp.

Table 6

	(1) temp
precp	-0.00146***
	(-4.87)
lnfert	-0.0113
	(-1.62)
lnirri	-0.0116
	(-0.77)
lnmech	-0.00679
	(-0.71)
lnagri_land	-0.0947***
	(-3.86)
lnemp	0.0153
	(0.98)
latitude	-0.166***
	(-92.29)
_cons	19.53***
	(75.94)
Country Fixed Effects	Yes
Time Fixed Effects	Yes
N	3781
R^2	0.998
adj. R^2	0.998

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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