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Robustness of geography as an instrument to assess impact of climate change on agriculture

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Abstract

Purpose – The empirical literature on climate change and agriculture does not adequately address the issue of potential endogeneity between climatic variables and agriculture, which makes their estimates unreliable. This paper aims to investigate the relationships between climate change and agriculture and test the potential reverse causality and endogeneity of climatic variables to agriculture.

Design/methodology/approach – This study introduces a geographical instrument, longitude and latitude, for temperature to assess the impact of climate change on agriculture by estimating regression using IV-two-stage least squares method over annual panel data for 60 countries for the period of 1999-2011. The identification and *F*-statistic tests are used to choose and exclude the instrument. The inclusion of some control variables is supposed to reduce the omitted variable bias.

Findings – The study finds a negative relationship between temperature and agriculture. Surprisingly, the magnitude of the coefficient on temperature is mild, at least 20 per cent, as compared to previous studies, which may be because of the use of the instrumental variable (IV), which is also supported by an alternative robust measure when estimated across different regions.

Practical implications – The study provides strong implications for policymakers to confront climate change, which is an impending danger to agriculture. In designing effective policies and strategies, policymakers should focus not only on crop production but also on other agricultural activities such as livestock production and fisheries, in addition to national and international socio-economic and geopolitical dynamics.

Originality/value – This paper contributes to the growing literature in at least four aspects. First, empirical settings introduce an innovative geographical instrument, Second, it includes a wider set of control variables in the analysis. Third, it extends previous studies by involving agriculture value addition. Finally, the effects of temperature and precipitation on a single aggregate measure, agriculture value addition, are separately investigated.

Keywords Causality, Agriculture, Endogeneity, Climate change

Paper type Research paper

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1. Introduction

The relationships between climate change and agriculture are complex and manifold (Bosello and Zhang, 2005). A growing body of economic research has analysed the impact of climate change on agriculture (Parry *et al.*, 1999; Mendelsohn and Dinar, 1999; Mathauda *et al.*, 2000; Aggarwal and Mall, 2002; Jones and Thornton, 2003; Kumar *et al.*, 2004; Seo *et al.*, 2005; Deschenes and Greenstone, 2007; Schlenker and Roberts, 2008; Deressa and Hassan, 2009; Zhai and Zhaung, 2009; Schlenker and Lobell, 2010; Fisher *et al.*, 2012; Lee *et al.*, 2012; Bezabih *et al.*, 2014; Dasgupta *et al.*, 2014; Babar *et al.*, 2014; Javed *et al.*, 2014), and predicted that climatic variations will inflict wide range of economic losses across different regions and sectors (Hunt and Watkiss, 2011), yet the results of these studies have remained empirically elusive and controversial across time, countries and methodologies. This difference of results warrants attention.

It is well known that agriculture-related activities significantly emit greenhouse gases that lead to global warming. However, most of the existing literature does not adequately address the potential reverse causality and endogeneity of climatic variables to agriculture, which makes their estimates of the relevant causal effects unreliable (Kevane and Hirani, 2012). Furthermore, majority of these studies do not include control variables, such as fertilizers, population, technological changes and agriculture land area, and suffer omitted variable bias that may lead to misleading cross-country estimates, as pointed out by Auffhammer *et al.* (2012).

Some of the previous studies which identified potential endogeneity problem have used traditional instruments to address this issue by using lag values of the independent variables in estimating the impact of climate change on agriculture. However, these studies make a very strong assumption that no bidirectional relationship exists between previous year temperature and precipitation and current agriculture, which does not convincingly address the endogeneity problem. Further, these studies do not adequately discuss about the plausibility of their instruments used for temperature. Another limitation of this lag independent variable instrument technique is that it does not exclude the possibility that these instruments can directly affect the agriculture, which downscales the usefulness of these instruments. Javed *et al.* (2014) uses the lag of dependent variable to address the issue of endogeneity in analysing the impact of climate change on agriculture yield in Pakistan. However, the rationale behind the choice of the lagged dependent variable as an instrument is missing in their analysis. They also do not provide any discussion about controlling the econometric issues arising from the inclusion of lagged dependent variable as a regressor.

This study introduces geographical instruments, longitude and latitude, for temperature to assess the impact of climate change on agriculture because instrumental variables method makes it possible to assert the relationship between agriculture and climate change as a causal relationship rather than merely a correlation. Geographical location is a plausible instrument for weather conditions as these coordinates, longitude and latitude, are significant predictors of climate variables being closely linked to each other. It is believed that novel instruments can affect agriculture only through the channel of temperature and not directly that endorses the validity of these instruments. The validity of these instruments is probed by tests of weak identification and over identification, the results of which support the choice of the instruments. The F-statistic of joint significance is greater than 10 for the excluded instruments, thus passing the test for weak identification. In the case of over identification tests, the null hypothesis that the selected instrument is not correlated with the error term is not rejected.

A further strength of adopted empirical methodology is that it helps to overcome the problem of measurement error that emerges from the available data on climate variables, which are thought to be less reliable because of the limitations of the methods used to measure climatic variations. An instrumental variable approach handles the attenuation bias that may arise from measurement errors in independent variables, which produce biased estimates of the coefficients (Miguel *et al.*, 2004). The inclusion of some of the control variables such as area under cultivation may reduce the omitted variable bias as fluctuations in production may depend also on the area under cultivation and climate change. Likewise, technological improvements, fertilizers and other inputs also play their due role in unearthing the relationship between climate change and agriculture.

No study has considered the reverse causality between the dependent and independent variables by using geographical instruments. This paper aims to address contributes to the growing literature in at least four aspects. First, empirical settings introduce an innovative geographical instrument to capture impact of climate on agriculture, which establishes a causal relationship between climate change and agriculture rather than the simply correlation. Second, this analysis highlights the importance of including a wider set of control variables in examining the impact of climate change on agriculture. Third, this research improves previous research by using agriculture value addition, one of the most comprehensive, reliable and comparable measure of agriculture activity, as it accounts for all agriculture-related activities such as livestock and fisheries, which are also vulnerable to climate change. Previous empirical literature uses crop production, economic growth or revenues from crops as a measure for agriculture (Mendelsohn and Dinar, 2003; Deressa and Hassan, 2009; Kavikumar, 2009), and these are not comprehensive measures of agriculture. For example, economic growth is an outcome of the economic activity of different sectors in the economy, and agriculture is only a part of this measure. Finally, the effects of temperature and precipitation on a single aggregate measure, agriculture value addition, are separately investigated. Specifically, this paper constructs temperature and precipitation data for panel of 60 countries for the period of 1999-2011 and combines this data set with agriculture data. The sample includes countries from all habitant continents of the world, which makes the results of this study more generalisable and comparable to previous studies. The study uses data from World Development Indicators and Climate Research Unit of the University of East Anglia. The main identification strategy uses year-to-year fluctuations in temperature and precipitation to estimate the impact of temperature and precipitation on agriculture for each country included in the sample. The effects of climate fluctuations are measured using relatively few assumptions. It examines aggregated outcomes directly, rather than relying on *a priori* assumptions about what mechanisms to include and how they might operate, interact and aggregate.

The plan of the paper is as follows. Section 2 discusses the theoretical background of the impacts of climate change on agriculture and the model. Section 3 elaborates on variables, data and empirical methodology. Section 4 presents the results, and Section 5 provides a detail discussion of the results. Conclusions are presented in Section 6.

2. Materials and methods

2.1 The conceptual underpinnings

This section focusses on the meaning and the impact of climate change on agriculture. The fourth assessment report of the Intergovernmental Panel on Climate Change unequivocally states that the climate system is warming, and if necessary policy actions are not taken in time, the increase in greenhouse gases emission will continue and affect the climate. These unabated changes will inflict wide range of economic losses across different regions and sectors (Hunt and Watkiss, 2011). How these large effects are captured has been a contentious yet very important debate.

A variety of models are in use to assess the potential impact of climate change on agriculture, yet the impact is not fully understood (Mendelsohn *et al.*, 1996) as environmental indicators are not included in the impact assessment (Antle, 1996). The most famous models in literature are the crop simulation models, production function models, Ricardian approach, general equilibrium models (GEMs), integrated assessment models (IAMs) and panel data models. A brief description of these models is available in Table I.

Table I shows that different approaches and techniques have been in use to assess the complex relationship between cropland and climatic variations across the world. These techniques range from simply mean averages to quantitative crop simulation models, panel and statistical time series models (Jones and Thornton, 2003; Lobell *et al.*, 2008). The choice of a model that better suits to unearth the link between climate change and agriculture is a complex area of research, because of factors such as data deficiencies, interactive behaviour and role of economic and agriculture policies across regions, lack of competency in understanding, applying and handling the models and role of uncertainties that are hard to anticipate in projection of the agriculture yield responses to future climate variability. Therefore, a few broad concepts such as clarity of objective, knowledge of agriculture policies, characteristics of the population and obtaining a reliable high frequency data could help in choosing a better model for the analysis.

Method	Description	Strengths	Weaknesses
Crop simulation models	Crops are grown under controlled experiments and predictions are made about climate effects (Hebbar, 2008)	These models can predict and forecast impact of climate on crop production under different scenarios (Geethalakshmi *et al.*, 2011)	These models are considered only agriculture oriented as they focus on plant physiology and compare productivity levels under different climate scenarios (Eitzinger *et al.*, 2003)
Production function approach	A mathematical function that links agriculture inputs to output	Explicitly measures macroeconomic effects of weather variability on agriculture (Adams, 1989)	Unable to capture adaptation behaviour of farmers popularly known as "dumb farmer" phenomenon
Ricardian approach	It is a cross-sectional, across climate method to measure how climate affects land values and net revenues (Mendelsohn and Dinar, 2003; Kavikumar, 2009)	Accounts for direct effect of climate on yield of different crops and indirect substitution of different inputs (Mendelsohn *et al.*, 1994)	It does not include transition costs and does not capture the impact of space invariant variable (Sohngen *et al.*, 2002). It also assumes prices as constant (Cline, 1996)
GEMs	These models link agriculture to climate change considering its link with other sectors of the economy (Calzadilla *et al.*, 2010a)	Asses complex system of relationship simultaneously (Calzadilla *et al.*, 2013)	Supress the special characteristics of variables (Mendelsohn and Dinar, 2009)
IAMs	Combine agriculture data and economic models (Mikiko *et al.*, 2003)	Incorporate information from other disciplines. Describe cause and effect of climate change (Mikiko *et al.*, 2003)	Complex in nature and take climate as exogenous variable (Dinar and Mendelsohn, 2011)
Panel data models	Used to see the impact of environment on agriculture yield (McCarl *et al.*, 2008)	Capture time and space specific characteristics of the variables (Saravanakumar, 2015)	Use deviation from country specific means that leads to large measurement errors (Schlenker and Lobell, 2010)

Table I. Different models used to measure impact of climate change on agriculture

2.2 Model

The present study uses stochastic production function approach suggested by Just and Pope (1978)[1] to estimate the effect of temperature and precipitation on agriculture, controlling for fertilizers, agriculture input imports, agriculture land area and population. This function has the following basic form:

$$y = f(X,\ \beta) \tag{1}$$

where y is measure of agriculture value addition, *f(.)* is a production function, X is vector of independent variables and β is vector of estimable parameters attached with X. The study uses the following estimable regression form of equation (1).

$$Y_{i,t} = B_0 + \beta_1 T_{i,t} + \beta_2 P_{i,t} + \beta_3 F_{i,t} + \beta_4 AII_{i,t} + \beta_5 POP_{i,t} + \beta_6 ALA_{i,t} + \alpha_i + \gamma_t + \in_{i,t} \ldots \tag{2}$$

where $Y_{i,t}$ is the agriculture value of ith country at time t, T is temperature, P is precipitation, F is fertilizer, AII is agriculture input imports, POP is population, ALA is arable land area and $\in$ is an error term.

3. Data and estimation scheme

3.1 Data

This study uses panel data on agriculture value added from 1999 to 2011 for 60 countries representing all six habitant continents corresponding to temperature, precipitation, fertilizer, population and agriculture input imports data during the same period. The detailed description of variables is given below.

3.1.1 Dependent variable. Agriculture value added is the dependent variable in the model, measured in current US dollars, which includes fishing, forestry and cultivation of crops and livestock production. It is a net output from all these activities that is obtained after subtracting intermediate inputs from all outputs. Degradation of natural resources and depreciation for assets is not considered. The origin of value added is determined by the International Standard Industrial Classification, revision 3. The data for the variable are taken from World Development Indicators.

3.1.2 Climate variables. A number of climate databases are used in empirical literature to assess the impact of climate on different social outcomes. These data sets use different methods to measure, some use blend of surface and satellite while the others solely rely on surface, precipitation and temperature across spatial scale.

3.1.2.1 Average annual temperature. The study obtained data on temperature developed by Climate Research Unit, University of East Anglia, in conjunction with the Hadley Centre (at the UK Met Office), collected at 5° latitude by 5° longitude resolution. The observations are added for each month for each node in each year, and then, all the nodes in a country are averaged, which ends up a unique annual observation.

3.1.2.2 Average annual precipitation. Precipitation series is constructed from global climate data set, widely used in climate-related studies, that provides data on different weather locations in a country on latitude/longitude/altitude bases. Then data are averaged in the same way as in the case of temperature.

3.1.3 Control variables. In the model, four control variables adapted from World Development Indicators are included. The details of these variables are given below.

3.1.3.1 Fertilizer consumption. Agriculture productivity and use of fertilizer are closely linked; therefore, we control for the impact of fertilizer by including fertilizer consumption in the model. It contains nitrogenous, potash and phosphate fertilizers used per unit of arable land. It excludes traditional nutrients such as animal and plant manure.

3.1.3.2 Agriculture land area. A country having a larger land area is expected to have higher agriculture value addition. To control for this potential bias, agriculture land area is included in the regression equation. According to FAO, agriculture land refers to the share of land area (square kilometres) that is arable and includes land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens and land temporarily fallow, but excludes land under trees grown for wood or timber.

3.1.3.3 Agricultural input imports. Agriculture input imports also contribute to the agriculture yield of a country and therefore is included in the estimation equation. It consists of crude materials but excludes crude fertilizers.

3.1.3.4 Total population. Population can affect the agriculture value added through different channels. It counts mid-year estimates of all residents, regardless of legal status or citizenship except for refugees, based on the definition in World Development Indicators.

3.1.4 Instrumental variables. Agriculture and temperature are endogenous, as two-way potential causality possibly exists between the variables. Latitude and longitude determine, to greater extent, the temperature and precipitation of a location, respectively. Therefore, these two coordinates are used as instrument in the model. The data are obtained on the capital city in each country and are available at https://en.wikipedia.org/wiki/List_of_capital

3.1.4.1 Longitude. These are lines/meridian that run between the North and South Poles and locate the position of a point East West. The Prime Meridian is assigned 0° which bisects the Earth into equal West and East halves. Both the East and West halves are measured from 0° to 180° with due East and West are called "90°" respectively.

3.1.4.2 Latitude. Latitude is an angle which ranges from 0° at the Equator to 90° (North or South) at the poles. Lines of constant latitude or parallels run East-West as circles parallel to the equator. Latitude is used together with longitude to specify the precise location that features on the surface of the Earth.

3.2 Estimation technique

The study estimates equation (2) and uses country fixed effect α_i to control country-specific time invariant characteristics, such as geographic location, soil quality and soil type. Year fixed effect γ_t is controlled for shocks such as changes in national agriculture policies, introduction of new crop seed and cost shocks such as fossil fuel and fertilizer price, which are common to all countries in the given year. $\in_{i,t}$ is an unobservable error term with zero mean. In analysing panel data, the decision whether to use random or fixed effects model is made on the basis of Haussmann test. But the choice of fixed effects is supported on the basis of two arguments. First, for random effect, the sample should be a random selection from a larger population, but this assumption is violated, as this study choses 60 countries across the world on some specific criteria. Second, a random effects model assumes that a country-specific effect is independent of the covariates included in the regression (Poudel and Kotani, 2013), which is unlikely to be fulfilled, as climate variable is correlated with the country-specific effect of agriculture production. At the end, this paper introduces instrumental variables to control for potential endogeneity of the climate variables with the agriculture production. To avoid the risk of spurious regression, it seems plausible to test time series properties of the variables included in the model. To achieve this purpose, Levin, Lin and Chu (LLC) panel unit root test (Levin *et al.*, 2002) is applied.

3.2.1 Panel unit root test. This study uses specification presented by Kula *et al.* (2009) for panel unit root test:

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + \sum_{l=1}^{Li} \gamma_{l,} \Delta y_{i,t-l} + \in_{i,t}$$

where subscripts i and t stand for country and year, respectively, while $\Delta y_{i,t} = y_{i,t} - y_{i,t-1}$ and α_i, β_i and γ_l are intercept and slope coefficients to be estimated, respectively; li is the lag length to be determined using Schwartz or Akaike information criterion and $\in_{i,t}$ is an error term. The null hypothesis for LLC panel unit root test is $H0$: $\beta = 0$ for all i against the alternative $H1$: $\beta < 0$ for all i. The test assumes that data are independent and identically distributed (i.i.d) across individuals, and the null hypothesis postulates that each individual time series is non-stationary against the alternative hypothesis that each time series has no unit root.

4. Results

4.1 Descriptive statistics

Descriptive statistics of all the variables used are reported in Table II. They show a large variation in precipitation while small changes in temperature.

It is found that the volatility of temperature is the highest in Asia and lowest in Africa. Also, highest volatility in precipitation is found in Asia and least is found in North America. Substantial differences in the variation of fertilizer use are found across continents. Arable land area, agriculture value added, population and agriculture input imports also reveal huge variation depending upon the differences in the geo-economic characteristics of the continents.

4.2 Result of panel unit root tests

The results of unit root tests are reported in Table III, which show that all the variables included in the model are stationary at level with constant, level with constant and trend and level with no constant and no trend.

Variables	Des. Stat	Overall	Africa	Asia	Europe	North America	South America	Oceania
Agriculture value	Mean	22.56	21.61	23.75	22.18	24.85	22.89	21.89
Added#	SD	1.66	1.17	1.69	1.44	0.81	1.05	1.76
Temperature	Mean	17.01	22.64	19.79	10.79	17.95	19.55	19.60
	SD	7.49	3.98	8.81	4.81	4.78	3.93	4.79
Precipitation	Mean	868	701	1133	739	817	871	1423
	SD	599	557	947	237	180	300	698
Fertilizer	Mean	230	142	323	181	94	223	669
	SD	352	262	451	102	26	193	934
Agriculture input Imports#	Mean	1.75	1.96	1.25	1.57	1.30	1.70	0.69
	SD	1.01	1.26	1.57	0.61	0.20	0.76	0.29
Population#	Mean	16.75	16.50	1.47	15.93	19.01	17.14	15.23
	SD	1.67	1.09	15.93	1.49	0.51	1.12	1.33
Agriculture land area#	Mean	11.63	11.78	1.83	10.33	14.55	12.92	11.79
	SD	2.08	1.72	10.33	1.77	0.69	1.06	2.86
N		780	169	169	286	26	91	39

Note: # shows that variables are measured in log form because of their large values

Table II.
Descriptive statistics

Variables	Individual effect[a]	Individual effect	None[c]
Individual linear trend[b]			
Agriculture value added	−20.86***	−20.62***	−15.13***
Temperature	−163.84***	−163.98***	0.82
Precipitation	−57.41***	−66.16***	−1.50*
Fertilizer	−11.51***	−14.69***	−1.79**
Agriculture input imports	−9.02***	−7.55***	−10.30***
Population	−4.69***	−42.68***	3.19
Agriculture land area	−4.88***	−100.03***	−35.53***

Notes: ***, ** and *show that the null hypothesis of the presence of unit root is rejected at 99, 95 and 90% confidence level, respectively; [a]results estimated using the equation with only constant included; [b]Results estimated using the equation with constant term and deterministic trend included; [c]results estimated using the equation without constant term and trend

Table III.
Unit root tests results

It can be observed that the *t*-statistics slightly, but not systematically, improves as the authors include trend in the model; therefore, there is no violation of the assumptions of classical linear regression model. So, it is not necessary to include the deterministic trend in the estimated equation (2), as suggested by Wooldridge (2008) to handle the problem of trending variables.

4.3 Identifying the mechanism

In this section, the authors identify the mechanism behind the bias caused by the omission of control variables by probing the sensitiveness of the estimated temperature, precipitation and agriculture nexus by adding each of the additional control variables one at a time. In Table IV, the first column reports estimates from the restricted model that include only temperature and precipitation. Then, each additional control variable is included separately. The last column shows the full model.

Overall, the estimated results support the full model as the preferred specification as the additional control variables are jointly significant with sufficiently large value of adjusted R^2. The coefficients on temperature and precipitation increase systematically when the

Variables	Temperature and precipitation (1)	Added (fertilizer) (2)	Added (agriculture inputs imports) (3)	Added (population) (4)	Added (agriculture land area) (5)
Temperature	−0.016*	−0.016*	−0.023*	−0.047***	−0.048***
Precipitation	0.001	0.001	0.003*	0.001*	0.002***
Fertilizer		−0.000	−0.000	0.000	0.003***
Agriculture Inputs imports			0.474***	−0.014	0.028*
Population				0.993***	0.827***
Agriculture Land area					0.092***
Adjusted R^2	0.003	0.004	0.009	0.488	0.489
Observation	780	780	780	780	780

Note: ***, ** and *show that the null hypothesis of the presence of unit root is rejected at 99, 95 and 90% confidence levels, respectively

Table IV.
Regression results after controlling for additional control variables

estimated model moves from restricted to full model. This suggests that after controlling for control variables indeed, the temperature and precipitation are relatively high. In addition, all the signs of the variables are according to the prior expectations. Temperature has a negative effect while precipitation and all control variables have positive effects on agriculture.

4.4 IV-two-stage least squares results

In climate- and agriculture-related literature, temperature is used as an exogenous variable that can affect agriculture. However, it is interesting to note that agriculture and temperature are endogenous and causality may run both ways, i.e. from temperature to agriculture and vice versa. Agricultural activities produce greenhouse gases that lead to an increase in temperature, which makes temperature endogenous variable with agriculture. To control for this endogeneity, the authors use a geographical instrument, longitude and latitude, which is substantially correlated with temperature and can affect agriculture through temperature, as two coordinates (longitude and latitude) can provide information about the temperature and its corresponding changes. No instrument is used for precipitation, as it is assumed to be exogenous to agriculture, and no theoretical evidence is available, which suggests a bi-directional causality between agriculture and precipitation.

Therefore, the study estimates regression by using IV-2SLS method to overcome the potential threat of endogeneity and reports the results of both stages (Stages 1 and 2). The authors test whether, through endogeneity test, variables are endogenous or exogenous. On the basis of Durban score ($p < 1$ per cent) and Wu-Hausman *F*-statistics ($p < 1$ per cent), the authors reject the null hypothesis of "variables are exogenous" in all alternative specifications, which means that 2SLS is a plausible technique as it caters for endogeneity. The method of 2SLS introduces instruments for endogenous regressors.

Results reported in Table V show that the instrumental variables have right signs and are statistically significant, which shows that they can be substituted as an instrument for temperature. Results of IV (Stage 2) reported in Table V are discussed in detail, as these are the conclusive results and have importance from research and policy perspectives.

4.5 Robustness

Panel A of Table V presents the estimated impact of climate change on agriculture in the panel of 60 countries selected from different continents while controlling for continent fixed and year fixed effects. To check the robustness of findings, the authors did the same exercise for different continents, and the results are reported in the same Panel of Table V. Results show, broadly speaking, that temperature has a negative significant effect on agriculture across all continents, except South America and North America (results not reported), where it shows a positive yet insignificant association between temperature and agriculture. The reason for this positive impact could be the small number of observations that makes the statistical analysis less reliable. It is interesting to note that the magnitude of the temperature coefficient is relatively small, which is just continuity of our previous findings.

At the end, some diagnostic tests are conducted to check the validity of instruments used in the analysis, as in instrumental variables technique, it is mandatory to test whether the instruments are valid and strong. For this purpose, *F*-test is used. The significantly high value of the *F*-statistics ($F = 137.19$ for full sample) is greater than all the critical values obtained under 2SLS (Stage 1), which rejects the null hypothesis of "instruments are weak". The critical *F*-value ranges from 50 in Africa to 1,064 in Oceania continent, supporting that the instrument used is not weak. One of the other characteristic of a good instrument is that it should be highly correlated with the variable for which it is being used. The partial

Table V. Regression results for 2SLS

2SLS	Full sample (1)	Africa (2)	Asia (3)	Europe (4)	South America (5)	Oceania (6)
Panel A						
Longitude	−0.077* (0.004)	−0.145*** (0.012)	−0.126*** (0.009)	−0.039** (0.021)	0.051 (0.031)	−0.399 (0.433)
Latitude	−0.142** (0.009)	−0.020*** (0.015)	−0.459* (0.28)	−0.480*** (0.028)	0.219*** (0.012)	0.080 (0.412)
Constant	6.083*** (2.13)	36.644*** (2.956)	23.222*** (6.712)	29.081*** (4.106)	24.286*** (7.877)	117.26 (127.34)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	
Clustered SE	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.346	0.507	0.748	0.639	0.807	0.99
F-statistics	70.84	50.23	107	174.08	147.82	1,064
Observation	780	169	169	286	91	39
Panel B						
IV Stage two						
Temperature	−0.076 (0.007)	− 0.049 *** (0.019)	0.15*** (0.009)	−0.022 *** (0.008)	0.043 *** (0.031)	−0.112*** (0.024)
Constant	8.162*** (0.222)	3.677*** (1.046)	7.394*** (0.82)	9.440*** (0.404)	12.780*** (0.742)	−12.39** (7.09)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Clustered SE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.84	0.828	0.832	0.89	0.910	0.990
Wald χ^2	4,919	857	948	2,620	933	5,001
Observation	780	169	169	286	91	39

Notes: Regressions control for fertilizer, agriculture input imports, population and agriculture land area. Temperature is instrumented with geographical coordinates (longitude and latitude). ***, ** and *show that the null hypothesis of the presence of unit root is rejected at 99, 95 and 90% confidence levels, respectively. Robust standard errors are reported in parenthesis. North America was excluded from the analysis because of less number of observations; SE: standard errors correlation coefficients (0.62) obtained under 2SLS (Stage 1) is sufficiently high which conclude that temperature and the instrument used are closely related. The range of partial correlation coefficients across different continents is from 0.36 in Africa to 0.88 in Oceania. In the last step, over identification test is applied to test over identification restrictions. The very small values of the Sargan score (0.03) and Basman χ^2 (0.02) do not provide sufficient evidence against the null hypothesis of "no over identification" to reject. Throughout the analysis, the authors allow the effects of country-specific characteristics and time variant properties to be absorbed using the standard procedure.

5. Discussion

5.1 Climate variables

The two climate variables, temperature and precipitation, are the main focus of this paper. The negative sign of the coefficient of temperature shows that temperature affects agriculture negatively. This negative effect can work through a wide array of channels (Dell *et al.*, 2012). For example, higher temperature could cause lower agriculture yields, reduce livestock and affect labour productivity. The negative relationship between temperature and agriculture uncovered by this study is consistent with the findings of previous studies such as Li *et al.* (2015), who report that climate change will cause a decrease in rice production in most areas of the world. Lehmann *et al.* (2015) also found that irrigated crops will face water shortages as a result of increased temperature, which will negatively affect yields. Aggarwal and Mall (2002) show that an increase of 1°C-2°C will lead to 3-17 per cent fall in rice production across different regions. Bezabih *et al.* (2014) conclude that in general, agriculture in Ethiopia is highly responsive to variation in temperature. Deressa and Hassan (2009) examine the effects of annual temperature on net farm incomes and show that marginal increase in temperature significantly and negatively affects net crop revenue per hectare in summer and winter in Ethiopia. Mathauda *et al.* (2000) discovered a reduction in rice yield from 3.2 to 8.4 per cent as a consequence of slight-to-extreme increases in temperature. Mendelsohn and Dinar (1999) use three different scenarios to show that crop yields are negatively affected by rise in temperature in developing countries.

Many studies report positive effects of climate change on productivity. Lee *et al.* (2012) found that in summer, an increase in temperature increases agriculture yield in tropical countries. Babar *et al.* (2014) unearthed that increased temperature in the season of Rabi, from November to April, increases crop yield in Pakistan as higher temperature helps crops to mature in time. The rising temperature in mountain terrain increases the crop area and helps winter crops to mature in time, leading to increase in yields (Hussain and Mudasser, 2007).

As stated above, the main empirical finding is that the temperature generates a statistically significant negative effect on agriculture. However, this study estimate is relatively smaller than the estimates of several previous studies. For example, Adams *et al.* (1998) predict decrease in crop productivity from minimum 45 per cent in northeast states to maximum 66 per cent in lake states in USA under different climate change scenarios. Likewise, Parry *et al.* (2004) find negative impact of climate change even after realising the direct beneficial effect of CO_2 on plant growth and farm-level adaptation up to 22 per cent on world crop. Seo *et al.* (2005) found that rise in temperature is harmful, and the damage could lead to 50 per cent decrease in current agriculture productivity in Sri Lanka. According to this study's results, the elasticities of agriculture with respect to temperature range from 8 per cent in Africa to 30 per cent in Asia, which are at least 20 per cent smaller than those of the previous studies. Furthermore, the negative effects of temperature further scale down as the authors introduce geographical instruments to control for potential endogeneity. This decrease ranges from 38 per cent in Africa to 92 per cent in Europe. The inclusions of some important exogenous variables as control variables and introduction of strong instruments for climate in the estimated model may partly explain the difference of the estimates of the impacts of temperature on agriculture compared to previous studies. The estimated alternative robust measures show that magnitude of the estimated coefficients on temperature remains mild when estimated across different regions.

The results show that a positive association exists between precipitation and agriculture, which is in line with findings of a number of previous studies. For example, Seo *et al.* (2005) show that increase in rainfall is beneficial to crops, and the net revenues from the crops could increase from 11 to 122 per cent in Sri Lanka. Malik *et al.* (2012) report that average seasonal precipitation shift towards south of Pakistan improves the availability of water in normally dry winter season for agriculture lands, which increases the crop yield in the region. However, results of many studies do not support a positive association between precipitation and agriculture. Lehmann *et al.* (2015) conclude that despite record breaking precipitation around the world in the past decade, huge agriculture losses have occurred through increased infestation of pests and fungi that required additional efforts for pest control and treatment. Byjesh *et al.* (2010) show that the pattern of monsoon rain in Himalayan range reduces production of maize. Interestingly, some studies (Deschenes and Greenstone, 2007) report that rise in temperature and precipitation is not going to affect yield of major crops.

5.2 Control variables

Results reported in Table IV show that fertilizers have a strong positive effect on agriculture value added, as expected. Javed *et al.* (2014) also found a strong positive and statistically significant impact of fertilizer on agriculture production in Pakistan. Researchers hold different views on the effect of population on agriculture. The positive relationship between population and agriculture found in this study is supported by Templeton and Scherr (1997) and Boserup (1965), who conclude that population pressure induces intensive use of labour and institutional changes and reduces fallow periods. However, this finding contradicts the Malthusian view on the relationship. Cuffaro (1997) states that population growth induces adjustments in agriculture in terms of technical progress and intensification, thus enhancing yield. However, this optimism may not be justified as there are serious and growing concerns about the impacts of rapid population growth on natural resources (Ehrlich and Ehrlich, 1990).

Results show that imports of agriculture inputs have a positive effect on agriculture. These imports include mechanical and non-mechanical imports used in agriculture and allied activities such as livestock and fisheries. So, the growth of agriculture increases the demand for imported inputs for agriculture, which in turn boosts agricultural output in the country. Several studies of green revolution of the twentieth century showed that state interventions were important in supporting critical stages of agricultural market development, as reported by Dorward *et al.* (2004). Arable land area is one of the confounding factors in analysing the impact of climate change on agriculture. An increase in arable land area may generate a negative effect on climate but a positive effect on agricultural output. The authors find that arable land area is positively related to agriculture, as expected. This result is also in line with the findings of Javed *et al.* (2014), who document a significant positive relation for cultivated area and agriculture production.

6. Conclusions

In this study, the impacts of temperature and precipitation on agriculture value addition are investigated using the method of instrumental variables. Two geographical measures, longitude and latitude, are used as instruments for temperature, but no instrument is used for precipitation. The estimated model also controls for potential confounding factors that could affect agriculture value added across 60 countries, sampled from all habitant continents, for the period of 1999-2011. The study findings indicate that temperature and precipitation are negatively and positively related to agriculture value addition, respectively. However, the magnitudes of the estimated effects of climate variables are relatively smaller (at least by 20 per cent) than those reported in previous empirical studies for different parts of the world. These impacts decrease with the introduction of geographical instruments in the model. The results of the previous studies overstate the effects of temperature on agriculture. The difference in these results may be due to the inclusion of instrumental variables and control variables and the use of a larger sample that consists of 60 countries. Most of the countries in the sample are European countries, which are less vulnerable to climate change according to previous literature. As expected, all the control variables, agriculture inputs imports, fertilizers, population and arable land area are positively related to agriculture value added.

The results of this study highlight the importance and the urgency of implementing effective policies to mitigate the adverse effects of current climate change on agriculture on a global scale. In designing effective policies and strategies, policymakers should focus not only on crop production but also on other agricultural activities such as livestock production and fisheries, in addition to national and international socio-economic and geo-political dynamics. They should also consider the possible long-term effects of agricultural activities on arable land area and precipitation. The agriculture imports including fertilizers needs to be encouraged, and cultivation area expansion can increase agriculture yield and help mitigate adverse effects of climate change. Results of the study also indicate that population policies have implications for growth of agriculture. To avoid possible future shortages of food due to adverse impact of climate on agriculture, policymakers should focus on feed storage, livestock species diversification and introduction of new weather resilient crop varieties along with an increase in cultivated areas, as pointed out by Olesen and Bindi (2002).

Note

1. This approach is also used by Poudel and Kotani (2013).

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