Ind. Jn. of Agri. Econ.
Vol.69, No.4, Oct.-Dec. 2014

How Sensitive is Indian Agriculture to Climate Change?

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ABSTRACT

Using district-level panel data, this paper has assessed sensitivity of Indian agriculture to climate change. Results show that a rise in temperature would reduce agricultural productivity, while rainfall unless it is in excess, will tend to counterbalance harmful effects of temperature. Irrigation is an important adaptation strategy to reduce harmful effects of warmer climate. Predictions suggest that by end of this century, a significant change in climate may reduce productivity of Indian agriculture by 25 per cent. Agriculture in arid and semi-arid regions is more sensitive to climate change, and would be more impacted by climate change. The loss will be higher in the absence of adaptation.

Keywords: Climate impacts, Agriculture, Agro-climatic zones, India

JEL: Q10, Q54, R58.

I

INTRODUCTION

Climate change is a matter of a global concern because of its impending threats to sustainable economic development. Compared to other economic activities, agriculture is more sensitive to climate change (Stern, 2006; Mendelsohn *et al*., 2006); hence will be affected more by it (Rosenzweig and Iglesias, 1994; Adams *et al*., 1998; Cline, 2007; Nelson *et al*. 2009; Kurukulasuriya and Ajwad, 2007; De Salvo *et al*., 2013). The impacts are likely to be severe for the developing countries, like India, because of their heavy dependence on agriculture, and lack of financial resources for mitigation and adaptation to climate change (Mendelsohn *et al*., 2006; Stern, 2006; Nelson *et al*., 2009).

The literature on climate impacts on Indian agriculture is limited but has been growing. In recent years, several studies have examined the impacts of climate change on agriculture. But their results vary widely probably due to differences in the estimation procedures and their underlying assumptions. Aggarwal (2009) reported that a 1.0°C rise in mean temperature would reduce yields of wheat, soybean, mustard, groundnut and potato by 3 - 7 per cent. By 2099, if temperature were to rise by 2.5°- 4.9°C, the damage to these crops will increase to 10 - 40 per cent, even after internalisation of the positive effects of carbon fertilisation. Sanghi *et al*., (1998),

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The authors are thankful to an anonymous reviewer for his valuable comments that helped bring this paper in its present shape. The financial support from the Indian Council of Agricultural Research through a megaprogramme ‘National Initiative on Climate Resilient Agriculture’ that was implemented by the Central Research Institute for Dryland Agriculture, Hyderabad is gratefully acknowledged.

Mendelsohn *et al*., (2001), Kumar and Parikh, (2001), and Sanghi and Mendelsohn, (2008) estimated that with a 2.0°C rise in annual temperature and a 7 per cent increase in annual rainfall (probable changes by 2099) the productivity of Indian agriculture, measured as net returns per hectare of cropped area, will be 8-12 per cent less than without such changes. Guiteras (2007) has reported that with a rise in annual temperature rises by 0.5°C and increase in rainfall by 4 per cent by 2039, the damage to agricultural productivity will be in the range of 4.5 to 9.0 per cent, and by 2099 with significant changes in climate the damage may increase beyond 25 per cent. However, with adaptation this could be reduced to about 3 per cent (Kumar, 2011).

In India, agriculture despite its declining share in national income, less than 15 per cent in 2012-13, continues to be an important sector of the economy because of its strategic importance to food security, employment generation and poverty reduction. The sector engages half of the country's total workforce, and is dominated by small holders; more than 85 per cent land holdings are of size less than or equal to 2 hectares. Thus, significant adverse impacts of climate change on agriculture would threaten livelihoods of a majority of the population dependent on agriculture. In this paper, we assess the impacts of climate change on agriculture using district-level panel data on 19 crops for the period 1969-70 to 2004-05.

The paper is organised as follows. In the next section, we discuss the estimation strategy and the data-set used for assessing climate impacts on agriculture. Section III discusses briefly the past trends in growing period temperature and rainfall. The impacts of climate change on agriculture are discussed in Section IV. Concluding remarks are made in the final Section.

II

METHOD AND DATA

Method of Estimation

There are three main approaches to estimate impacts of climate change on agriculture. These are: (i) bio-physical crop modeling approach also known as production function approach, (ii) Ricardian or hedonic approach, and (iii) panel data approach. Most studies have employed either the crop modelling approach (Adams *et al.,* 1998; Kane *et al.,* 1992; Kaiser, *et al.,* 1993; Reilly *et al*., 1994; Rosenzweig and Iglesias, 1994; Aggarwal and Sinha, 1993; Rao and Sinha, 1994; Lal *et al.,* 1998; Mathauda *et al.,* 2000; Aggarwal, 2009) or the Ricardian approach (Sanghi *et al.,* 1998; Mendelsohn *et al.,* 1994; 2001; Kumar and Parikh, 2001; Sanghi and Mendelsohn, 2008). Crop modelling approach is based on controlled experimentations wherein a crop is exposed to varying degrees of temperature; and crop yields are, then, compared across temperature levels as to assess its impact. Nonetheless, its main limitation is that it over-estimates the negative impacts and under-estimates the positive impacts, implying that it does not consider farmers' responses or adaptations to changes in climate change.

Ricardian approach assumes that in a perfectly competitive market, value of land reflects present value of future streams of profits (or rent) earned from it. *Ceteris paribus*, a farmer maximises profits by allocating land in declining order of its fertility and climate. The approach is similar to the hedonic price method wherein, all else remaining constant, regional differences in land value or productivity are explained by the differences in climate. Its application to studying climate impacts was popularised by Mendelsohn and colleagues (Mendelsohn *et al*. 1994; 2001; Mendelsohn and Dinar, 2009). In Ricardian studies, land value per hectare or net revenue per hectare from a cross-section of heterogeneous units is regressed on climate normal along with some controls. The estimated impacts are lower than those obtained using crop modelling approach (Mendelsohn *et al*., 2010). Critics, however, question its application to studying the climate impacts (Cline, 1996; Darwin, 1999; Quiggin and Horowitz, 1999; Schlenker and Roberts, 2006; Guiteras, 2007). It is argued that that Ricardian approach fails to fully control the effects of unobservable farm and farmer characteristics on farm incomes that may be correlated with climate change. Further, it uses cross-section or repeated cross sections that are often mis-specified; leading to bias in estimates (Schlenker and Roberts, 2006; Guiteras, 2007). Also, it does not account for the effects of factors that do not vary across space and time (Deschenes and Greenstone, 2007; Mendelsohn and Dinar, 2009; Polsky, 2004). Putting it differently, the approach assumes little or no variation in crop choices and production technology over time regardless of the climate change.

In recent years, some studies have used panel data approach, as suggested by Deschenes and Greenstone (2007) because of its several advantages over others. One, the dependent variable, that is land value or net revenue or gross revenue per hectare, is an annual measure rather an average of cross-sections as in the case of Ricardian analysis. Two, with panel data it is possible to capture the effects of time-invariant variables, like soils, elevation, etc. Three, the regressors of interest are the functions of monthly or yearly realised weather variables rather than climate normal. Four, use of panel data also makes it possible to account for short-term effects of adaptations on productivity; for example, in response to year-to-year fluctuations in climate variables the farmers may adjust their crop mix, input use etc. Five, geographical fixed effects absorb location-specific time-variant determinants of agricultural productivity that may be correlated with climate (Deschenes and Greenstone, 2007). In this paper, we employ the panel data approach to assess climate impacts.

Data and Model Specification

To assess the climate impacts we use district-level data on climate variables (temperature and rainfall), and production and area of 19 major crops for the period 1969-70 to 2004-05 for 200 districts at their 1970 status. The crops are: rice, wheat, sorghum, pearl millet, maize, finger millet, barley, chickpea, pigeon pea, groundnut, sesame, rapeseed and mustard, safflower, castor, linseed, sunflower, soybean, sugarcane and cotton. These crops account for around 80 per cent of the total cultivated area in these districts.

To find out a measure of agricultural productivity we estimate value of output of the selected crops by multiplying their production with their average farm harvest prices for the triennium ending 2004-05. The sum of values of outputs is divided by the sum of area under these crops to obtain gross value of output per hectare.

The data on temperature and rainfall for a district were extracted from 1 x 1 degree high-resolution daily gridded data available from the Indian Metrological Department, Government of India. The daily data were converted into monthly averages. Many studies have used averages of temperature and rainfall during different quarters of the year or the monthly means for January, April, July, and October as representative of the respective quarters. But, there is a possibility of high correlation between quarterly or monthly series of these variables. We have used mean monthly temperature and cumulative rainfall for India's two main crop growing periods, viz., *kharif* (June to September) and *rabi* (October to February), which are less correlated than the quarterly or monthly averages.

Irrigation is important to mitigate the harmful effects of extreme climate events, and neglecting it in modelling climate impacts may lead to inconsistent and biased estimates. Schlenker *et al*. (2005) and Kurukulasuriya *et al*. (2011) found that omission of irrigation leads to overestimation of climate impacts. Jacoby *et al*. (2011) assessed the effects of irrigation interacting with growing period temperature and rainfall, and found that irrigation indeed is important to mitigate the harmful impacts of climate change. We include irrigation as an exogenous variable in our model.

For expositional purpose, the panel fixed effects model is specified as:

$$y_{it} = D_i + T_t + \sum_{k=1}^{K} \beta_k W_{kit} + \epsilon_{it} \qquad \text{....(1)}$$

Subscripts 'i' and 't' denote district and time, respectively and W_k represents climate variables. The dependent variable y_{it} is the gross value of output (in rupees per hectare at 2004-05 prices). The effect of temperature and rainfall on crop yields is generally non-linear (Schlenker and Roberts, 2006; Jacoby *et al*., 2011); and to account for non-linear effects we have included quadratic terms of temperature and rainfall, and also their interactions. Further, to account the farmers' responses to climate change, we assume irrigation as an important response and include gross cropped area irrigated, in per cent, as an exogenous variable in our model.[1]

Equation (1) is estimated with district (D) and time (T) fixed effects. District fixed effects are assumed to absorb the unobserved district-specific time-invariant variable (e.g., soil and water quality that influence crop yields), and minimise estimation bias due to omitted variables. Time fixed effects control for annual differences in productivity, which might have arisen due to changes in technology, infrastructure, human capital, etc. Thus, with fixed effects the estimated coefficients β_k are likely to be unbiased and consistent.

There is a possibility that the dependent variable y_{it} is non-stationary, causing problem of autocorrelation. The autocorrelation may be severe if the series of explanatory variables (temperature and rainfall) too are non-stationary. To test for stationarity we have employed panel unit root tests, viz., Levin-Lin-Chu, Im, Pesharan and Shin (IPS) and the Fisher type tests, and reject the null hypothesis for all the series (Annexure Table 1).

Equation (1) is estimated as log-linear. We calculate the marginal effects of temperature and rainfall using regression coefficients associated with their linear, quadratic and interaction terms at their mean values. To predict loss in productivity due to future changes in climate, we estimate mean predicted gross value of output per hectare $\hat{y}_a$ from equation (1) and compare it with the mean predicted gross value of output per hectare $\hat{y}_p$ from each of the counterfactual climate scenario. The difference between $\hat{y}_p$ and $\hat{y}_a$ provides us an estimate of the loss in productivity due to climate change.

$$\% \, \Delta\widehat{Loss} = \left(\hat{y}_a - \hat{y}_p\right) * 100 \qquad \text{....(2)}$$

To obtain standard errors for these estimates, we employ a non-parametric bootstrap, and resample the data 500 times for each specification.

There is considerable regional heterogeneity in climate, crops and agronomic practices in India suggesting that geography and location are important for climate as well as agriculture. Therefore, we estimate the climate impacts at the level of an agro-climatic zone. The zones are: humid, semi-arid temperate and arid-semi-arid tropics.[2]

III

TRENDS IN TEMPERATURE AND RAINFALL

Table 1 presents mean values of growing period temperatures and rainfall for the period 1969-2005 for different agro-climatic regions. The mean temperature in the *kharif* season is lowest (27.5°C) in the humid zone and highest (29.7°C) in the semi-arid temperate zone. The *kharif* season covers sweltering summer months of June and July, and also receives most of the annual rainfall. The *rabi* season is somewhat cooler. The mean temperature during this season is lower in the semi-arid temperate zone than in any other zone. There are considerable regional differences in rainfall; being much higher in the humid zone than in any other zone.

To look into the dynamics of climate change we estimate the trends in the growing period temperatures and rainfall by regressing these on time along with district fixed effects. Table 2 presents the results. We observe an upward trend in annual mean temperature at all-India level as well as at regional levels. During 1969-2005, the annual temperature increased by 0.30°C or 0.08°C per annum. The rise was relatively more in the arid-semi-arid tropical zone (0.34°C). With the growing period, the temperature rose faster in the *rabi* (except in the semi-arid temperate zone) indicating that winters are becoming warmer.

TABLE 1. MEAN AND STANDARD DEVIATIONS OF CLIMATE VARIABLES, 1969-2005

	Rabi		*Kharif*		Annual	
	Temperature	Rainfall	Temperature	Rainfall	Temperature	Rainfall
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Humid zone	23.0	235.8	27.5	1377.7	26.0	1660.9
	(2.0)	(204.7)	(2.0)	(787.2)	(1.2)	(825.7)
Semi-arid temperate zone	18.8	75.3	29.7	743.1	24.7	838.3
	(1.5)	(63.9)	(1.3)	(297.6)	(1.5)	(328.7)
Arid-semi-arid tropics zone	22.3	128.6	28.3	653.9	26.1	799.9
	(2.4)	(169.9)	(1.7)	(410.8)	(1.2)	(415.4)
All India	21.8	141.8	28.4	829.8	25.8	996.1
	(2.6)	(172.8)	(1.8)	(581.0)	(1.4)	(629.3)

Note: Standard errors in parentheses.

TABLE 2. TRENDS IN CLIMATE VARIABLES, 1969-2005

	All India	Humid	Semi-arid temperate	Arid-semi-arid tropics
(1)	(2)	(3)	(4)	(5)
Annual temperature (AT)	0.0082***	0.0059***	0.0080***	0.0092***
	[0.30]	[0.22]	[0.30]	[0.34]
Rabi temperature (RT)	0.0102***	0.0076***	0.0069***	0.0122***
	[0.38]	[0.28]	[0.26]	[0.45]
Kharif temperature (KT)	0.0083***	0.0066***	0.0084***	0.0090***
	[0.31]	[0.24]	[0.31]	[0.33]
Annual rainfall (AR)	-0.4847	-0.4493	-2.5931***	0.1921
	[-17.93]	[-16.62]	[-95.94]	[7.11]
Rabi rainfall (RR)	0.0153	0.8489**	-0.0354	-0.2787
	[0.57]	[31.41]	[-1.31]	[-10.31]
Kharif rainfall (KR)	-0.6190*	-1.4363	-2.5662***	0.3229
	[-22.90]	[-53.14]	[-94.95]	[11.95]

Notes: Figures in parentheses represent the cumulative change during 1969-2005.
***, ** and * denote significance at 1 per cent, 5 per cent and 10 per cent level, respectively.

During this period, annual rainfall at all-India level decreased, mainly due to a significant decline in the *kharif* rainfall (23mm). The rate of change, however, varies across seasons and zones. In the semi-arid temperate zone, the annual rainfall declined by 96mm in the *kharif* season, more than the decline in any other zone. The humid zone experienced a significant increase in the *rabi* rainfall (31mm). But, there was no significant change in rainfall in the arid-semi-arid tropical zone in the *kharif* as well as *rabi* season. These findings indicate no significant trend in rainfall at the national level, but pockets of significant change in the seasonal rainfall.

IV

IMPACT OF CLIMATE CHANGE

Regression Results

Table 3 presents estimated regressions of the gross value of output per hectare on climate variables after controlling for district and time fixed effects. In order to assess

TABLE 3. REGRESSION ESTIMATES OF THE IMPACT OF RAINFALL AND TEMPERETURE ON GROSS VALUE OF OUTPUT PER HECTARE

	All India		Humid		Semi-arid temperate		Arid-semi-arid tropics	
	Without irrigation as control	With irrigation as control	Without irrigation as control	With irrigation as control	Without irrigation as control	With irrigation as control	Without irrigation as control	With irrigation as control
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RT	0.203*	0.115	0.0741	0.0219	0.447***	0.483***	0.242	0.0853
	(0.109)	(0.0956)	(0.232)	(0.221)	(0.0998)	(0.0944)	(0.180)	(0.148)
RT*RT	-0.00573**	-0.00332	-0.00253	-0.00128	-0.0122***	-0.0130***	-0.00641	-0.00235
	(0.00264)	(0.00231)	(0.00527)	(0.00499)	(0.00266)	(0.00245)	(0.00427)	(0.00351)
KT	-0.387**	-0.215	-0.414*	-0.403*	-0.289*	-0.183	-0.237	0.114
	(0.164)	(0.145)	(0.221)	(0.229)	(0.170)	(0.152)	(0.278)	(0.238)
KT*KT	0.00548*	0.00206	0.00756*	0.00711*	0.00463	0.00309	0.00184	-0.00466
	(0.00291)	(0.00260)	(0.00399)	(0.00411)	(0.00281)	(0.00253)	(0.00503)	(0.00434)
RR	-0.000728*	-0.000466	-0.000497	-0.000670	0.00284***	0.00303***	-0.000663	-0.000338
	(0.000402)	(0.000365)	(0.000709)	(0.000633)	(0.000797)	(0.000670)	(0.000743)	(0.000686)
RR*RR	-3.11e-07***	-2.37e-07***	-2.32e-08	3.67e-08	-1.20e-06***	-1.18e-06***	-3.99e-07***	1.50e-07
	(6.86e-08)	(7.99e-08)	(1.01e-07)	(8.39e-08)	(3.75e-07)	(2.92e-07)	(1.08e-07)	(1.64e-07)
KR	-0.000478*	-0.00142***	-0.000130	-0.000325	-0.00114***	-0.000300	-0.00159***	-0.00252***
	(0.000247)	(0.000420)	(0.000386)	(0.000427)	(0.000379)	(0.000329)	(0.000509)	(0.000773)
KR*KR	-3.97e-08***	-4.07e-08**	-2.20e-08	-1.87e-08	4.13e-08	-7.76e-08**	-5.68e-08	-4.19e-08
	(1.33e-08)	(1.99e-08)	(1.58e-08)	(1.79e-08)	(3.85e-08)	(3.35e-08)	(4.48e-08)	(4.81e-08)
RT*RR	0.0000464**	0.0000396**	0.0000208	0.0000311	-0.000133***	-0.000137***	0.0000536	0.0000480
	(0.0000190)	(0.0000166)	(0.0000317)	(0.0000276)	(0.0000398)	(0.0000338)	(0.0000335)	(0.0000296)
KT*KR	0.0000255***	0.0000691***	0.0000103	0.0000182	0.0000380***	0.0000264**	0.0000679***	0.000111***
	(0.00000894)	(0.0000164)	(0.0000127)	(0.0000140)	(0.0000116)	(0.0000103)	(0.0000185)	(0.0000290)
IR (per cent area)		1.445***		0.590**		0.608***		1.980***
		(0.243)		(0.220)		(0.131)		(0.384)
RT*RR*IR		-0.0000188**		-0.0000148**		-0.0000102		-0.0000456**
		(0.00000783)		(0.00000625)		(0.0000109)		(0.0000200)
KT*KR*IR		-0.0000307***		-0.00000592		-0.0000181***		-0.0000412***
		(0.00000647)		(0.00000421)		(0.00000282)		(0.0000105)
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	13.24***	11.59***	13.84***	14.37***	9.28***	6.723***	11.27***	7.701**
	(2.334)	(2.190)	(4.531)	(4.679)	(2.321)	(2.255)	(3.692)	(3.461)
N	6919	6919	1517	1517	1332	1332	4070	4070
Adj-R^2	0.777	0.795	0.780	0.785	0.905	0.911	0.759	0.782

Notes: Standard errors in parenthesis are adjusted for district-level clustering. IR is the proportion of area irrigated.
***, ** and * denote significance at 1, 5 and 10 per cent level, respectively.

the importance of irrigation as a coping strategy to climate change we estimate two different specifications of equation (1). In one, we include quadratic and interaction terms of rainfall and temperature. In another, we include irrigation and allow it to interact with rainfall and temperature. The objective is to maximise the explained variation and to minimise the unexplained variation in the outcome variable, and thus the influence of any omitted variable. The adjusted R^2 is more than 0.75 in both the specifications.

District fixed effects are significant, suggesting that it is important to control for the time-invariant location-specific factors that could be correlated with climate variables. The time fixed effects are also significant, implying the importance of farmers' responses to climate change, in terms of adjustments of their crop mix, crop varieties, input use etc.

Coefficients of the quadratic and interaction terms of growing period temperatures and rainfall are statistically significant at all-India level. Here, we would like to stress the importance of statistical significance of the interaction terms. The results suggest that the effects of temperature and rainfall on productivity are not mutually exclusive. Note that, there is a correlation between temperature and rainfall as depicted by Figure 1 for *kharif* temperature and rainfall.[3] It is, therefore, important to include the interactions of temperature and rainfall, and their non-inclusion in the model will lead to biases in estimates.

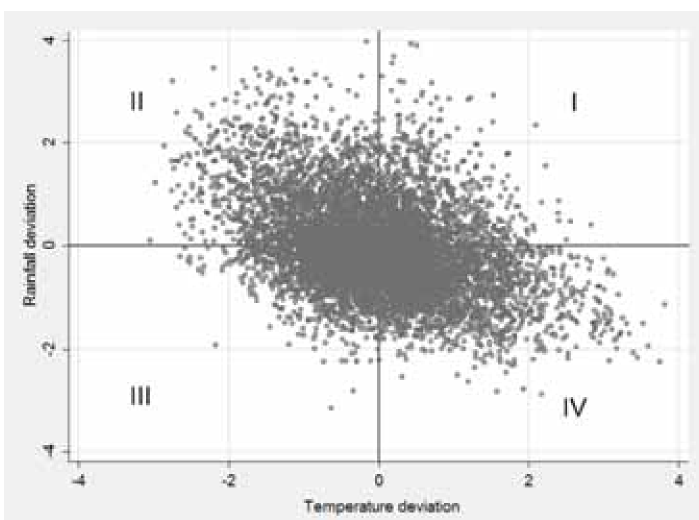

Figure 1. Relationship between Deviations in Rainfall and Temperature from their Respective Normal, 1969-2005.

Coefficient of irrigation is positive and highly significant. The interaction of irrigation with temperature and rainfall is also statistically significant. However, due to non-linearity in climate variables, it is difficult to interpret the regression coefficients of rainfall and temperature; hence we aggregate the linear marginal effects of these variables at their long-term averages.

Table 4 presents the average marginal effects of temperature and rainfall. The marginal effects of both the temperature and the rainfall at all-India level are statistically significant. Higher growing period temperature in *kharif* as well as *rabi* adversely affects agricultural productivity. A 1°C rise in the *rabi* temperature reduces the gross value of output per hectare by 4.0 per cent.[4] A similar increase in the *kharif* temperature reduces it by 5.6 per cent. Irrigation, however, reduces the harmful effects of warmer climate.

TABLE 4. ESTIMATED MARGINAL EFFECTS OF TEMPERETURE AND RAINFALL

	All India		Humid		Semi-arid temperate		Arid-semi-arid tropics	
	Without irrigation as control	With irrigation as control	Without irrigation as control	With irrigation as control	Without irrigation as control	With irrigation as control	Without irrigation as control	With irrigation as control
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
RT	-0.03954**	-0.03128**	-0.03701	-0.0311	-0.02178	-0.01936	-0.03678	-0.02755
	(0.01562)	(0.01462)	(0.01902)	(0.01748)	(0.01382)	(0.0135)	(0.02355)	(0.02123)
KT	-0.05439**	-0.04515**	0.0159	0.01561	0.01384	0.01163	-0.08831**	-0.07488**
	(0.01212)	(0.01125)	(0.0225)	(0.0223)	(0.01521)	(0.01561)	(0.01688)	(0.01671)
RR	0.00019**	0.00025**	-0.00003	-0.00001	0.00015	0.00017**	0.00043**	0.00048**
	(0.00005)	(0.00005)	(0.00005)	(0.00005)	(0.00008)	(0.00007)	(0.00008)	(0.00008)
KR	0.00018**	0.00018**	0.00009**	0.00009**	0.00005**	0.00006**	0.00025**	0.00024**
	(0.00003)	(0.00003)	(0.00003)	(0.00003)	(0.00002)	(0.00002)	(0.00006)	(0.00005)

Notes: Standard errors in parentheses are calculated by delta method.
***, ** and * denote significance at the 1, 5 and 10 per cent level, respectively.

Marginal effect of *kharif* rainfall is positive and pretty much similar with and without irrigation. This effect of *rabi* rainfall is also positive, and irrigation enhances it further. Note that, the effect of rainfall in either of the seasons is much smaller than the effect of temperature.

The marginal effects of climate variables vary in their magnitude, direction and significance across agro-climatic zones (Table 4). The arid-semi-arid tropics are most vulnerable to climate change. Marginal effect of temperature, *kharif* as well as *rabi* is negative, but more pronounced in the *kharif* season. A 1°C increase in the *kharif* temperature reduces the gross value of output by 9.2 per cent. The damages due to temperature are partially offset by irrigation. The effect of *kharif* rainfall is positive and significant in all the zones.

We compare our results with those of Guiteras (2007) and Jacoby *et al.* (2011), who also estimated the climate impacts on Indian agriculture using panel regressions. Our study differs in the choice of crops and time periods from their studies. Guiteras (2007) used a long-time series (1960-99) on five major crops, while Jacoby *et al.* (2011) included 20 crops but for a shorter period 1999-2005. Their estimates of the marginal effects of climate change, however, are different. Guiteras (2007) estimated that a 1°C rise in temperature reduces gross value of output per hectare by about 11 per cent, much lower than the estimate of 24 per cent by Jacoby *et al*. (2011). Notwithstanding such differences, almost all studies reveal that climate change would have negative impact on Indian agriculture and largely through rise in temperature (Sanghi *et al*., 1998; Sanghi and Mendelsohn, 2008; Kumar and Parikh, 2001; Kumar, 2011).

Climate Simulations

In order to know how future changes in climate will influence Indian agriculture, we have simulated climate change impacts using the econometric model presented in the previous section. It is assumed that the structure of agriculture will remain as it is now. This indeed is a very restrictive assumption, as a number of economic and non-economic factors may reinforce changes in agriculture.

To simulate climate impacts, we have used changes in surface air temperature and rainfall for South Asia as predicted by IPCC (2014) (Annexure Table 2). We, however, estimate impacts of climate change using the median counterfactuals of temperature and rainfall (50 per cent) for 2035, 2065 and 2100. The short-run changes in temperature and rainfall are small. In the long-run, there are significant changes in temperature and rainfall.

The IPCC projections for climate are for the period June-August and December-February. We consider June-August counterfactuals to represent changes in climate in *kharif* season, and December-February in *rabi* season. While simulating climate impacts at the regional level, we assume similar changes in the climate across the agro-climatic zones.

Table 5 presents changes in the gross value of output per hectare due to future changes in climate. In the short-run, the effects of climate change on productivity are significant but not as large as in the long-run. By 2035, the loss in gross value of output is predicted to be 9 per cent. However, with the progression of time, the loss will increase –16 per cent by 2065 and 21 per cent by 2100. However, after controlling for the irrigation these losses are reduced to three-fourths.

TABLE 5. ESTIMATED IMPACTS OF CLIMATE CHANGE ON GROSS VALUE OF OUTPUT PER HECTARE

	2035		2065		2100	
Agro climatic zones (1)	No irrigation (2)	Irrigation (3)	No irrigation (4)	Irigation (5)	No irrigation (6)	Irrigation (7)
All India	0.0803	0.0610	0.1477	0.1120	0.1916	0.1454
	(0.0181)	(0.0158)	(0.0353)	(0.0307)	(0.0476)	(0.0413)
Humid	0.0240	0.0195	0.0396	0.0300	0.0467	0.0334
	(0.0301)	(0.029)	(0.0603)	(0.0587)	(0.0826)	(0.0808)
Semi-arid temperate	0.0219	0.0194	0.0527	0.0507	0.0779	0.0775
	(0.0154)	(0.0143)	(0.0296)	(0.0267)	(0.0397)	(0.0352)
Arid-semi-arid tropics	0.1038	0.0785	0.1933	0.1472	0.2534	0.1946
	(0.0296)	(0.0255)	(0.0578)	(0.0497)	(0.0779)	(0.0669)

Notes: Standard errors in parenthesis are generated by bootstrapping with 500 replications. Losses are projected using the 50th percentile of projected climate scenarios (See Annexure Table 2).

The projected impacts are not uniform across zones. Agriculture in the arid-semi-arid tropics is more sensitive to climate change; by 2100, with climate change the productivity is expected to be 29 per cent less than without it. The semi-arid temperate zone will be least affected by climate change, the expected productivity loss being 8 per cent.

V

CONCLUSIONS

In this paper, we have examined the climate sensitivity of Indian agriculture using district-level panel data for the period 1969-2005. Gross value of output per hectare was regressed on the growing period temperature and rainfall along with their quadratic and interaction terms and irrigation as a control. Marginal effects show that rise in temperature in *kharif* as well as *rabi* seasons have harmful effect on agricultural productivity. Higher rainfall, unless it is in excess, has a beneficial effect, but the effect is too small to offset the negative effect of temperature. Irrigation, reduces the harmful effects of higher temperature. The projections indicate that though the loss in productivity in the short run is mild (6 per cent) by 2035, but will increase to 12 per cent by 2065 and 16 per cent by 2100. The effects will be more pronounced in the arid-semi-arid tropics.

An important message from this study is that management of irrigation will be critical to enhance resilience of agriculture to climate change. About 80 per cent of the available water in India is used in agriculture, yet more than half of the cropped area remains rainfed. However, if it were possible to harvest, conserve and utilise rain water an additional 25-30 per cent of the area can be provided with irrigation (Sharma *et al*. 2010). Harnessing this potential will require investment to create on-farm structures for harvesting, storage and distribution of water. Further, it is essential to improve water-use efficiency applying micro-irrigation technologies, such as sprinkler and drip irrigation (Palanisami *et al.*, 2011). Another way to reduce the adverse effects of climate change on agricultural production is through breeding of crop varieties that can tolerate or escape abiotic stresses such as droughts, floods, heat waves. Biotechnology offers opportunities to move forward in this direction (Varshney *et al*. 2011).

Received February 2014. *Revision accepted February 2015.*

NOTES

1. We could have included fertiliser use (kg/ha) as one of the adaptations to climate change. But due to its high correlation with irrigation we did not include it our model. We preferred irrigation over fertiliser as the former is considered the best bet against higher temperature and deficit rainfall.

2. The districts were classified into homogeneous regions based on average annual temperature, annual rainfall and soil types as described in TAC (1992).

3. Figure 1 plots standardised deviation in cumulative rainfall and mean monthly temperature from their respective historical means during the kharif season, the main cropping season in India.

4. As the dependent variable is in logarithm we calculate change as: $(\exp^{\text{Coefficient}}-1)*100$.

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ANNEXURE TABLE 1. PANEL UNIT ROOT TESTS

	Ho: Panels contain unit roots Ha: Panels are stationary (lags chosen to minimise AIC)			Ho: All panels contain unit roots Ha: Some panels are stationary (lags chosen to minimise AIC)		Ho: All panels contain unit roots Ha: At least one panel is stationary (lags 2)	
Variables (1)	LLC (t-bar) (2)	LLC (adjusted statistics) (3)	p-value (4)	IPS (z-t-tilde-bar) (5)	p-value (6)	Fisher (modified inverse chi2 Pm) (7)	p-value (8)
Ln (Gross return per hectare)	-22.82	-11.92	0.00	-31.71	0.00	55.22	0.00
RT	-51.23	-29.96	0.00	-41.22	0.00	76.27	0.00
KT	-74.45	-60.14	0.00	-50.41	0.00	71.90	0.00
RR	-66.42	-48.65	0.00	-50.92	0.00	73.24	0.00
KR	-67.77	-43.82	0.00	-47.90	0.00	67.79	0.00
IR	-10.89	-2.41	0.01	-4.87	0.00	26.17	0.00

ANNEXURE TABLE 2. PROJECTED CHNAGES IN SURFACE AIR TEMPERETURE AND PRECIPITATION IN SOUTH ASIA

Months	Year	Minimum	25 per cent	50 per cent	75 per cent	Maximum
				Temperature (°C)		
DJF	2035	0.1	0.7	1	1.1	1.4
	2065	0.6	1.6	1.8	2.3	2.6
	2100	1.4	2	2.3	3	3.7
JJA	2035	0.3	0.6	0.7	0.9	1.3
	2065	0.9	1.1	1.3	1.7	2.6
	2100	0.7	1.4	1.7	2.2	3.3
Annual	2035	0.2	0.7	0.8	1	1.3
	2065	0.8	1.4	1.6	1.9	2.5
	2100	1.3	1.7	2.1	2.7	3.5
				Precipitation (per cent)		
DJF	2035	-18	-6	-1	4	8
	2065	-17	-3	4	7	13
	2100	-14	0	8	14	28
JJA	2035	-3	2	3	6	9
	2065	-3	5	7	11	33
	2100	-7	8	10	13	37
Annual	2035	-2	1	3	4	7
	2065	-2	3	7	9	26
	2100	-3	6	10	12	27

Note: Temperature and precipitation projections by the CMIP5 global models from IPCC WGI Fifth Assessment Report. The figures shown are averages of the projections by a set of 42 global models for the RCP4.5 scenario. The area mean temperature and precipitation responses are first averaged for each model over 1986–2005 from the historical simulations, and the 2016–2035, 2046–2065 and 2081–2100 periods of the RCP4.5 experiments. Based on the difference between these two periods, the table shows the 25th, 50th and 75th percentiles, and the lowest and highest response among the 42 models, for temperature in degrees Celsius and precipitation as a percent change.

DJF: December-January-February; JJA: June-July-August.