WORKING PAPER 43/2009

CLIMATE SENSITIVITY OF INDIAN AGRICULTURE

K.S. Kavi Kumar

MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

April 2009

Climate Sensitivity of Indian Agriculture

K.S. Kavi Kumar
Email : kavi@mse.ac.in; kavikumar@gmail.com

WORKING PAPER 43/2009

April 2009

Price : Rs. 35

MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

Phone: 2230 0304/ 2230 0307/2235 2157
Fax : 2235 4847 /2235 2155
Email : info@mse.ac.in
Website: www.mse.ac.in

Climate Sensitivity of Indian Agriculture

K.S. Kavi Kumar

Abstract

Climate change impact studies on agriculture are broadly based on agronomic-economic approach and Ricardian approach. The Ricardian approach, similar in principle to the Hedonic pricing approach of environmental valuation, has received significant attention due to its elegance and also some strong assumptions it makes. This paper attempts to extend the existing knowledge in this field by specifically addressing two important issues: (a) extent of change in climate sensitivity of Indian agriculture over time; (b) importance of accounting for spatial features in the assessment of climate sensitivity.

The analysis based on four decades of data suggests that the climate sensitivity of Indian agriculture is increasing over time, particularly in the period from mid-eighties to late nineties. This finding corroborates the growing evidence of weakening agricultural productivity over the similar period in India. The results also show presence of significant positive spatial autocorrelation, necessitating estimation of climate sensitivity while controlling for the same. While many explanations may exist for the presence of spatial autocorrelation, this paper argued that inter-farmer communication could be one of the primary reasons for the spatial dependence. Field studies carried out in Andhra Pradesh and Tamil Nadu through focus group discussions provided limited evidence in this direction.

Key Words: *Climate Change; Indian Agriculture; Environmental Valuation; Spatial Econometrics; Adaptation*

JEL Codes: *Q54, Q1, R1*

Acknowledgements

This paper is presented at IV Congress of the Latin American and Caribbean Association of Environmental and Natural Resource Economics, Universidad Nacional, Heredia, Costa Rica, 19-21 March 2009. The author would like to thank the conference participants for useful comments; and Brinda Viswanathan and Jaya Krishnakumar for helpful suggestions on spatial econometric work. The financial support provided by South Asian Network for Environment and Development Economics (SANDEE) is gratefully acknowledged.

1. INTRODUCTION

Over the past two decades the debate on global climate change has moved from scientific circles to policy circles with the world nations more seriously than ever exploring a range of response strategies to deal with this complex phenomenon that is threatening to have significant and far reaching impacts on human society. The Intergovernmental Panel on Climate Change (IPCC) in its fourth assessment report observed that, 'warming of climate system is now unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level' (Solomon *et al.*, 2007). Policy responses to climate change include mitigation of GHGs that contribute to the expected changes in the Earth's climate, and adaptation to potential impacts caused by the changing climate. While the first one is largely seen as a reactive response to climate change, the second one is a proactive response. Though GHG mitigation policies have dominated the overall climate policy so far, adaptation strategies are also being emphasized now to form a more comprehensive policy response.

The United Nations Framework Convention on Climate Change (UNFCCC) – the international apex body on climate change – refers to adaptation in the context of change in climate only. In other words without greenhouse gas emissions there is no climate change and hence no need for adaptation. Going by this widely accepted interpretation, adaptation is necessary only because mitigation of greenhouse gases may not completely halt climate change. Stern Review summarizes this view: 'adaptation is crucial to deal with the unavoidable impacts of climate change to which the world is already committed' (Stern, 2006, emphasis added).

For both mitigation and adaptation policy formulation, one of the crucial inputs needed is the potential impacts due to climate change on various climate sensitive sectors. For mitigation, such information would provide the required justification for de-carbonizing the energy systems. On the other hand, in the context of adaptation, knowledge on climate change induced impacts will be helpful in prioritizing the adaptation in the most needed sectors and regions. Further, climate change impacts estimated with proper accounting of adaptation will be helpful in identifying the factors that ameliorate the adverse effects of climate change.

1.1 Climate Change and Indian Agriculture

With more than sixty percent of its population dependent on climate sensitive activities such as agriculture, the impacts of climate change on agriculture assume significant importance for India. Climate change projections made up to 2100 for India, indicate an overall increase in temperature by 2-4^{o}C coupled with increase in precipitation, especially during the monsoon period. Mall *et al.* (2006) provide an excellent review of climate change impact studies on Indian agriculture mainly from physical impacts perspective. The available evidence shows significant drop in yields of important cereal crops like rice and wheat under climate change conditions. However, biophysical impacts on some of the important crops like sugarcane, cotton and sunflower have not been studied adequately.

The economic impacts of climate change on agriculture have been studied extensively world over and it continues to be a hotly debated research problem. Two broad approaches have been used so far in the literature to estimate the impact of climate change on agriculture:

(a) Agronomic-economic approach that focuses on structural modeling of crop and farmer response, combining the agronomic response of plants with economic/management decisions of farmers. This approach is also referred as Crop Modeling approach and Production Function approach;

(b) Spatial analogue approach that exploits observed differences in agricultural production and climate among different regions to estimate a climate response function. This approach is referred as Ricardian approach and is similar in spirit to hedonic pricing technique of environmental valuation.

In the first approach the physical impacts (in the form of yield changes and/or area changes estimated through crop simulation models) are introduced into an economic model exogenously as Hicks neutral technical changes. In the Indian context Kumar and Parikh (2001a) showed that under doubled carbon dioxide concentration levels in the later half of twenty first century the gross domestic product would decline by 1.4 to 3 percentage points under various climate change scenarios. More significantly they also estimated increase in the proportion of population in the bottom income groups of the society in both rural and urban India under climate change conditions. While this approach can account for the so-called carbon fertilization effects[1], one of the major limitations is its treatment of adaptation. Since the physical impacts of agriculture are to be re-estimated under each adaptation strategy, only a limited number of strategies can be analyzed.

In an alternative approach, called Ricardian approach, Mendelsohn *et al.* (1994) have attempted to link land values to climate through reduced-form econometric models using cross-sectional evidence. This approach is similar to Hedonic pricing approach of environmental valuation. Since this approach is based on the observed evidence of farmer behavior it could 'in principle' include all adaptation possibilities. Of course, if the predicted climate change is much larger than the observed climatic differences across the cross-sectional units

---

[1] Higher carbon dioxide concentrations in the atmosphere under the climate change conditions could act like aerial fertilizers and boost the crop growth. This phenomenon is called carbon fertilization effect.

then the Ricardian approach can not (even in principle) fully account for adaptation.

While the Ricardian approach has the potential for addressing the adaptation satisfactorily, the issues concerning the cost of adaptation are not completely addressed. One of the main concerns of this approach is that it may confound climate with other unobserved factors. Recently, Deschenes and Greenstone (2005) and Schlenker and Roberts (2008) among others, have addressed this issue. Further, the constant relative prices assumption used in this approach could bias the estimates (see, Cline, 1996; Darwin, 1999; Quiggin and Horowitz, 1999 for a critique on this approach). For India, Kumar and Parikh (2001b) and Sanghi and Mendelsohn (2008) have used a variant of this approach and showed that a 2^oC temperature rise and seven percent increase in rainfall would lead to almost 10 percent loss in farm level net revenue (1990 net-revenue). The regional differences are significantly large with northern and central Indian districts along with coastal districts bearing relatively large impact. Mendelsohn *et al.* (2001) have compared climate sensitivity of the US, Brazilian and Indian agriculture using the estimates based on the Ricardian approach and have argued that using the US estimates for assessing climate change impacts on Indian agriculture would lead to under-estimation of impacts.

The results of the two broad approaches outlined above correspond to what could be termed as 'typical' and 'clairvoyant' farmer, respectively. While the estimates from agronomic-economic approach account for adaptation only in partial manner, the Ricardian approach treats farmer as though she has perfect foresight. In the Ricardian approach farmers are assumed to identify instantaneously and perfectly any change in climate, evaluate all associated changes in market conditions and then modify their actions to maximize profits. These assumptions also imply that agricultural system is ergodic – i.e., space and time are substitutable. Ergodic assumption imply, for example, that skills, institutional and financial endowments for responding to say, drought (that are typically refined in arid places) are assumed to be available for use by people in humid areas (where such resources are under-developed) immediately and in essentially cost-less manner. Further there is scope for inter-farmer communication and information diffusion. Both these factors motivate incorporation of spatial features in the Ricaridan analysis. There are other motivations for accounting for spatial autocorrelation in the Ricardian analysis. Scope for spatial autocorrelation of error terms could lead to inefficient estimation of the coefficients. Recent evidence from the US suggests that either way it is important to account for spatial autocorrelation to get accurate estimates of climate sensitivity of agriculture (Polsky, 2004; Schlenker *et al.*, 2006).

Similarly, careful analysis of the changing nature of climate sensitivity of Indian agriculture is important to understand the role of technology in ameliorating the climate change impacts. This paper attempts to incorporate these features into the Ricardian approach to assess the climate change impacts on Indian agriculture. These also form the objectives of the paper. The rest of the paper is structured as follows: The next section explains the model structure and data. The third section presents results and discusses the distributional issues of climate change impacts on Indian agriculture. The fourth section briefly discusses the lessons learned about inter-farmer communication through focus group meetings in Andhra Pradesh and Tamil Nadu. Finally, the last section concludes the paper.

2. MODEL SPECIFICATION AND DATA

While the original Ricardian approach developed by Mendelsohn *et al.* (1994) estimated relationship between land values and climate, due to non-existent and/or absence of well functioning land markets in the developing countries, a variant of Ricardian approach has been used in the earlier Indian studies (see, Dinar *et al.*, 1998). In place of land values, farm level net-revenue is used as welfare indicator and the value of the change in the environment is assessed through change in farm level net revenue. The Ricardian model is thus specified as follows:

$$\begin{aligned} NR \quad = \quad & f(T_j, T_j^2, R_j, R_j^2, T_j R_j, \, SOIL, BULLOCK, TRACTOR, \\ & POPDEN, LITPROP, CULTIV, HYV, IRR, ALT) \end{aligned} \qquad \ldots(1)$$

where, NR represents farm level net revenue per hectare in constant rupees; T and R represent temperature and rainfall respectively (subscript *j* denotes the season). It may be noted that based on the existing literature a quadratic functional specification is adopted along with climate interaction terms. The control variables include soil (captured through dummies representing several soil texture classes and top-soil depth classes; represented as SOIL in equation (1)), extent of mechanization (captured through number of bullocks and tractors per hectare; represented as BULLOCK and TRACTOR in equation (1)), percentage of literate population (LITPROP in equation (1)), population density (POPDEN in equation (1)), altitude (to account for solar radiation received; ALT in equation (1)), number of cultivators (since the cost of own labor could not be accounted for while calculating the dependent variable; CULTIV in equation (1)), fraction of area under irrigation and fraction of area under high-yielding variety seeds (IRR and HYV, respectively in equation (1)).

Cross-sectional data is used for estimating the above model. Districts are the lowest administrative unit at which reliable agricultural data is available in India. A comprehensive district level dataset of the period 1956 to 1999 is developed for the purpose of analysis. Agricultural data at district level is assembled in the dataset along with relevant demographic and macro economic data. This dataset expands an earlier dataset developed by the author along with two other researchers for the period 1956 to 1986 and used in Dinar *et al.* (1998). The dataset covers 271 districts defined as per 1961 census across thirteen major states of

India (Andhra Pradesh, Haryana, Madhya Pradesh, Maharashtra, Karnataka, Punjab, Tamil Nadu, Uttar Pradesh, Bihar, Gujarat, Rajasthan, Orissa and West Bengal).

The variables covered in the dataset include, gross and net cropped area; gross and net irrigated area; cultivators; agricultural laborers; cropped area under high-yielding variety seeds; total cropped area under five major crops (rice, wheat, maize, bajra and jowar) and fifteen minor crops (barley, gram, ragi, tur, potato, ground nut, tobacco, sesamum, ramseed, sugarcane, cotton, other pulses, jute, soybean, and sunflower); bullocks; tractors; literacy rate; population density; fertilizer consumption (N, P, K) and prices; agricultural wages; crop produce; farm harvest prices; soil texture and top soil depth. For the purpose of analysis farm level net revenue per hectare is defined as follows:

$$Net\ \mathrm{Re}venue\ per\ ha \;=\; \frac{\left\{(Gross\ \mathrm{Re}venue) - (Fertilizer\ and\ Labor\ Costs)\right\}}{Total\ Area} \qquad \text{...(2)}$$

where, gross revenue is calculated over twenty crops mentioned above, total area is the cropped area under the twenty crops, fertilizer costs are total yearly costs incurred towards use of fertilizer for all the crops and labor costs are yearly expenses towards hiring agricultural laborers. It may be noted that costs attributable to cultivators, irrigation, bullocks and tractors are not included in the net revenue calculations as appropriate prices are difficult to identify. However these variables are used as control variables in the model as specified in equation (1).

Unfortunately there is no ‘clean’ climate data available for the analysis. Meteorological data is typically collected at meteorological stations and any district may have one or many stations with in its boundary. Since all other data is attributable to a hypothetical centre of the district, the climate data should also be worked out at the centre of the district. For this purpose meteorological station data is interpolated to arrive at district specific climate (see, Kumar and Parikh, 2001b and Dinar *et al.*, 1998 for more details on the surface interpolation employed to generate district level climate data). Climate data corresponding to about 391 meteorological stations spread across India is used for the purpose of developing district level climate. The data on climate – at the meteorological stations and hence at the districts – corresponds to average of observed weather over the period 1951-1980 and is sourced from a recent publication of India Meteorological Department. All the climate variables are represented through four months – January, April, July and October, corresponding to the four seasons. The climate variables include daily mean temperature and monthly total rainfall.

For the purpose of analysis the dataset is divided into three distinct periods of almost equal length: 1956-1970; 1971-1985; 1986-1999. These periods roughly correspond to the pre-green revolution, green-revolution, and post-green revolution periods of Indian agriculture. Analysis over these three periods is expected to provide insight on changing nature of climate sensitivity of Indian agriculture over time. In each case the panel data is analyzed with year fixed effects[2]. Fixed and random year effects specification is tested through Hausman test in each case. In each time period, Hausman test rejected the null hypothesis, implying that the random effects model produces biased estimates. Hence, the fixed effects estimators are preferred. Further, since the units of analysis (i.e., districts) differ significantly in size and agricultural activities, the measurement errors might also substantially differ across districts. Hence the data for each unit of analysis is weighted by the total area under the twenty crops.

---

[2] It may be noted that district fixed effects are not considered as the climate data is invariant over time and hence such specification would knock out the climate coefficients.

2.1 Climate Sensitivity and Spatial Autocorrelation

As argued in the first section presence of spatial autocorrelation necessitates re-specification of model as either spatial lag or spatial error model as shown below:

Spatial error model: $\boldsymbol{y} = \boldsymbol{X}\beta + \eta$, where $\eta = \rho\boldsymbol{W}\eta + \varepsilon$ ...(3a)

Spatial lag model: $\boldsymbol{y} = \rho\boldsymbol{W}\boldsymbol{y} + \boldsymbol{X}\beta + \varepsilon$ ...(3b)

where, $\boldsymbol{y}$ is (nx1) vector of dependent variable observations, $\boldsymbol{X}$ is (nxm) matrix of observations on independent variables including the climate and other control variables, β is (mx1) regression coefficient vector, η is (nx1) vector of spatially correlated error terms, ρ is (1x1) the spatial autoregressive parameter, $\boldsymbol{W}$ is (nxn) spatial weights matrix, ε is (nx1) vector of random error terms. Note that $\boldsymbol{y}$ and $\boldsymbol{X}$ are respectively, the left hand and right hand side variables specified in equation (1) above. The period 1966-1986 is considered for the spatial analysis.

One of the crucial inputs needed for spatial analysis is the weight matrix W. While there are several ways to generate the weight matrix, the present analysis used rook contiguity based weight matrix generated for the Indian districts in GeoDa software[3]. Since it is not feasible to estimate the spatial fixed effects model in GeoDa, the weight matrix is transferred via R-software to ASCII data format. The spatial panel model is estimated using MATLAB software[4] for computational efficiency through the use of sparse matrices. Table 1 summarizes the details of various analyses carried out.

---

[3] Spatial econometric software developed by Prof. Luc Anselin of University of Illinois (version 0.9.5).

[4] The MATLAB codes for spatial panel analysis are written by J. Paul Elhorst (www.spatial-econometrics.com).

Table 1: Details of Various Analyses

Aim of the Analysis	Period(s) of Analysis	Model Specification	Estimation Procedure and Software Used
Explore changing nature of climate sensitivity over time	1956-1999 with sub-periods: 1956-1970; 1971-1985; 1986-1999	Equation (1)	Panel fixed (year) effects by weighting the observations; STATA 9.2
Explore influence of spatial autocorrelation on climate sensitivity	1966-1986	Equation (3a) and (3b)	Panel fixed (year) effects with correction for spatial autocorrelation; GeoDA; R; MATLAB 7

2.2 Climate Change Projections for India

The climate change projections for India used for the analysis are those reported in Cline (2007). The climate change projections are average of predictions of six general circulation models including HadCM3, CSIRO-Mk2, CGCM2, GFDL-R30, CCSR/NIES, and ECHAM4/OPYC3. Table 2 shows the region-wise and season-wise temperature and rainfall changes for the period 2070-2099 with reference to the base period 1960-1990. From these regional projections, state-wise climate change predictions are assessed by comparing the latitude-longitude ranges of the regions with those of the states. Besides this India specific climate change scenario, the impacts are also assessed for two illustrative uniform climate change scenarios (+2^{o}C temperature change along with +7 percent precipitation change; and +3.5^{o}C temperature change along with +14 percent precipitation change) that embrace the aggregate changes outlined in the fourth assessment report of IPCC (Solomon, 2007).

Table 2: Projected Changes in Climate in India : 2070-2099

Region	Jan.-March	April-June	July-Sep.	Oct.-Dec.
Temperature Change (^{o}C)				
Northeast	4.95	4.11	2.88	4.05
Northwest	4.53	4.25	2.96	4.16
Southeast	4.16	3.21	2.53	3.29
Southwest	3.74	3.07	2.52	3.04
Precipitation Change (%)				
Northeast	-9.3	20.3	21.0	7.5
Northwest	7.2	7.1	27.2	57.0
Southeast	-32.9	29.7	10.9	0.7
Southwest	22.3	32.3	8.8	8.5

Source: Cline (2007).

3. RESULTS

The results are reported in two sub-sections: in the first sub-section the changing nature of climate response function over time is presented along with estimates of climate change impacts. The second sub-section reports the results based on spatial analysis along with the estimates of climate change impacts with and without the correction for spatial autocorrelation.

3.1 Climate Sensitivity of Indian Agriculture over Time

Equation (1) is estimated using the pooled data over the period 1956-1999 by separating out climate coefficients for three distinct periods: 1956-1970, 1971-1985, and 1986-1999. Year effects are included in the estimation. Hausman test favored fixed effects specification against the random effects.

Table 3: Climate Response Function over Time

	1956-1970		1971-1985		1986-1999	
Variable	**Coefficient**	**p-value**	**Coefficient**	**p-value**	**Coefficient**	**p-value**
Climate Variables						
Jan-T	-449.9	0.000	-327.5	0.001	-399.9	0.000
Apr-T	-26.2	0.809	-855.2	0.000	-985.8	0.000
Jul-T	-737.5	0.000	-838.7	0.000	-763.3	0.000
Oct-T	1603.6	0.000	2158.3	0.000	2624.2	0.000
Jan-P	17.1	0.189	39.9	0.001	122.5	0.000
Apr-P	-8.1	0.038	-19.5	0.000	-16.7	0.000
Jul-P	-0.3	0.755	-2.9	0.000	1.0	0.194
Oct-P	25.9	0.000	26.7	0.000	12.5	0.002
Jan-T-sq	-6.2	0.702	-49.9	0.001	26.6	0.111
Apr-T-sq	-15.2	0.605	150.2	0.000	50.1	0.049
Jul-T-sq	-157.3	0.007	-88.4	0.109	-350.6	0.000
Oct-T-sq	-154.4	0.000	-269.8	0.000	-321.1	0.000
Jan-P-sq	-0.7	0.069	-3.0	0.000	-3.1	0.000
Apr-P-sq	0.1	0.003	0.2	0.000	0.2	0.000
Jul-P-sq	0.004	0.016	0.002	0.276	0.003	0.034
Oct-P-sq	-0.01	0.686	0.05	0.161	-0.07	0.049
Jan-TP	-21.7	0.000	-34.6	0.000	-20.2	0.000
Apr-TP	8.0	0.000	16.6	0.000	15.8	0.000
Jul-TP	-1.3	0.022	-1.9	0.000	-2.07	0.000
Oct-TP	1.2	0.546	-3.2	0.074	-6.1	0.001
Control Variables						
Cultivators /ha	336.7	0.263	435.8	0.068	587.3	0.009
Bullocks/ha	958.3	0.009	-200.0	0.484	-727.1	0.006
Tractors/ha	676432.5	0.000	152806.9	0.000	88268.5	0.000
Literacy	124.0	0.873	2829.2	0.000	3326.2	0.000
Pop. Density	376.7	0.000	217.1	0.000	47.4	0.019
Irrigation %	4442.8	0.000	2178.5	0.000	2091.5	0.000
No. of Obs.	11924					
Adj R^2	0.5398					

Table 3 shows the estimates of climate coefficients along with important control variables for the three time periods. The dependent variable in each case is net revenue per hectare expressed in constant 1999-2000 prices. The control variables are all significant in all the three periods and have expected sign. Barring a very few exceptions, in all the three periods the climate coefficients are all significant and the F-tests for joint significance of climate coefficients in each period rejected the null-hypothesis. As mentioned in the previous section, it is not feasible to introduce district fixed effects as some of the independent variables, including climate variables, are invariant across the cross-sectional units. Some recent studies (Deschenes and Greenstone, 2005, and Schlenker and Roberts, 2008) have introduced regional fixed effects in the Ricardian model arguing that it would be appropriate under the possibility of unobserved variables. In such case climate variables are replaced by weather (or, deviations of weather from climate) in equation (1). However, such specification may only provide estimate of weather shocks on agriculture instead of impact of climate on agriculture. Given the overall objective of assessing climate change impacts on agriculture, the present analysis avoided district fixed effects specification even though it is tempting to use such specification purely for econometric reasons.

Inclusion of interaction terms makes it difficult to interpret the marginal effects of temperature and precipitation. To gain insight about the impact of various climate change scenarios and variability in the impacts based on climate response functions that correspond to different time periods, the climate change impacts are estimated. The climate change induced impacts are measured through changes in net revenue triggered by the changes in the climate variables. The impacts are estimated for each year at individual district level and are then aggregated to derive the national level impacts. Average impacts over all the years are reported in Table 4. The table reports the all India level impacts estimated in each time period as percentage of 1990 all India net revenue expressed in 1999-2000 prices. Comparison with 1990 net revenue is considered mainly to accommodate comparison with previous results reported in the literature. The impacts are interpreted as change in 1990 net-revenue if the future climate changes were to be imposed on 1990 economy. As could be seen the impacts (based on the illustrative uniform scenarios) are increasing over time indicating increasing climate sensitivity of Indian agriculture. This is despite the possible advances made through technology adoption and overall development. Significantly higher impacts reported in the period from mid-eighties to late nineties. This finding corroborates the growing evidence of weakening agricultural productivity over the similar period in India. The impacts estimated using India specific climate projections show that impacts decline in period 1971-1985 and again increase in the last period. The decline in the middle period could possibly be due to improved resilience of Indian agriculture during this period and also due to the regional variation in the climate projections.

Table 4: Climate Change Impacts Over Time

Scenario	1956-1970		1971-1985		1986-1999	
	Impacts	**% of 1990 Net Revenue**	**Impacts**	**% of 1990 Net Revenue**	**Impacts**	**% of 1990 Net Revenue**
+2°C/7%	-53.7	-6.1	-76.8	-8.7	-188.7	-21.3
+3.5°C/14%	-297.4	-33.6	-303.4	-34.3	-754.9	-85.3
India Specific CC Scenario	-219.6	-24.8	-153.6	-17.4	-544.4	-61.5

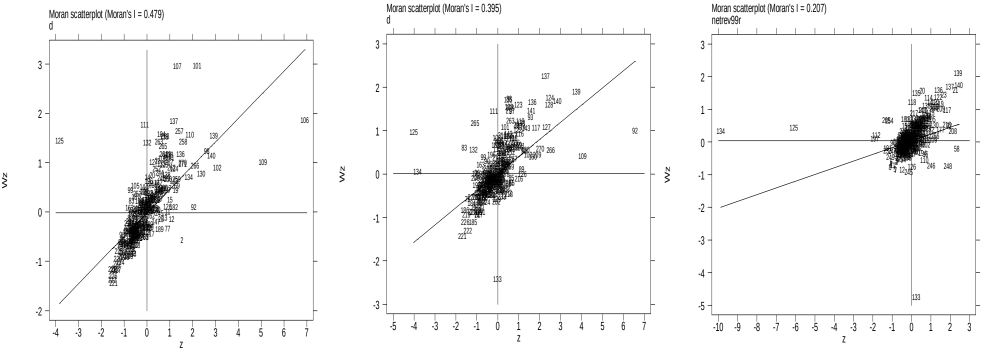
Note: Impacts are in billion rupees, 1999-2000 prices: Net revenue in India in 1990 in Rs. 885 billion (1990-2000 prices). The first two scenarios use hypothetical increases in temperature and precipitation, in degree centigrade and percentage, respectively.

3.2 Effect of Spatial Autocorrelation on Climate Sensitivity

The spatial clustering of the dependent variable (i.e., net revenue per hectare) is analyzed by constructing Moran scatter plots for several time points in the period 1956-1999. Figure 1 shows the scatter plots along with the Moran's I value. The scatter plot is graph of Wy versus y, where W is a row-standardized spatial weight matrix and y = [(net revenue –

mean net revenue)/standard deviation of net revenue]. Clustering of values in the upper right quadrant and lower left quadrant represents significant positive spatial autocorrelation. As could be seen from Figure 1 in all the three periods for which the scatter plots are reported the dependent variable exhibited significant positive spatial autocorrelation.

Figure 1: Spatial Autocorrelation – Moran Scatter Plots of Net Revenue



1960: Moran's I = 0.479 1980: Moran's I = 0.395 1995: Moran's I = 0.207

Indication of significant spatial clustering given by the spatial autocorrelation statistic represents only the first step in the analysis of spatial data. Two typically considered specifications for modeling spatial dependence are: spatial error and spatial lag model. These models specified in equations (3a) and (3b) are estimated for the period 1966-1986. Table 5 shows the climate response functions estimated with and without consideration of spatial autocorrelation.

Table 5: Effect of Spatial Autocorrelation on Climate Sensitivity

Variable	Without Spatial Autocorrelation		With Spatial Autocorrelation			
			Spatial Lag Model		Spatial Error Model	
	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Climate Variables						
Jan-T	-443.3	0.000	-394.8	0.000	-395.3	0.000
Apr-T	-695.6	0.000	-537.1	0.000	-668.5	0.000
Jul-T	-817.9	0.000	-575.3	0.000	-809.3	0.000
Oct-T	2160.4	0.000	1833.0	0.000	1709.1	0.000
Jan-P	38.5	0.000	13.6	0.106	-7.3	0.448
Apr-P	-17.2	0.000	-14.6	0.000	-7.8	0.004
Jul-P	-2.2	0.000	-1.3	0.027	-2.5	0.000
Oct-P	29.5	0.000	20.8	0.000	18.4	0.000
Jan-T-sq	-43.8	0.000	-24.1	0.033	-11.4	0.332
Apr-T-sq	118.4	0.000	101.9	0.000	139.0	0.000
Jul-T-sq	-96.9	0.014	-25.6	0.524	117.7	0.006
Oct-T-sq	-264.0	0.000	-234.0	0.000	-236.3	0.000
Jan-P-sq	-2.8	0.000	-2.6	0.000	-1.9	0.000
Apr-P-sq	0.2	0.000	0.2	0.000	0.1	0.000
Jul-P-sq	0.004	0.001	0.005	0.000	0.002	0.039
Oct-P-sq	0.03	0.232	0.1	0.000	0.066	0.019
Jan-TP	-36.3	0.000	-38.5	0.000	-26.8	0.000
Apr-TP	15.8	0.000	15.2	0.000	10.4	0.000
Jul-TP	-1.5	0.000	-0.7	0.071	-0.4	0.346
Oct-TP	-2.9	0.024	-4.1	0.001	1.8	0.192
Control Variables						
Cultivators/ha	253.4	0.119	163.1	0.331	758.5	0.000
Bullocks/ha	103.03	0.615	558.5	0.009	1105.6	0.000
Tractors/ha	147348.7	0.000	63282.8	0.000	67539.0	0.000
Literacy	2429.3	0.000	4039.1	0.000	3160.2	0.000
Pop. Density	179.0	0.000	174.5	0.000	182.1	0.000
Irrigation %	2669.5	0.000	2648.4	0.000	3538.1	0.000
Spatial Lag/Spat. Auto.			0.1	0.000	0.6	0.000
No. of Obs.	5691		5691		5691	
Adj. R^2	0.7		0.7		0.7	

All the estimates are based on fixed (year) effects specification in the pooled data and observations are weighted by the total area under all the crops considered in the analysis. Barring a few exceptions, the climate coefficients in the models that accounts for spatial autocorrelation (either through spatial lag or spatial error models) are uniformly lower than that ignores the presence of spatial autocorrelation indicating the true climate change impacts to be lower. This is confirmed by the climate change impacts reported in table 6. The overall impacts estimated (for same climate change scenario) using climate coefficients obtained from model that accounts for spatial autocorrelation are significantly lower than those obtained from model that ignores the spatial effects. Figures 2 compare the distribution of climate change impacts at the district level between the model accounts for spatial autocorrelation and that does not[5].

Table 6: Climate Change Impacts – Without and With Spatial Autocorrelation

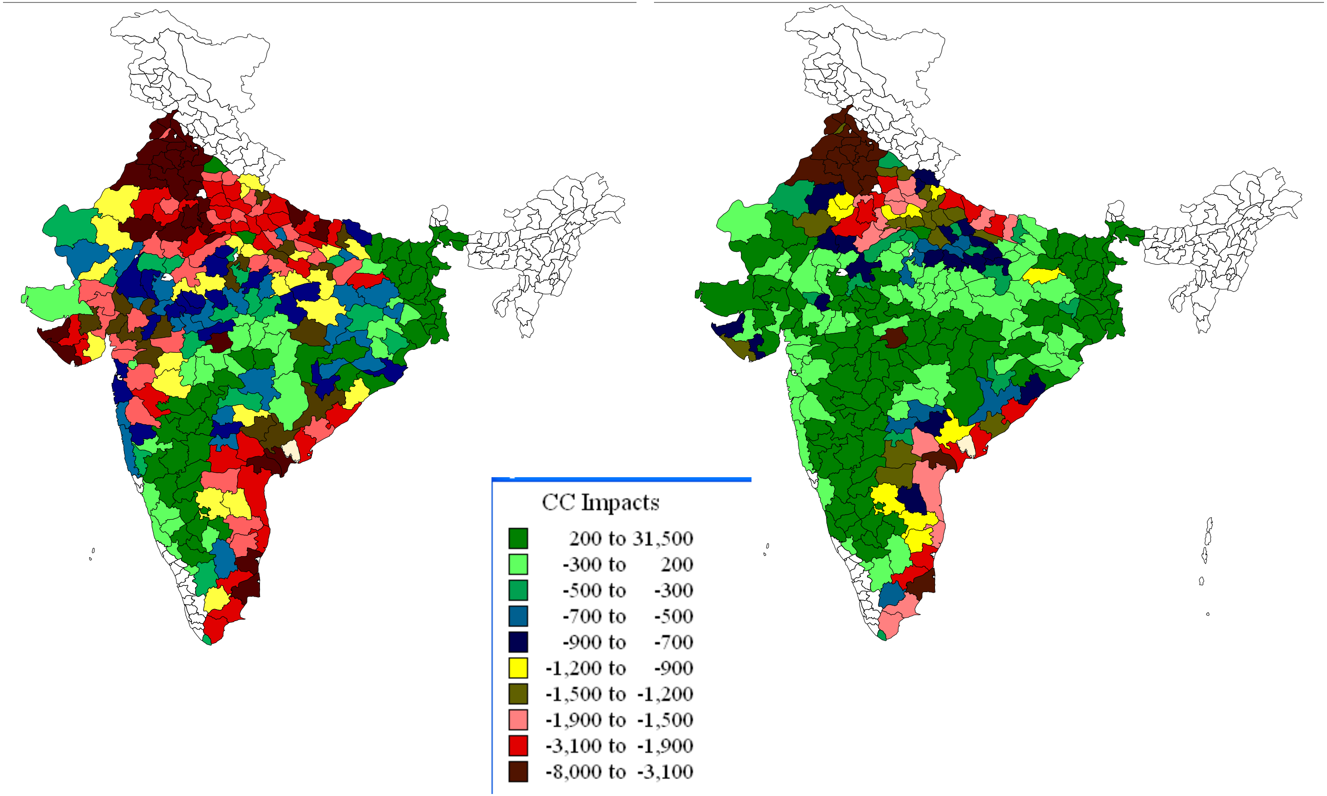
Scenario	Without Spatial Autocorrelation		With Spatial Autocorrelation			
			Spatial Lag Model		Spatial Error Model	
	Impacts	% of 1990 Net Revenue	Impacts	% of 1990 Net Revenue	Impacts	% of 1990 Net Revenue
+2^{o}C/7%	-81.2	-9.17	14.2	1.6	-22.9	-2.6
India Specific CC Scenario	-195.1	-22.1	43.4	4.9	-2.1	-0.23

Note: Impacts are in billion rupees, 1999-2000 prices: Net revenue in India in 1990 is Rs. 885 billion (1999-2000 prices).

---

[5] Only spatial lag model results are reported for the purpose of comparison.

Figure 2. Distribution of Climate Change Impacts across Districts – Without and With Spatial Autocorrelation



4. EVIDENCE ON INTER-FARMER COMMUNICATION

As observed in the previous section consideration of spatial effects has contributed to positive spin-offs in terms of reduced climate change impacts. For designing enabling policy responses, it is important to explore factors contributing towards such spatial effects. Hypothesizing that inter-farmer communication could among other factors be responsible for spatial autocorrelation, an attempt has been made to understand the scope and extent of information exchange between farmers through focus group meetings held at six villages each in Tamil Nadu and Andhra Pradesh[1]. The focus group meetings mainly explored the perceptions of the villagers about the climate change and their views on strategies helpful in ameliorating the climate change impacts. Among other things, special attention is paid to the channels through which information diffusion takes place.

The field level analysis showed that while most farmers are familiar with the term climate change, their understanding is often overlapping with other phenomenon. All climate/natural patterns are perceived as climate change with little and/or no distinction between future climate change and preset day climate concerns (that manifest in the form of climate extremes like droughts, floods and cyclones, and

---

[1] The focus group discussions are attempted only to gather preliminary insights about the information exchange between several groups of farmers and by no means these modest number of focus group discussions are claimed to reflect the reality in the varied agricultural systems that are practiced in India. The field studies are carried out during the months of March-April 2008 with the help of local NGOs. In Tamil Nadu the villages covered include Manampathy, Thevoor, Kumaramangalam, Echur, Arungunram, and Thirunilai. In Andhra Pradesh Kothapatnam, Nidavanur, Kuchipudi, Nilayeepalem, Chinagangam villages are covered for the focus group discussions. Further, given the small number of discussions, no attempt has been made to quantify the findings.

abnormal weather patterns like un-seasonal rainfall etc.). However, there is a consensus in most discussions that anthropogenic activities leading to excess pollution are often responsible for the abnormal weather.

Most farmers also consider climate/weather concerns to be more threatening than other risks, such as price changes. The reasons cited for such perceptions include, bigger scale of impact that climate/weather risks may cause, and limited scope for adaptation. Such perceptions are uniformly held by small, medium and large farmers.

Almost all focus group meetings indicated that there is dearth of information. Farmers irrespective of size are in search of information – which could include advice on input use, pest control, agronomic practices, and soil and water conservation practices. Among the various sources through which information diffusion takes place, most focus group discussions ranked large farmers in the neighborhood as the primary source. Not surprisingly, the agricultural extension services offered by the government are not seen as appropriate source of information, mainly due to the manner in which the extension services provide information. While the information needs are different across farmers based on their scale of operation and kind of crops cultivated, the agricultural extension services often package the information in uniform manner as though one size fits all. Similarly, the usual information diffusion sources such as television and radio also appear to be less effective in reaching out, partly because these sources are often seen as entertainment sources rather than information channels. Discussion in several focus group meetings revealed that farmers often depend on fertilizer and pesticide dealers for information on new varieties and new agricultural practices. While this source has appropriate self regulated checks against provision of wrong information, it is important to ensure that incorrect information does not reach the farmers even inadvertently. Most importantly these sources provide information in a case-by-case manner that suits most farmers.

New information does not often reach agricultural laborers. Given the large size of this group and the important role it plays in determining agricultural productivity, it is important to ensure that this group is also targeted along with farmers in providing information on agricultural practices. Similarly, the information diffusion must take place to reach female farmers also alongside their male counterparts, which appeared to be lacking presently based on the evidence from the focus group discussions with the female farmers. There is two-tier structure for the information flow with the male farmers receiving it first and the female farmers learning through their male counterparts. Perhaps this is due to larger social prejudices and needs immediate attention.

The field studies also revealed that new sources of information diffusion should be explored and experimented. Given the fragmented nature of Indian agricultural lands, large scale participation of corporate sector in providing agricultural extension services could be difficult, and hence other options must be explored. Among other things, the farmers favored participation of agricultural cooperatives, NGOs, and dealers of inputs and fertilizers in information diffusion. In this context, other country experiences should also be carefully studied to identify the routes through which the agricultural extension services could be provided to the farmers. For instance, in Ecuador the agricultural extension workers operate in tandem with the farmers through share cropping to ensure proper information diffusion. On the other hand, Chile finances the costs of private sector firms transferring the technology know-how and information on new agricultural practices to small scale farmers.

5. CONCLUSIONS

The evidence presented in this paper suggests that (a) climate change impacts are increasing over time indicating the increasing climate sensitivity of Indian agriculture; and (b) accounting for spatial autocorrelation is important due to the presence of significant spatial clustering of the data; further, the climate change impacts are significantly lower after incorporating spatial effects in the model specification. The positive spatial effects could be due to the presence of numerous communication channels between the 'better-off' and 'not-so-better-off' farmers. Of course the information flow could also be in the opposite direction. To exploit the presence of information flows between the farmers, adaptation strategies through policy intervention can be thought out to improve such channels. A crucial issue that should be addressed in the context of adaptation is – how to adapt and adapt to what.

The impact assessment literature mainly focused on what could be termed as engineering/technological adaptation options. One measure of the potential and cost of adaptation is to consider the historical record of past speeds of adoption of new technologies. For example, Reilly and Schimmelpfenng (1999) show the relative speed of adoption of various adaptation measures. While the time taken for relatively soft adaptation measures such as variety adoption and fertilizer adoption could be in the range of 3 to 10 years, the hard options like development of irrigation equipment and irrigation systems take much longer time. Jodha (1989) also provides similar estimates based on evidence from post-independent India. These adjustment times indicate that for effective implementation of adaptation strategies appropriate planning must start well before the manifestation of climate change. Also, soft options could be more cost effective and hence should be explored first. Often the soft options (which include enhancing the information flows mentioned above) may provide dual advantage of gearing up for the future climate change as well as providing benefits under the present-day conditions.

This leads the discussion to the next issue: adapt to what? This has significant policy relevance in the ongoing discussion on ‘mainstreaming’ the climate policies. For vast majority of developing countries (including India) climate change is a distant and invisible threat whereas they are presently exposed to a range of stresses (including climate related shocks such as cyclones, droughts and floods). If climate change response strategies were to be embraced by these countries it is imperative that such response strategies are aligned with development agenda. Also, the local population should feel that the adaptation is relevant and in their own interest. It is unrealistic to expect special policy initiatives to deal with climate change adaptation by itself, especially when so many of the suggested adaptation measures (such as drought planning, coastal zone management, early warning etc.) are currently being addressed in other policies and programs.

Underlying this is the implicit assumption that adaptation strategies geared to cope with large climate anomalies that society faces currently embrace a large proportion of the envelope of adjustments expected under long-term climate change. In other words the climate policies (at least in the local context) need not be something different from the development policies. However, this need not be interpreted as nullification of need for research on climate change specific adaptation options. On the contrary the two should be seen as complimentary to each other.

REFERENCES

Cline, W.R. (1996), "The Impact of Global Warming on Agriculture: Comment" *American Economic Review*, 86(5): 1309-11.

Cline, W. (2007), *Global Warming and Agriculture: Impact Estimates by Country,* Washington D.C., Peterson Institute.

Darwin, R. (1999), "The Impact of Global Warming on Agriculture: A Ricardian Analysis: Comment", *American Economic Review*, 89(4): 1049-52.

Deschenes, O. and M. Greenstone (2007), "The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather", *American Economic Review*, 97(1): 354-385.

Dinar, A., R. Mendelsohn, R. Evenson, J. Parikh, A. Sanghi, K. Kumar, J. McKinsey, and S. Lonergan (1998), "Measuring the Imapct of Climate Change on Indian Agriculture", Technical Paper 402, World Bank, Washington, D.C.

Jodha, N.S. (1989), "Potential Strategies for Adapting to Greenhouse Warming: Perspectives from the Developing World", In Rosenberg, N.J., W.E. Easterling, P.R. Crosson, and J. Darmstadter (eds.). *Greenhouse Warming: Abatement and Adaptation.* Washington D.C.: Resources for the Future.

Kumar, K.S. Kavi, and J. Parikh (2001a), "Socio-economic Impacts of Climate Change on Indian Agriculture", *International Review of Environmental Strategies,* 2(2): 277-293.

Kumar, K.S. Kavi, and J. Parikh (2001b), "Indian Agriculture and Climate Sensitivity", *Global Environmental Change,* 11(2): 147-154.

Mall, R.K., R. Singh, A. Gupta, G. Srinivasan, and L.S. Rathore (2006), "Impact of Climate Change on Indian Agriculture: A Review", *Climatic Change,* 78: 445-478.

Mendelsohn, R., A. Dinar, and A. Sanghi (2001), "The Effect of Development on the Climate Sensitivity of Agriculture", *Environment and Development Economics,* 6(1): 85-101.

Mendelsohn, R., W. Nordhaus, and D. Shaw (1994), "The Impact of Global Warming on Agriculture: A Ricardian Analysis", *American Economic Review*, 84(4): 753-71.

Polsky, C. (2004), "Putting space and time in Ricardian climate change impact studies: Agriculture in the US Great Plains, 1969-1992", *Annals of the Association of American Geographers,* 94(3): 549-564.

Quiggin, J. and J. K. Horowitz (1999), "The Impact of Global Warming on Agriculture: A Ricardian Analysis: Comment", *American Economic Review*, 89(4): 1044-45.

Reilly, J.M. and D. Schimmelpfennig (1999), "Agricultural Impact Assessment, Vulnerability, and the Scope for Adaptation", *Climatic Change,* 43: 745-788.

Sanghi, A. and R. Mendelsohn (2008), "The Impacts of Global Warming on Farmers in Brazil and India", *Global Environmental Change,* 18: 655-665.

Schlenker, W., W.M. Hanemann and A.C. Fisher (2005), "Will US agriculture really benefit from global warming? Accounting for irrigation in the Hedonic approach", *American Economic Review,* 95(1): 395-406.

Schlenker, W. and M. Roberts (2008), *Estimating the Impact of Climate Change on Crop Yields: The Importance of Non-linear Temperature Effects,* Working Paper 13799. Cambridge: National Bureau of Economic Research.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller, *eds.* (2007), *Climate Change 2007: The Physical Science Basis,* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.

Stern, N. (2006), *The Economics of Climate Change: The Stern Review*, Cambridge: Cambridge University Press.

World Bank (2008), *Climate Change Impacts in Drought and Flood Affected Areas: Case Studies in India,* Report No. 43946-IN; New Delhi: India Country Management Unit.

MSE Monographs

Monograph 1/2006
A Tract on Reform of Federal Fiscal Relations in India
Raja J. Chelliah

Monograph 2/2006
Employment and Growth
C. Rangarajan

Monograph 3/2006
The Importance of Being Earnest about Fiscal Responsibility
C. Rangarajan and Duvvuri Subbarao

Monograph 4/2007
The Reserve Bank and The State Governments: Partners in Progress
Y.V.Reddy

Monograph 5/2008
India's Dilemmas: The Political Economy of Policy-Making in a Globalized World
Kaushik Basu

MSE Working Papers

Recent Issues

$ Working Paper 34/2008
Customer Relationship Management (Crm) to Avoid Cannibalization: Analysis Through Spend Intensity Model
Saumitra N Bhaduri, Avanti George and David J Fogarty

* Working Paper 35/2008
Innovation in India and China: Challenges and Prospects in Pharmaceuticals and Biotechnology
Jayan Jose Thomas

* Working Paper 36/2008
An Analysis of Life Insurance Demand Determinants for Selected Asian Economies and India
Subir Sen

* Working Paper 37/2008
The Impact of R&D and Foreign Direct Investment on Firm Growth in Emerging-Developing Countries: Evidence rom Indian Manufacturing Industries
Adamos Adamou and Subash S

* Working Paper 38/2008
Stock Returns-Inflation Relation in India
K.R. Shanmugam and Biswa Swarup Misra

* Working Paper 39/2009
Designing Fiscal Transfers: A Normative Approach
K.R. Shanmugam and D.K. Srivastava

* Working Paper 40/2009
Determining General and Specific Purpose Transfers: An Integrated Approach
Richa Saraf and D.K. Srivastava

* Working Paper 41/2009
Socio-Economic Characteristics of the Tall and Not So Tall Women of India
Brinda Viswanathan and Viney Sharma

* Working Paper 42/2009
Inter-State Imbalances in Essential Services: Some Perspectives
C. Bhujanga Rao and D.K. Srivastava

* Working Paper 44/2009
Finance Commission and The Southern States: Overview of Issues
D.K.Srivastava (forthcoming)

---

* Working papers are downloadable from MSE website http://www.mse.ac.in
$ Restricted circulation