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How can weather affect crop area diversity? Panel data evidence from Andhra Pradesh, a rice growing state of India

This study analyses the temporal as well as the spatial shift in cropping pattern in Andhra Pradesh during the period from 1971 to 2009. The temporal associations between crop diversity, weather and economic variables have been examined to understand adaptation dynamics by means of cropping pattern shift. We find a significant impact of *rabi* (winter) season temperature and *kharif* (summer) season rainfall on cropping diversity. Along with mean weather, annual rainfall distribution has a significant, positive influence on crop diversity. The intra-seasonal distribution of dry days during *rabi* and *kharif* has a heterogeneous impact on crop diversity in districts of Andhra Pradesh. Within the state, geographical redistribution of rice area over the years can be considered as adaptation to climatic risk; however, sustainability of the emerging cropping pattern is under question due to a declining share of dry land crops during the study period. Drawing from the results, improving cropping intensity, increasing use of technology inputs and employing a season-wise incentive policy can be useful measures for sustainable diversification of the crop sector in the state.

Keywords: climate change, adaptation

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Introduction

Adaptation of the agriculture sector to climate change is increasingly becoming a major developmental challenge. For meaningful adaptation intervention and mainstreaming adaptation with broader developmental goals, an enquiry into farmers' decision making is essential. With adaptation in mind, the number of studies analysing the decision making of farmers, both individual as well as collective, has grown manifold in past years (see, for instance, Bradshaw *et al*., 2004; Howden *et al*., 2007; Kurukulasuriya and Mendelsohn, 2008; Seo *et al*., 2008; Howe *et al*., 2014; Jain *et al*., 2015). *Agricultural diversification*, be it increasing the variety of production locations, crops, enterprises or income sources, is considered as a potential response to a variety of risks. In the case of climate change adaptation, *crop switching* has been considered as a major long-term response to minimise climate change impact on agriculture (Mendelsohn *et al*., 1994).[1] However, crop switching is a long-term phenomenon and can be best understood in terms of incremental shifts in the areas of a few crops which eventually transform the historical trends in *crop diversification/specialisation* (see Kates *et al*., 2012). In the context of developing countries, agricultural diversification is of critical importance not only for ensuring the economic well-being of the rural population but also for sustainability. From a policymaker's perspective, understanding climate impacts on agricultural diversification, in general, and on crop diversity, in particular, is essential to identify useful adaptation interventions (Figure 1).

Economic theory suggests that if farmers in a region detect climate trends correctly amid the noise of climate variability and they also have full knowledge regarding the climatic requirements of different crops, the cropping pattern must shift towards those crops which are more remunerative under changed climatic conditions (Zilberman *et al*., 2004; Burke and Lobell, 2010). In other words, if temperature is increasing then farmers will eventually shift farmed land

towards heat tolerant and less water-intensive crops to cut the cost or revenue loss. However, climate-induced shift in cropping patterns may be a slow process due to lack of economic, institutional and policy incentives needed for adaptation (Adger *et al*., 2009; Zilberman *et al*., 2012). Additionally, the direction of weather-induced change in regional cropping pattern cannot be predicted, *a priori*. For example, a region which was diversifying earlier may begin specialising towards less water-intensive and heat-tolerant crops due to rising temperature. On the contrary, crop diversification may increase due to rising temperature in a region which was earlier specialising in production of water-intensive or heat-sensitive crops. Therefore, a test of temporal association between weather conditions and crop diversification is required to understand climate change adaptation by means of cropping pattern change. Having this objective in mind, this study analyses the relationship between crop diversity and weather in Andhra Pradesh, India.

India has been seeking to adapt its diverse agriculture sector to climate change. Within India, the coastal state of Andhra Pradesh is especially exposed to various climatic hazards such as drought, flood and wind (Kumar *et al*., 2006). While coastal districts of Andhra Pradesh are well endowed in terms of monsoon rainfall and irrigation, southern districts are rainfall scarce and face frequent drought incidents (WB, 2006). While farmers in Andhra Pradesh grow multiple crops due to its diverse agro-climatic characteristics, cropping pattern in the state is strongly biased toward rice. Rice contributes 77 per cent of total food grain production which amounts to 12 per cent of state Gross Domestic Product (MoA, 2003). Cotton, groundnut and maize are other important crops in the state. All the major crops in Andhra Pradesh can be harvested across the seasons: *kharif*, which is the main cultivation season during the summer, and *rabi*, which is the secondary winter cultivation season.[2] Since monsoon rainfall distribution across the state is very diverse, we have taken special care to model the impact of rainfall on crop diversity. Econometric results are juxtaposed against the

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[1]   While crop switching may be a possibility from a developed country's perspective; it seems unrealistic in a developing country's framework where subsistence farming coexists with a capitalist mode of farming.

[2]   The crop calendar is available at http://eands.dacnet.nic.in/Advance_Estimate-2010.htm.

observed changes in the cropping pattern to explore future adaptation possibilities.

Background

Increasing supply of agricultural infrastructure and institutional support to ensure effective input supply, market expansion and diversification expands a farmer's choice set and eases constraints on adaptation to climate change (Kates *et al*., 2012; Banerjee *et al*., 2013; Jain *et al*., 2015). A society's adaptation efforts are closely linked with the economic growth and basic development indicators such as income, education and quality of institutions (Bowen *et al*., 2012). For example, Dell *et al*. (2009) have shown that increasing temperature has a more harmful impact on agriculturally dominated, least developed countries which possess poor physical and institutional infrastructure. Diversification of agriculture is an endogenous process and is closely associated with the structural transformation of an economy and economic growth (Pingali and Rosegrant, 1995). Earlier studies explored the nature and pattern of agricultural diversification across various regions and highlighted the role of various economic factors in explaining agriculture diversification. For example, Lichtenberg (1989) empirically tested a theoretical construct to show that technological innovations put significant impact on cropping pattern by affecting farmers' area allocation decisions. Ali (2004) provided an overview of agricultural diversification and international competitiveness of Asian countries and highlighted the need for improved infrastructure, technological progress and market reforms. Joshi *et al*. (2004), in an attempt to identify drivers of diversification towards the horticulture and livestock subsectors in South Asian countries, observed that urbanisation, roads and markets are major factors explaining diversification in these countries. Kurosaki (2003) highlighted the importance of markets in explaining crop specialisation in the Punjab region of south Asia. Singh *et al*. (2006) examined crop diversification of Indian provinces for two years (1991 and 2001) and concluded that risk mitigation was the driving force to explain diversification towards non-food crops in Indian states. The findings of this study also inferred that increasing supply of physical infrastructure (roads, irrigation and electricity) was a major factor explaining crop specialisation in Indian states. Rao *et al*. (2006) analysed agriculture diversification using district level data from India and concluded that urbanisation and dominance of smallholders were major determinants of agricultural diversification in post-liberalisation India.

Most of the earlier studies analysing agricultural diversification assumed climatic factors as fixed (for example, see Joshi *et al*., 2004) but this assumption is too restrictive. However, emerging adaptation literature provides enough evidence to show that farmers pursue various forms of diversification strategies depending on weather perception and resource availability. For instance, Kurukulasurya *et al*. (2008) and Seo *et al*. (2008) used farm level data from African countries to show that farmers account for weather conditions while making crop selection decisions. Fleischer *et al*. (2011) used survey data from Israeli farms to show

that farmers adapt to different climatic conditions by choosing a bundle of crops and associated technologies. It was argued that the use of technological bundles instead of a single technology or crop allows more control of climate and other physical impacts. In a study based on a survey of farmers in semi-arid tropical regions of India, Jain *et al*. (2015) observed that investments such as installation of tube wells which were made to reduce weather risks have worked to increase land devoted to risky but remunerative crops. Vijaysarathi and Ashok (2015) surveyed farmers in Tamil Nadu, India to examine the determinants of climate adaptation and to measure the impact of climate adaptation measures on technical efficiency of agriculture and found that climatic factors significantly explain probability of cropping pattern change. This study also points out that awareness regarding climate change increases probability of cropping pattern change. In a study to show the process of farmers' adaptation in the context of multiple exposure in Akita Prefecture, an apple producing region of Japan that has shifted to peach farming, Fujisawa and Kobayashi (2013) observed that spontaneous change in cropping pattern took place due to interregional communication among farmers.

Methodology

Data

The data used in this study come from two sources. Information on yearly crop area, net cultivated area, gross cultivated area, area under high yielding variety (HYV) seeds, and irrigation come from the Village Dynamics in South Asia (VDSA) database of the International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, India. ICRISAT also provides data on agriculture labourers and cultivators[3]; however, information on these factors is available only at decadal intervals. Gaps in census data are filled by using a linear interpolation method. Daily gridded rainfall and temperature, interpolated at the district level, are extracted from the National Innovations on Climate Resilient Agriculture website (http://www.nicra-icar.in). While agricultural data are available for longer periods, we consider the longest time span from 1971 to 2007 for econometric analysis for which climate data are available. Additionally, district boundaries in the ICRISAT database are defined according to the 1967 status and data of newly-formed districts were given back to the parent district, leaving only 20 districts in the ICRISAT dataset. Of the 20 districts in Andhra Pradesh which existed before 1967, three new districts, Vijiyanagaram, Rangareddy and Prakasam, have been carved out to increase the number of districts in the state 23. To remove this discrepancy in the two datasets, we use the parent district's climate distribution as a proxy of the undivided district's climate.

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[3]   For purposes of the census in India a person is classified as 'cultivator' if he or she is engaged in cultivation of land owned or held from the Government or held from private persons or institutions for payment in money, kind or share. Cultivation includes effective supervision or direction in cultivation. A person who has given out her/his land to another person or persons or institution(s) for cultivation for money, kind or share of crop and who does not even supervise or direct cultivation of land is not treated as cultivator. Similarly, a person working on another person's land for wages in cash or kind or a combination of both (agricultural labourer) is not treated as cultivator.

Variables

Dependent variable

The dependent variable is the Simpson's diversification index which reduces crop related area share to a scalar number. A zero to one scale diversification index represents the probability of having different crops when two parcels of land are chosen randomly (Pope and Prescott, 1980). The more specialised is the cropping pattern, the closer is the diversification index to zero. A discussion on variable construction is provided below.

Explanatory variables

Climate variables: Both temperature- and rainfall-related variables for each season are constructed using daily weather data. Average *rabi* temperature is measured by averaging daily temperature from the months from November to February. Similarly, we have averaged daily temperature data from July to September to represent average *kharif* temperature. A similar methodology has been applied for getting a measure of average rainfall in two seasons. As per the crop calendar of the state provided by the Indian Ministry of Agriculture and Farmers Welfare, the weather during these months is the best representative of the climate relevant for agricultural activities in these seasons.

Many districts in the state fall in a scarce rainfall zone; therefore, monsoon rainfall is a major constraint on the choice of crop mix. Mean rainfall in rainfall-scarce districts is less than the state average (WB, 2006), therefore it is important to analyse the impact of rainfall on crop diversification more carefully. At a district scale, land allocation decisions, in any season, are spread over several weeks to avoid risk related with moisture availability. In rain shadow regions[4] of the state, farmers have had to re-sow the seed because of the delay in the onset of the rainfall followed by dry spells (Banerjee *et al.*, 2013). While access to irrigation reduces crop failure risk, it negatively affects agricultural profitability. Additionally, risk related with rapid loss in soil moisture is high during the *rabi* season due to sporadic and infrequent rainfall. We take the number of dry (no rain) days as a proxy for moisture availability (Pandey and Ramshastri, 2001) and examine the impact of intra-seasonal frequency of rainfall days on crop diversity. Using data from ICRISAT villages located in Andhra Pradesh and Maharashtra, Jodha (1977) observed that annual rainfall distribution is an important determinant of cropping pattern in these villages. We take rainfall intensity, defined as the ratio of maximum rainfall in any month of a year and total annual rainfall, as a proxy for inter-month rainfall distribution. This variable takes a value 1 if the entire rainfall in a year falls in one month. In the case of evenly distributed rainfall, it takes a value 1/12.

Economic variables: Apart from climate-related factors, we have also considered non-climatic factors in the econometric model and the justification for inclusion of these vari-

ables is as follows. Access to modern irrigation facilities is an important prerequisite for using yield enhancing agricultural inputs such as fertilisers and pesticides. A lack of modern irrigation facilities is a major impediment to agricultural growth (Kurosaki, 2003). Irrigation is also important from the adaptation perspective as it helps to minimise climate change pressure on the existing cropping pattern. However, irrigation may not be conducive for crop diversification as it reduces risk by homogenising moisture conditions irrespective of the climatic conditions (Benin *et al.*, 2004).

Cropping intensity is a measure of resource use efficiency in agriculture. Cropping intensity measures the frequency of agricultural land use in a calendar year. Most of the major crops in the state including rice are cultivated across the seasons. In that case, cropping intensity and specialisation will move in same direction; however, crop diversification may increase with rising cropping intensity when the inter-seasonal difference in climatic conditions is large. Most of the non-*kharif* months in the state receive nominal rainfall; therefore, cultivation of water-intensive crops may turn out to be cost-intensive. Another important factor which explains crop diversity is the share of area under HYV seeds. Increasing the area under HYV crops may promote crop diversification by fulfilling food requirements by using relatively less cultivable land. Another effect of HYV crops on crop diversification can be considered in terms of increased agricultural surplus which enables farmers to invest in intensive cropping. Availability of labour affects agriculture decisions too, as abundant labour supply allows cultivation of labour-intensive crops such as fruits and vegetables (F&V) which are crucial for profitable diversification (Rao *et al.*, 2006). In this study, both cultivators and agricultural labourers are considered as 'labour', considering the extensive use of family labour in farms in India.

Based on the discussion above, we hypothesise the following econometric model which is quadratic in climate variables:

$$Diversification_{it} = \alpha_i + g(t) + \beta_1(Temperaturekharif)_{it} + \beta_2(Temperaturekharif)_{it}^2 + \beta_3(Temperaturerabi)_{it} + \beta_4(Temperaturerabi)_{it}^2 + \beta_5(Rainkharif)_{it} + \beta_6(Rainkharifi)_{it}^2 + \beta_7(Rainrabi)_{it} + \beta_8(Rainrabi)_{it}^2 + \beta_9(Rainintensity)_{it} + \beta_{10}(Drydayskharif)_{it} + \beta_{11}(Drydaysrabi)_{it} + \beta_{12}(Labourperhectare)_{it} + \beta_{13}(Irrigationshare)_{it} + \beta_{14}(Croppingintensity)_{it} + \beta_{15}(HYVshare)_{it} + \varepsilon_{it}$$

(1)

where α_i stands for district specific intercepts, $g(t)$ represents quadratic time trend which captures impact of change in policy regime on crop diversity and β's are common slope coefficients. ε_{it} is the random error term associated with the district i at time t.

Methods

Trend analysis

For examining various trends in the area distribution we use simple ratios and compound annual growth rate (CAGR). We have taken a five-year moving average of data to analyse

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[4]   A rain shadow region is an area having relatively little precipitation due to the effect of a topographic barrier, especially a mountain range, that causes the prevailing winds to lose their moisture on the windward side, causing the leeward side to be dry.

trends and pattern in area distribution. We estimate CAGR using a time series model in the form of: $\ln A_t^i = a + b_t + u_t$ where, A_t^i is area under crop i, t is measured in years and u_i is an *iid* error term. CAGR is produced as: $antilog(b) - 1$ (Gujrati and Sangeetha, 2007).

Panel unit root test

Deterministic and stochastic trends in variables can introduce spurious correlation between the variables because the error associated with the data generating process of both variables might be integrated (Granger and Newbold, 1976). Earlier, it was believed that inclusion of a deterministic time trend in regression can solve the problem of trending variables, however, now it is well known that correlation between the variables can still be spurious when the time trend is included. Therefore, it is necessary to test stationarity to examine presence of a deterministic and stochastic trend in macroeconomic time series. A stationary time series is integrated at order 0 or $I(0)$ and those time series which are integrated at higher orders can be made stationary by differencing the time series. To test stationarity in the panel variable y_{it}, which stacks data for N units over T time periods, a first order autoregressive data generating process of following type is assumed:

$$y_{it} = (1 - \phi_i)\mu_i + \phi_t y_{i(t-1)} + \varepsilon_{it} \quad i = 1,2,\ldots,N; \, t = 1,2,\ldots,T \qquad (2)$$

where initial values y_{i0} is given and we test null hypothesis of unit roots $\phi_i = 1$ for all i. The data generating process can alternatively be represented as:

$$\Delta y_{it} = \alpha_i + \beta y_{i(t-1)} + \varepsilon_{it} \qquad (3)$$

where $\alpha_i = (1 - \phi_i)\mu_i$ and $\beta_i = -(1 - \phi_i)$ and $\Delta y_{it} = y_{it} - y_{i(t-1)}$. In this case, the null hypothesis to be tested becomes:

$H_0 : \beta_i = 0; \quad$ for all i,

against the alternative:

$H_0 : \beta_i < 0; \quad$ for $i = 1, 2, \ldots, N_1, \; \beta = 0; \quad$ for $i = N_1 + 1, \ldots, N$.

Based on this construction, Im *et al.* (2003) suggested three different tests statistic under different assumption regarding N and T.

Pesaran's LM test for cross sectional dependence

Consider the standard panel data model with time series dimension T ($t = 1, 2, 3, \ldots, T$), cross sectional dimension N ($n = 1, 2, 3, \ldots, N$) and number of parameters to be estimated is k. Typical error term ε_{it} is assumed to be independently and identically distributed over time periods and cross sectional units. Under the alternative hypothesis, ε_{it} may be correlated across cross sections, but the assumption of no serial correlation remains. Pesaran (2004) proposes a Lagrange multiplier (LM) test for cross sectional dependence which is defined by:

$$CD = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right)} \qquad (4)$$

in which:

$$\hat{\rho}_{ij} = \hat{\rho}_{ji} = \frac{\sum_{t=1}^{T}\hat{\varepsilon}_{it}\hat{\varepsilon}_{jt}}{\left(\sum_{t=1}^{T}\varepsilon_{it}^2\right)^{1/2}\left(\sum_{t=1}^{T}\varepsilon_{jt}^2\right)^{1/2}}$$

Under the null hypothesis of no cross sectional dependence, Pesaran (2004) demonstrated that CD is normally distributed for $N \to \infty$ and T sufficiently large.

Results and discussion

Cropping pattern in Andhra Pradesh

Whether crop diversification in the past implies adaptation to climate change or not can be understood retrospectively. Past movements in the cropping pattern can be indicative for future adaptation planning. Past patterns in crop diversity can also be useful to explain econometric findings. For these reasons, we provide a brief review of past changes in area distribution in the state at different levels of aggregation.

In terms of area, a major shift in cropping pattern from food grains to non-food grains can be observed in Andhra Pradesh during the study period (Table 1). While the share of coarse cereals has been diminishing continuously, maize has benefitted from liberalisation-induced market expansion. Maize occupied around 2 to 3 per cent of the total area until 1990 but accounted for more than 6 per cent in 2009. The area share of oilseeds increased from 17.8 per cent in 1970 to 24.6 per cent in 1990, but then declined in the post-liberalisation period. Similarly, pulses held a 12 per cent share of

Table 1: Growth and distribution of crop area in Andhra Pradesh, 1970-2009.

	Share in total gross cropped area (%)					Area growth rate (per cent per year)			
	1970	1980	1990	2000	2009	1970-1979	1980-1989	1990-1999	2000-2009
Rice	29.4	33.4	34.1	34.0	32.0	0.84 (4.07)	-0.19 (-0.91)	-0.14 (0.00)	0.16 (0.26)
Sorghum	23.5	20.3	10.9	5.9	2.7	-0.79 (-4.50)	-2.20 (-27.31)	-2.50 (-35.04)	-3.96 (-12.71)
Maize	2.2	2.8	2.5	3.7	6.6	1.01 (8.13)	-0.29 (-2.30)	1.45 (6.80)	3.12 (12.34)
Groundnut	12.5	11.7	19.3	15.3	13.2	-1.28 (-4.30)	2.07 (8.95)	-1.10 (-6.07)	-0.45 (-1.86)
Sugarcane	1.3	1.2	1.4	2.7	2.9	0.81 (2.15)	0.26 (0.67)	1.50 (4.42)	0.92 (0.91)
Cotton	2.8	3.6	5.4	9.1	10.8	0.83 (2.00)	2.09 (10.01)	2.75 (20.32)	0.83 (1.74)
Fruits & vegetables	2.5	2.9	4.4	7.0	8.5	0.90 (3.64)	1.94 (13.27)	2.20 (54.66)	0.92 (15.90)

Figures in parentheses are *t* values
Data source: VDSA database, ICRISAT

Table 2: Area distribution of major crops within regions of Andhra Pradesh, 1970-2009*.

Region	Year	Rice	Sorghum	Maize	Groundnut	Sugarcane	Cotton	Fruits & vegetables
Coastal Northern	1970	56.9	3.1	0.3	7.1	3.8	0.1	5.6
	1980	61.3	2.0	0.5	5.4	3.2	0.1	6.8
	1990	58.3	0.7	0.5	8.0	3.5	0.4	8.9
	2000	54.4	0.2	1.2	5.7	6.3	0.9	13.1
	2009	52.6	0.1	3.4	3.4	8.2	0.9	15.4
Coastal South	1970	47.4	18.8	0.2	5.4	0.7	0.9	2.8
	1980	49.8	13.0	0.2	4.0	0.8	4.9	3.2
	1990	47.9	3.9	0.5	6.7	0.9	10.0	4.6
	2000	49.2	0.4	1.1	2.1	1.7	11.1	7.3
	2009	48.5	0. 5	4.8	1.5	1.8	10.7	8.3
Inland North Western	1970	15.8	34.4	4.3	6.7	1.2	3.7	0.7
	1980	19.8	33.9	5.9	6.1	1.1	5.1	0.8
	1990	21.2	28.8	6.1	8.1	1.4	8.1	1.5
	2000	21.8	19.2	8.4	5.9	2.9	10.6	2.9
	2009	18.6	7.1	13.2	4.6	2.7	16.4	4.3
Inland Southern	1970	14.3	23.5	0.1	31.4	1.0	7.6	2.5
	1980	16.3	20.6	0.1	34.3	0.9	6.8	3.1
	1990	12.1	9.4	0.1	56.2	1.0	3.3	4.1
	2000	11.6	4.9	0.2	48.6	2.0	6.0	6.5
	2009	10.2	3.7	1.2	43.9	1.8	1.6	7.6
Inland North Eastern	1970	21.6	32.0	5.5	8.0	0.0	0.2	0.6
	1980	28.5	26.9	6.5	6.0	0.1	0.1	0.6
	1990	37.3	9.3	5.3	11.3	0.2	5.5	2.3
	2000	41.1	2. 8	8.1	6.2	0.3	18.3	4.1
	2009	39.9	1.0	10.7	3.7	0.4	26.5	6.1

* Classification of districts into agro-ecological regions is based on the information provided by the National Sample Survey Office (http://mospi.nic.in/Mospi_New/upload/nsso/nss_regions.pdf); inland south and inland north-west region include districts falling in the rainfall and irrigation scarce zone of the state
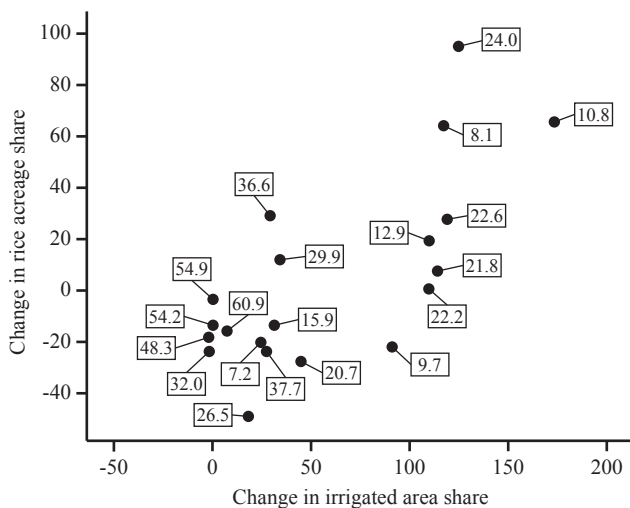Data source: VDSA database, ICRISAT

Figure 1: Change in rice area share due to irrigation expansion in districts of Andhra Pradesh. (Boxes show the area share of rice in 1970).

Data source: VDSA database, ICRISAT

the total area until 2000, but declined thereafter. Among non-food grains, the area share of F&V crops has been increasing since 1970, although the rate of growth has decelerated after 2000. Groundnut share in total area, after peaking in 1980, has declined considerably in the post-liberalisation period.

At the regional level, a clear redistribution of the rice growing area can be identified. Losses in area share in coastal north and inland south have been overcompensated by gains in inland north regions. (Table 2). But while rice is

expanding in new areas, the share of groundnut in total area has declined in all regions except in the inland south region which falls in the rainfall scarce semi-arid region of Andhra Pradesh.

Figure 1 depicts the change in the irrigated area share against the change in the rice share for all districts, while the share of rice in the total area in the initial period (1970) is reported in rectangular boxes. Districts which used to dominate rice cultivation have shifted area towards other crops. On the other hand, districts which witnessed higher gains in terms of irrigation have added new area to rice cultivation, barring a few exceptions. While increasing area under rice adds to the vulnerability of the agricultural system by compounding pressure on groundwater resources, it cannot be denied that spatial distribution of the rice area in the state has helped agriculture to adapt by distributing risk related with rice production (Smit *et al.*, 2000).

To examine the impact of area redistribution on crop diversity, Figure 2 plots the diversification index for median, top 25 per cent and bottom 25 per cent in each year for all districts along with the state.[5] The diversification plot for the top 25 per cent of districts shows an increasing trend over the study period while the plot for the bottom 25 per cent indicates a sustained shift toward diversification after a wave of specialisation observed before 1991. Finally, a higher province-level plot than the median of districts plot suggests that cropping pattern is more specialised at the district level

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[5]   Median index value of the top five most diversified districts out of 20 districts is termed as the top 25 per cent. Similarly median index value of the five least diversified districts is termed as the bottom 25 per cent.
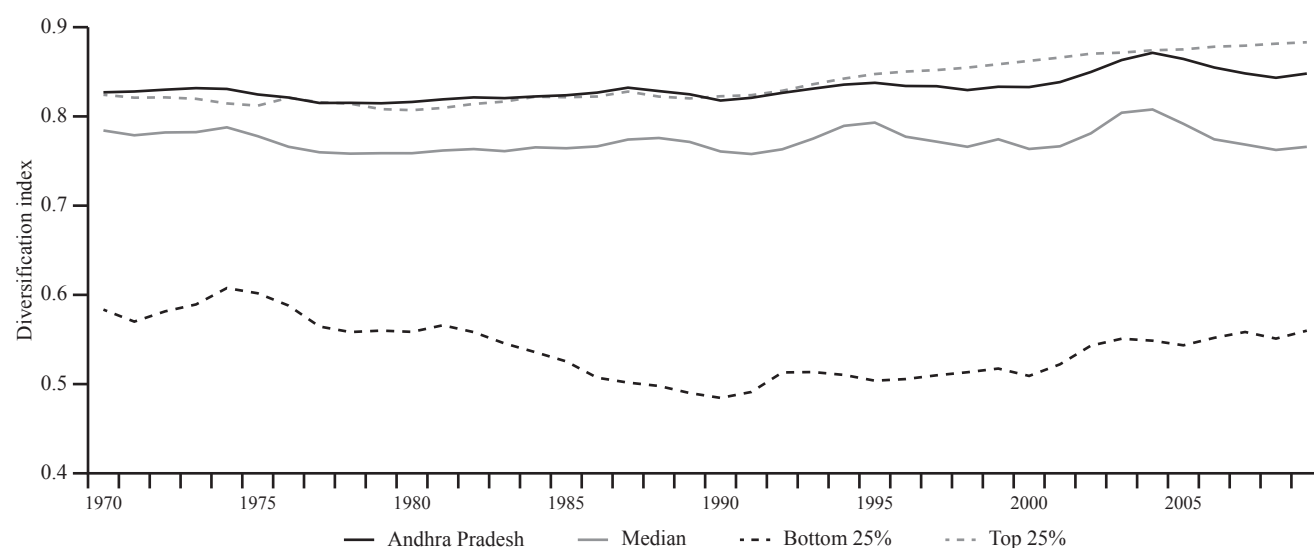
Figure 2: Trends in crop diversity at district and state level in Andhra Pradesh, 1970-2009.

Data source: VDSA database, ICRISAT

Table 3: Definition of variables used in the econometric model (equation 1) and summary of data (n = 740).

Variable	Definition	Unit	Mean	Std. dev.	Min	Max
Diversification Index	$1 - \sum_{i}^{n}\left(\dfrac{A_i}{\sum A_i}\right)^2$; Where A_i is the area under crop i, n is the number of crops	-	0.7	0.1	0.3	0.9
Temperature *kharif*	Average of June to September daily temperature	ºC	29.8	0.9	27.1	32.0
Temperature *rabi*	Average of November to February daily temperature	ºC	24.1	0.7	21.8	26.2
Rainfall *kharif*	Average of June to September daily rainfall	mm	132.9	55.8	29.0	386.1
Rainfall *rabi*	Average of November to February daily rainfall	mm	22.0	25.9	0.0	191.0
Rainfall intensity	Maximum rainfall in a month/total annual rainfall	-	0.3	0.1	0.2	0.5
Dry days *kharif*	Days without rainfall from July to September	Number	15.6	7.4	0.0	39.0
Dry days *rabi*	Days without rainfall from November to February	Number	102.3	13.0	31.0	120.0
Labour per hectare	Number of agricultural labourers and cultivators/total population	-	1.5	0.4	0.6	3.1
Cropping intensity	Gross cultivated area/net cultivated area	-	121.0	17.2	100.5	183.3
Irrigation share	Net irrigated area/net cultivated area	-	40.1	19.3	3.5	88.7
HYV share	Total area under HYV seeds/gross cropped area	-	36.4	23.6	1.0	56.0

Source: own calculations

than at the state level.

Demand-led growth in the share of F&V crops in India has been supported by an increasing network of public infrastructure as well as a favourable policy environment for investment in food processing (Birthal *et al*., 2008). However, lethargic growth in the area of F&V crops indicates a need for more dedicated incentives and infrastructure. Increased imports of cheap oil under WTO obligations has been a major factor explaining the declining area share of oilseed crops (Reddy and Bantilan, 2012). The decline in the shares of pulses and oilseeds in the state reflects poor implementation of *Pulses and Oilseeds Mission* in the state and is a matter of concern from an adaptation perspective. Sustainability of the emerging cropping pattern which is biased against dry-land crops is critically dependent on irrigation infrastructure. Technological intervention along with subsidised supply of farm inputs and high incentive prices seems important to explain the specialisation wave in the state during the 1970s and 1980s; however, diversification brings crucial adaptation benefits. Rainfall distribution seems vital to explain highly diversified cropping pattern in a few districts, especially in southern Andhra Pradesh.

Determinants of crop diversity

Here we examine the impact of weather on crop diversity over time in districts of Andhra Pradesh. Considering a large time dimension (T = 37 years; N = 20) of the panel, it is imperative to examine time series properties of the data. In this regard, we have used the unit root test developed by Im *et al*. (2003) and find that all variables are stationary at level.

Table 3 lists the definitions of the variables of the regression model given in equation 1 and Table 4 reports the parameter estimates. We start with estimating the fixed and random effects model. The Hausman (1978) test statistic for fixed versus random effects specification is 45.1 (p-value = 0.000) which infers that parameter estimates of the model specified with fixed effects (FE) are preferred over random effects (RE). However, the assumption of homoscedastic errors in the estimated FE model is refuted due to high significance of modified Wald test statistic (Baum, 2001). Similarly, cross-sectional correlation can be a potential problem in panels dealing with data on geographical entities. We also examine the presence of cross-sectional dependence in errors using a test proposed by Pesaran (2004). A high level of statistical significance of the

Table 4: Climatic and economic determinants of crop diversification in 20 districts of Andrha Pradesh (n = 740).

Independent variables	Dependent variable: Simpson's diversification index		
	Fixed effects model	**Random effects model**	**Fixed effects model with corrected SEs**
Climatic factors			
Temperature *kharif*	-9.11 (0.147)	-6.02 (0.149)	-9.11 (0.281)
Temperature *kharif* sq.	0.152 (0.0025)	0.100 (0.0025)	0.152 (0.0047)
Temperature *rabi*	-0.278* (0.154)	-27.10* (0.157)	-0.278** (0.123)
Temperature *rabi* sq.	0.0057* (0.0032)	0.55* (0.0033)	0.0057** (0.0026)
Rain *rabi*	0.032 (0.0223)	2.82 (0.0227)	0.032 (0.0227)
Rain *rabi* sq.	-0.028* (0.0158)	-2.56 (0.0161)	-0.028 (0.0175)
Rain *kharif*	-0.031* (0.0174)	-2.98* (0.0177)	-0.031* (0.0154)
Rain *kharif* sq.	0.0082* (0.0049)	0.797 (0.0050)	0.0082* (0.0045)
Rain intensity	5.70 (0.0357)	6.42* (0.0364)	5.70* (0.0322)
Dry days *kharif*	-0.055 (0.0004)	-0.0532 (0.0004)	-0.055** (0.0002)
Dry days *rabi*	0.028 (0.0002)	0.0287 (0.0002)	0.028* (0.0002)
Economic factors			
Irrigation share	-0.107*** (0.0003)	-0.153*** (0.0003)	-0.107** (0.0005)
Labour per hectare	4.94*** (0.0108)	4.69*** (0.0108)	4.94*** (0.0124)
Cropping intensity	0.116*** (0.0003)	0.0879*** (0.0003)	0.116*** (0.0003)
HYV share	0.033** (0.0148)	0.0311** (0.0151)	0.033*** (0.0115)
Trend	-0.561*** (0.0009)	-0.511*** (0.0009)	-0.561*** (0.0008)
Trend sq.	0.0127*** (1.99e-05)	0.0123*** (2.03e-05)	0.0127*** (1.63e-05)
Constant	531.40** (2.640)	482.30* (2.680)	5.314 (3.809)
R-squared (within)	0.134	0.129	0.134
Model goodness of fit	F (17, 703) = 6.40***	Chi-squared (17) = 106.81***	F (17, 36) = 78.28***
Hausman test (fixed vs random effects) [a]	Chi-squared (17 df) = 45.05***	-	-
Modified Wald test for group-wise heteroscedasticity in fixed effect regression model [b]	Chi-squared (20 df) = 3735.66***	-	-
Pesaran's LM test of cross sectional independence	Chi-squared = 2.89***; Average absolute value of the off-diagonal elements = 0.34	-	-
Wooldridge test for autocorrelation in panel data [c]	F (1, 19) = 78.40***	-	-

***/**/*: statistically significant at the 1%, 5%, and 10% levels respectively; all coefficients are multiplied by 100; figures reported in parentheses are standard errors; rainfall data which are given at millimetre scale in the original dataset are rescaled to decimetres to make coefficients more reasonable; standard errors reported in the last column are corrected for cross sectional dependence using the Driscoll-Kraay (1998) method

[a] H_0: difference in coefficients is not systematic i.e. random effects coefficients are efficient and consistent under H_0

[b] H_0: $sigma_i^2 = sigma^2$ for all *i*, i.e. error variance is constant across all districts

[c] H_0: no first order autocorrelation

Source: own calculations

Pesaran's test statistic causes us to reject the null hypothesis of no cross sectional dependence. Additionally, the Wooldridge (2002) test is used to examine the presence of serial correlation in errors and a significant test statistic confirms that errors are serially correlated in the FE model.

Considering that errors in the FE model do not satisfy the least squares assumptions, standard errors of FE model estimates are not reliable. However, FE model estimates are still consistent in large samples; therefore we use the Driscoll-Kraay (1998) approach to correct standard errors in the FE model. By exploiting moment conditions to correct cross sectional dependence in a fashion proposed by Newy and West (1987), the Driscoll-Kraay approach eliminates the deficiencies of other feasible generalised least squares meth-

ods. Additionally, the Driscoll-Kraay covariance estimator is consistent for unknown forms of correlation, therefore we need not specify the structure of correlation (Hoechle, 2007). This feature of the Driscoll-Kraay estimator provides flexibility because it is very difficult to detect the form of spatial correlation in data. Furthermore, its asymptotic properties depend on time series dimension only, free from the order of cross sectional dimension.

As hypothesised, econometric results confirm a statistically significant nonlinear relationship between crop diversity and weather. We find level and squared terms of *kharif* rainfall statistically significant at the 10 per cent level with negative and positive signs respectively. It implies that specialisation in cropping pattern which started with the introduction of new technology will saturate due to the changing mean and/or or variance of rainfall. The changing summer monsoon is expected to increase diversification in the districts. Considering the fact that general circulation models still have difficulty to predict distribution of monsoon rainfall (Turner and Annamalai, 2012), the observed trend in rainfall indicates increasing variability in monsoon rainfall (Goswami *et al*., 2006; Rajeevan *et al*., 2008). Singh *et al*. (2014) observed increasing frequency of dry events and increasing intensity of wet events during the summer monsoon in India. Considering this evidence, increasing diversity in districts seems an adaptation measure by farmers in the state. The mean rainfall level at which the cropping pattern in districts will start diversifying turns out to be higher (approximately 188 mm) than the sample mean (132.9 mm); however, few districts in coastal region are very close to the turning point.

Of the two temperature variables, level and square terms of *rabi* temperature turn statistically significant at 5 per cent level with negative and positive signs respectively which infers that crop diversity in districts may increase with rising *rabi* temperature. Rising temperature increases crop water demand as well as irrigation demand. Both of these factors contribute to increasing production cost as well as risk in a bleak rainfall season (Table 3). A more evenly distributed crop portfolio, in which irrigation-intensive crops are mixed with drought tolerant crops, not only reduces production cost but also minimises production risk. Since the turning point of temperature (approximately 24°C) based on the estimated coefficients turns very close to the mean *rabi* temperature; it can be said that crop diversity in the districts will increase with rising winter temperature.

We find a negative and statistically significant relationship between *kharif* dry days and diversification index which implies that more wet days during the *kharif* season are not conducive to crop specialisation. The sample mean of dry days in the *kharif* season is very low (Table 3). Too few rainless days reduces the window for effective application of fertilisers and pesticides, which affects yields negatively, especially in rice producing districts. Additionally, cotton, which is a major competing crop of rice in a few districts, requires weed removal for a higher yield. Weed removal is not possible in wet alluvial black soil regions of the state where most of the cotton fields lie (Jodha, 1977). Similarly, groundnut is the principal *kharif* crop in rainfall scarce southern region of Andhra Pradesh due to its drought tolerance (Table 2). The average number of rainfall days in this region is much lower than the state average. Therefore, more dry days than average leads to increased specialisation in different regions of the state for different reasons. In contrast, a statistically significant and positive relationship has been observed between *rabi* dry days and diversity index which implies that diversity increases when districts witness more dry days during the *rabi* season. Diversification is a rational strategy when faced with longer dry spells in a rainfall-scarce season. Cultivation of resource-intensive crops in a rainfall-scarce season is cost intensive and risky; therefore, it is justified that districts which witness more rainless days the during *rabi* season maintain more diversified cropping patterns.

Rainfall intensity has a positive and statistically significant impact on crop diversity in districts. The literature on monsoon rainfall pattern in India has shown that rainfall intensity is increasing (Goswami *et al*., 2006; Rajeevan *et al*., 2008; Dourte *et al*., 2013) which may lead to greater runoff. Too much or too little rainfall in few months of the year disrupt agricultural operations and causes damage to the sown area. Increasing diversity when faced with an uneven intra-annual distribution of rainfall, therefore, is indicative of farmers' response to rising weather risk.

The influence of economic factors, related with the development of agricultural infrastructure, on crop diversity is very strong and varied.[6] Labour per hectare is positively related to crop diversity indicating that cheap availability of labour incentivises farmers to diversify towards labour-intensive non-food grains. Irrigation reduces agricultural risk by increasing uniformity in soil moisture conditions throughout the year. A negative and significant relationship between irrigation share and crop diversity highlights this fact. Singh *et al*. (2006) observed a similar association between irrigation and crop diversity in a study of Indian states. A positive and statistically significant coefficient of cropping intensity highlights that crop choice differs across the seasons, i.e. farmers grow different crops during *rabi* and *kharif*. We find a positive relationship between diversity index and share of HYV area in total area.

Conclusion

We examined the relationship between crop diversity and climate change from the climate change adaptation perspective. On linking our econometric findings with crop area redistribution at regional level, it can be said that changing weather conditions influence crop diversity.

The results bring forth a few issues which may be useful from an adaptation perspective. Firstly, the specialisation pattern which evolved after a half century long adaptation of seed-water-fertiliser technology is changing and climate change is an important factor explaining it. In addition, cropping patterns in districts are sensitive to intra-annual distribution of rainfall and increasing rainfall intensity increased crop diversity. Additionally, the number of dry days across the seasons showed different impacts on crop diversity which implies that farmers respond differently to the frequency of

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[6]   We included road density and urban population share as a proxy for connectivity and market expansion; however, coefficients of these variables turned statistically insignificant.

rainfall events across seasons, therefore, season-specific adaptation planning is a better idea. Secondly, expenditure on agricultural research and intensification is instrumental to adaptation as the results show that increasing use of technological inputs such as HYV seeds and land augmentation has a positive influence on crop diversity. Thirdly, the declining share of pulses and oilseeds indicates a serious adaptation deficit. In addition, an increasing share of rice and other water- and resource-intensive crops in Andhra Pradesh may be a welcome sign as far as agricultural income is concerned, but the rice based cropping system is not sustainable in the long run. For example, the state has successfully relieved some pressure on the water and soil resources by redistributing the rice area across districts; however, rice cultivation has increased in inland districts which are water scarce. Any policy intervention meant to increase crop diversity will further boost adaptation if rice area can be substituted by dry land crops such as pulses and oilseeds. A seasonal pricing of electricity, credit and other inputs can be useful to increase diversity as well as to ensure sustainable intensification of agriculture in the state. Since rainfall is a scarce resource in most of the districts therefore, new irrigation techniques such as drip irrigation should be promoted to ensure agriculture sustainability in the state.

A nonlinear relationship between crop diversity and climate is sensitive to future changes in agricultural infrastructure and resource use. Any change in these factors may affect the estimation results. Another shortcoming of our approach is that it informs nothing regarding how the area of individual crops has changed over time. Therefore, an examination of the impact of climate change on crop area can be a possible extension of the present study.

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