Heterogeneous Climatic Impacts on Agricultural Production: Evidence from Rice Yield in Assam, India

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ABSTRACT

Understanding the nature and extent of climatic impacts on agricultural productivity under a variety of scenarios is extremely important for developing countries, where a sizable portion of the population relies on agriculture for life and livelihood. Thus, this paper presents evidence of heterogeneity in climatic impacts on crop yield in Assam, India. In particular, applying the non-parametric quantile regression technique to district-level data from 1978 to 2005, this study examined heterogeneity in the impacts of temperature and rainfall across seasonal rice varieties (autumn, winter, and summer), agro-climatic (AC) zones, and the distribution of rice yield. The results suggested that, in general, the effects of temperature on yield were not statistically significant for any of the three seasonal rice varieties. However, these effects were not uniform in their magnitudes, signs, and statistical significance across AC zones and yield distribution for each variety of rice. Similarly, there were wide variations in the effects of total precipitation across seasonal varieties, AC zones, and yield distribution. The results also suggested that an increase in temperature variability is beneficial and that rainfall variability is harmful to autumn and winter rice yield. For summer rice, the effects of these two climate variables were positive but statistically insignificant. Given the importance of rice yield for food security and poverty alleviation in Assam, these results could inform the design of appropriate adaptation strategies and public policies to counter the adverse impacts of climate change on agriculture in Assam. Furthermore, since most people in rural areas are engaged in agriculture, these results are important for the sustainability of rural economies.

Keywords: climatic impacts, rice yield, Assam, India, autumn rice, winter rice, summer rice, quantile regression, median regression
JEL Classification: Q11, Q18, Q54

INTRODUCTION

The study of climatic impacts on agricultural productivity is extremely important for developing countries where a sizable portion of the population relies on agriculture for life and livelihood. Although what causes climatic changes is debatable, the evidence of changes in temperature, precipitation, and extreme weather events is indisputable. Since climatic conditions directly affect agriculture, it is but natural to examine the impacts of changes in these conditions on crop yield.

There is substantial empirical literature on how climatic changes impact agriculture using data on various crops from different parts of the world. In the beginning, the literature primarily focused on developed countries (Kaiser et al. 1993; Mendelsohn, Nordhaus, and Shaw 1994; Adams et al. 1998; Adams, Hurd, and Reilly 1999; Lewandrowski and Schimmelpfennig 1999; Bryant et al. 2000). However, some more recent studies examined climatic impacts on agriculture in developing countries (Sanghi and Mendelsohn 2008; Molua 2009; Deressa and Hassan 2009; Wang et al. 2009; Sarker, Alam, and Gow 2012; Poudel and Kotani 2013; Burney and Ramanathan 2014; Singh et al. 2017). In general, these studies found evidence of significant impacts of climatic changes on mean yield, growth, and yield variability of different crops, and used these findings to derive implications for adaptation strategy in cropping patterns.

Several recent studies that investigated climatic impacts on agriculture in India have mixed results—while some studies found evidence of negative impacts of climate change (Auffhammer, Ramanathan, and Vincent 2006; Cline 2007; Aggarwal 2008; Guiteras 2009; Burney and Ramanathan 2014; Rao et al. 2014; Kumar et al. 2015; Singh et al. 2017), others showed that climatic changes have positive effects (Mohandass et al. 1995; Lal et al. 1998; Rathore et al. 2001; Aggarwal and Mall 2002; Abeysingha et al. 2016). There were other studies that reported both positive and negative effects under different climate change scenarios (Dubey et al. 2014; Yadav et al. 2015). An interesting finding was that the climatic impacts on agriculture are non-linear (Auffhammer, Ramanathan, and Vincent 2012).[1] This is particularly important for policymakers for adoption of appropriate countermeasures in response to the negative impacts of climate change. The distributional heterogeneity in the climatic impacts on crop yield was further highlighted by Krishnamurthy (2012) and Barnwal and Kotani (2013). These studies applied quantile regression technique to district-level data for India and the state of Andhra Pradesh, respectively.

In this paper, the heterogeneity in climatic impacts on agricultural production was studied further. The case of rice yield in Assam, a state in the northeast region of India where it is a staple crop for its population of over 30 million, was considered. In particular, heterogeneity in the impacts of temperature and rainfall on rice yield was studied along three dimensions: rice varieties grown in different seasons, agro-climatic conditions that would primarily reflect differences in soil quality, and different levels along the distribution of rice yield. The knowledge of these heterogeneities would be useful in developing an understanding of the nature and magnitude of adaptations to climatic changes, and in formulating appropriate policy to ensure food security in a state like Assam.

This paper primarily applied a non-parametric regression technique to district-level data from 1978 to 2005 to examine the above-mentioned heterogeneities in climatic impacts on rice yield in Assam. By considering rice

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[1] Schlenker and Roberts (2006, 2009) document nonlinearity in the effects of weather on corn yield for the U.S.

grown in three seasons of the year, it uncovers seasonal disparities in climatic impacts. High resolution gridded daily temperature and rainfall data were used to construct the climate variables.[2] The results suggested that, in general, the effects of temperature on yield were not statistically significant for any of the three seasonal rice varieties. However, these effects were not uniform in their magnitudes, signs, and statistical significance across agro-climatic zones (AC zones) and yield distribution for each variety of rice.

Similarly, there were wide variations in the effects of total precipitation across seasonal varieties, agro-climatic zones, and yield distribution. The results also suggested that an increase in temperature variability was beneficial, but rainfall variability was harmful to autumn and winter rice yields. For summer rice, although the effects of these two variables were positive, they were statistically insignificant. Given the importance of crop yield for food security and poverty alleviation, these results seem to suggest that growing season, location, and current yield should be taken into account in formulating appropriate adaptation strategies and public policies for rice cultivation to counter the adverse effects of climatic changes. No other study has examined the climatic impacts on rice yield focusing on their heterogeneity across seasonal varieties, agro-climatic zones, and yield distribution for the state of Assam.

METHODS AND DATA

Empirical Model and Methodology

For the empirical analysis, the model below, which postulates that rice yield depends on a number of climatic and other variables, was used:

$$y = \boldsymbol{x}'\boldsymbol{\beta} + \boldsymbol{z}'\boldsymbol{\gamma} + \epsilon \qquad (1)$$

where y is the rice yield, $\boldsymbol{x}$ is a (k × 1) vector of climate variables, $\boldsymbol{z}$ is a (m × 1) vector of control variables, $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ are the corresponding vectors of coefficients to be estimated, and ϵ is the error term. In the baseline specification, climatic variables included mean of daily temperature during a growing season, temperature variability (standard deviation of daily temperature during the season), total rainfall, and rainfall variability during the season. Control variables included a set of five dummy variables that captured AC zone-specific fixed effects, a time trend that represented technology, total cropped area under the specific seasonal rice variety, fertilizer consumption, and a dummy variable for the districts that were frequently and heavily affected by floods.[3,4] In the extended specification, the interactions of mean temperature and total rainfall with the AC zone dummies were also included to examine differential effects of the climate variable across these zones.

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[2] Previous studies (Mearns, Rosenzweig, and Goldberg 1996; Schlenker and Roberts 2009) showed that day-to-day variations in weather conditions such as temperature and rainfall during the growing season have crucial effects on the growth and yield of crops. Therefore, high resolution daily weather data are extremely valuable in studying the impact of climate change on agriculture. However, most studies on climatic impact on agricultural yield in India used monthly weather data primarily due to a lack of high-resolution daily weather data until recently.

[3] There are six agro-climatic zones in Assam and five dummies were included. In a similar study for India, Krishnamurthy (2012) used district fixed effects. Since the districts in Assam were small and adjacent districts were very similar, location-specific fixed effects at the agro-climatic zone level were controlled. This was similar to the study of Barnwal and Kotani (2013).

[4] The flood dummy took the value of 1 for a district that experienced frequent and widespread floods (in terms of total cropped area inundated) and 0 otherwise.

The quantile regression (QR) technique was used to estimate model (1).[5] First, a median regression (50th quantile regression) was used to examine the heterogeneity in climatic impacts on rice yield across three varieties grown in three different seasons, and then across six AC zones.[6] In both cases, panel ordinary least square (OLS) regression was also estimated for comparison with the results from the median regression. In order to investigate the differences in the impacts of temperature and rainfall across distribution, regressions were estimated for the 20th, 40th, 60th, and 80th quantile.

Unlike the conventional parametric linear regression techniques, this non-parametric approach allowed the consideration of the climatic impacts on the entire distribution of rice yield and not merely on its conditional mean. Thus, it provided a richer characterization of the data by uncovering the heterogeneity in the impacts of climatic changes. This is important because, as Barnwal and Kotani (2013) argued, the potential non-stationarity of climatic variables and crop yield unfolded the possibility of asymmetric effects of temperature, rainfall, and other covariates across the conditional distribution of rice yield. Other advantages of QR over OLS regression included the fact that while OLS estimates could be inefficient in case of non-normal errors, QR estimates were robust to non-normal errors and outliers. Furthermore, by allowing for different coefficients at different quantiles, the technique took care of potential heteroskedasticity. Only Barnwal and Kotani (2013) and Krishnamurthy (2012) used the QR technique to examine the climatic impacts on agriculture in the Indian context.

The estimation of the coefficients involved minimizing a non-differentiable objective function through the simplex method that was guaranteed to yield a solution in a finite number of iterations. The standard errors were computed by bootstrapping. Since QR is a non-parametric method, no specific assumption about the distribution of the error term was required.

Study Area

Located south of the eastern Himalayas, Assam comprises the Brahmaputra and the Barak river valleys along with Karbi Anglong and the North Cachar Hills with an area of 78,437.79 km^2. Assam has sub-tropical humid climate conducive to rice cultivation. Average temperatures in the state range from high 90ºF (about 32ºC) in August to mid-40ºF (about 4ºC) in January. Although the state receives some rain between March and May, the heaviest precipitation comes with the southwest monsoon, which arrives in June and stays through September. With annual average rainfall that varies from about 1,800 mm in the west to more than 3,000 mm in the east, Assam ranks among the world's regions with the highest rainfall. Assam is primarily an agrarian economy with about two-thirds of its workforce engaged in agriculture. Rice is the staple crop that accounts for more than 60 percent of the total cropped area in the state.

Based on rainfall pattern, geographic terrain, and soil characteristics, Assam has been divided into six AC zones: Lower Brahmaputra Valley zone, Central Brahmaputra Valley zone, North Bank Plain zone, Upper Brahmaputra Valley zone, Hill zone, and Barak Valley zone. The AC zones are shown in inset in Figure 1. Table 1 lists the districts in each AC zone. The table also shows the relative sizes (in total areas) of these zones and the distribution of cropped areas under the three seasonal rice varieties.

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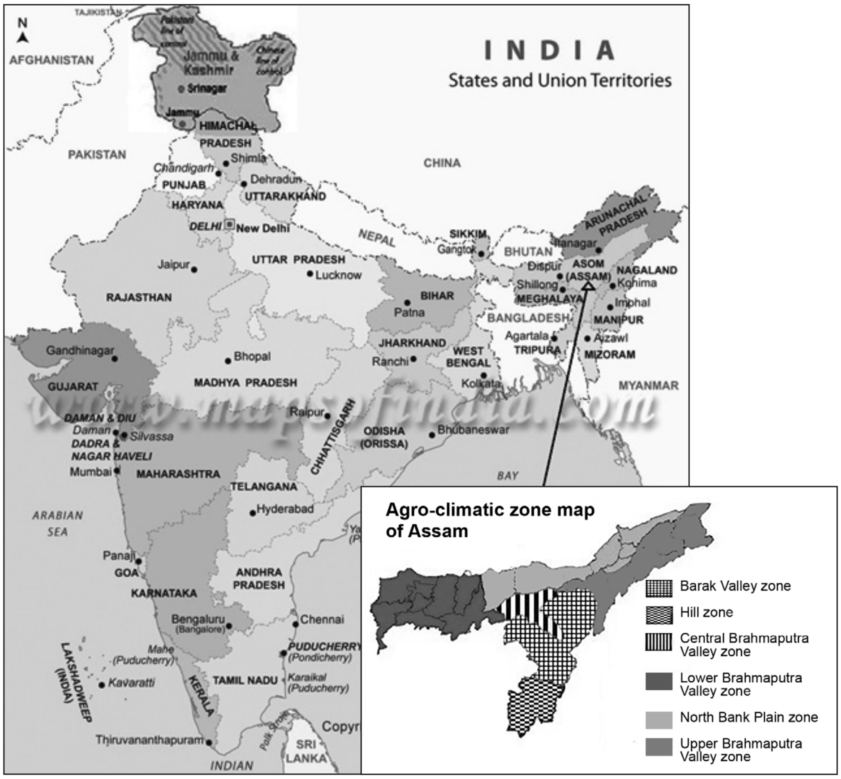
[5] Quantile regression technique was proposed by Koenker and Bassett (1978)

[6] Sarker, Alam, and Gow (2012) used median regression to examine the relationship between climate change and rice yield in Bangladesh.

Figure 1. Map of India (with the AC zones of Assam in inset)



Sources: Maps of India (2014) and NESAC (n.d.)

Data Collection

This study focused on the impacts of climate variables, namely, temperature and rainfall, on average yield of three distinct seasonal varieties of rice in Assam: autumn rice, winter rice, and summer rice.[7] The data used in this study covered 22 districts of the state from 1978 to 2005.[8] The selection of the sample was determined primarily by the availability of data on all relevant variables in a consistent manner. The districts have undergone boundary changes with the creation of new districts from time to time. Until 1981, there were only 10 districts. Between 1981 and 1991, eight of them were split to create 13 new districts, bringing the total number to 23.

Since these new districts were sub-divisions of the parent districts and data for most relevant variables were collected at the level of those sub-divisions, the data series for the entire sample period for all but the Bongaigaon district could easily be constructed. Therefore, this district was dropped from the sample. Four more districts were carved out in 2003–04. However, since these new districts were created combining parts of more than one erstwhile districts, it was difficult to construct data for these new districts for the entire sample period. Furthermore, data for these new districts were published separately

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[7] They are so named according to the respective seasons of their harvesting.

[8] Districts are administrative units with clearly demarcated geographical boundaries. They are much like the counties in the United States. A district is often divided into two or more sub-divisions.

Table 1. Agro-climatic zones (AC zones) in Assam

Zone No. (as used in the paper)	AC Zones	Districts	Total Geographical Area (ha)	Percentage of Total Cropped Area (Average over 1978–1979 to 2004–2005)		
				Autumn Rice	Winter Rice	Summer Rice
1	Lower Brahmaputra Valley zone	Dhubri, Bongaigaon, Goalpara, Kokrajhar, Barpeta, Nalbari, Kamrup	2,014,800 (25.69)	21.58	37.53	5.85
2	Central Brahmaputra Valley zone	Nagaon, Morigaon	553,500 (7.06)	14.03	39.71	13.18
3	North Bank Plain zone	Darrang, Sonitpur, Lakhimpur, Dhemaji	1,431,900 (18.26)	16.41	43.88	3.12
4	Upper Brahmaputra Valley zone	Dibrugarh, Tinsukia, Sibsagar, Jorhat, Golaghat	1,619,200 (20.64)	4.91	51.24	0.43
5	Hill zone	Karbi Anglong, North Cachar	1,532,200 (19.53)	8.11	53.87	0.42
6	Barak Valley zone	Cachar, Hailakandi, Karimganj	692,200 (8.82)	9.82	59.66	4.32
	Assam		7,843,800 (100.00)	13.05	44.29	5.91

Sources: Compiled from DoA (1978–1979 to 1996–1997) and DES (1978–1979 to 2005–2006)

Note: Percentage shares of the agro-climatic zones in total area are shown in parentheses.

after 2004–05; but it was almost impossible to map those data back to the pre-2003–04 districts that were used in the sample. Therefore, the sample period was extended only up to 2005. The data used in this study can be divided into two broad categories: agricultural data and climate data.

Agricultural data

Data on agricultural variables were obtained from three government agencies: Directorate of Agriculture, Government of Assam (DoA-GOA); Directorate of Economics and Statistics, Government of India (DES-GOI); and Directorate of Economics and Statistics, Government of Assam (DES-GOA). The three main agricultural variables used in the empirical model were average rice yield (output of a seasonal rice variety in kilogram per hectare), total rice area (area under a seasonal rice variety in hectares), and fertilizer consumption (use of all kinds of chemical fertilizer in ‘000 kg for all crops). The data on average rice yield and total rice area were compiled from various issues of Basic Agricultural Statistics published by DoA (1978–1979 to 1996–1997) and Estimates of Area, Production and Average Yield of Principal Crops in Assam published by DES (1978–1979 to 2005–2006). Fertilizer consumption data were obtained from DoA; however, fertilizer data were available for all crops and not separately for rice.

Climate data

The study used high-resolution (1º×1º latitude-longitude) daily gridded temperature and rainfall data compiled by the National Climate Centre of India Meteorological Department (IMD), Government of India. IMD uses Shepard's angular distance weighting method on historical data from 395 quality-controlled stations for the period 1969 to 2005 to create the gridded temperature data (Srivastava, Rajeevan, and Kshirsagar 2009). The dataset has been recently updated until 2014. Similarly, IMD uses daily rainfall data from 1,803 stations across India to create a high-resolution gridded precipitation dataset for the period 1951–2003 (Rajeevan et al. 2006), which was later updated to 2015.

A modified Shepard's inverse weighting interpolation method was used to obtain district-level daily temperature and rainfall data from the high-resolution gridded data. The geographical center of each district was taken and the grid points that fell within 100 km from this center were identified. Then the district-level temperature and rainfall as a weighted average of their respective recorded values at the identified grid points were calculated. The inverse square roots of the distances between these grid points and the district center were used as corresponding weights. The daily weather data, thus obtained, were then used to construct various climatic variables for different growing seasons.

According to the Directorate of Rice Development (DRD), India (2014), autumn rice was sown between mid-February and April and harvested between June and July every year in Assam. There were substantial variations in sowing and harvesting dates across districts. For the construction of climate data, the period between the mid-points of the sowing and harvesting seasons (i.e., March 24–June 30) as the growing season for autumn rice was taken. Similarly, the sowing and harvesting seasons for winter rice were June–August and November–December, respectively. For summer rice, the corresponding seasons were December–February and May–June. Accordingly, July 16–November 30 was considered as the growing season for winter rice and 16 January–31 May for summer rice.[9]

Using the district-level daily temperature and rainfall data as obtained above, data on four weather variables for each of the above growing seasons were constructed. From the temperature data, the mean and standard deviation of daily average temperature during a particular season were calculated. From the daily rainfall data, total rainfall and standard deviation of daily rainfall for the respective seasons were also calculated.

The agricultural data reported for the crop year begins in July and ends in June of the subsequent calendar year. For consistency, the constructed seasonal data on climatic variables to the corresponding crop year was mapped.[10] The summary statistics of the data are presented in Table 2.

RESULTS AND DISCUSSION

Since the study's objective was to examine heterogeneity in climatic impacts on rice yield across seasonal varieties, AC zones, and yield distribution, the results are reported and discussed in such a way that the differences along these three dimensions are highlighted. Although the focus was primarily on the median/quantile regression results for reasons discussed above, panel OLS results were also reported for comparison.

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[9] The climate data were constructed using alternative specifications of the growing seasons (instead of using mid-points). The results were robust to this alternative data construction.

[10] For example, climatic data for the year 1978–1979 refer to a period from July 1978 to June 1979.

Table 2. Descriptive statistics

Variables	Mean	Median	Maximum	Minimum	Std. Dev.	Obs.
Autumn Rice						
Yield (kg/ha)	992.4	926.0	2,224.0	18.0	390.4	594
Daily temperature (ºC)	25.3	25.3	27.1	23.4	0.7	594
Temperature variability (ºC)	2.1	2.1	3.7	1.3	0.4	594
Total rainfall (cm)	89.4	86.3	193.6	19.2	28.0	594
Rainfall variability (cm)	1.3	1.2	3.7	0.3	0.6	594
Fertilizer ('000 kg)	1,274.6	481.7	17,251.0	0.0	2,151.2	594
Area sown (ha)	25,008.9	16,302.5	90,000.0	1,443.0	21,386.1	594
Winter Rice						
Yield (kg/ha)	1,380.0	1,345.5	2,441.0	407.0	329.7	594
Daily temperature (ºC)	25.4	25.3	28.5	23.4	0.8	594
Temperature variability (ºC)	2.7	2.7	4.0	1.8	0.3	594
Total rainfall (cm)	112.8	107.0	280.0	56.1	34.5	594
Rainfall variability (cm)	1.4	1.3	3.9	0.6	0.5	594
Fertilizer ('000 kg)	1,223.1	515.0	14,872.0	0.0	1,900.9	593
Area sown (ha)	75,132.0	75,361.0	155,015.0	5,400.0	31,034.6	594
Summer Rice						
Yield (kg/ha)	1,441.5	1,389.0	3,092.0	139.0	463.7	587
Daily temperature (ºC)	21.6	21.6	24.5	19.6	0.7	594
Temperature variability (ºC)	3.7	3.7	23.2	3.0	0.9	594
Total rainfall (cm)	58.7	55.5	153.5	16.3	20.2	594
Rainfall variability (cm)	0.9	0.8	3.0	0.3	0.3	594
Fertilizer ('000 kg)	1,274.6	481.7	17,251.0	0.0	2,151.2	594
Area sown (ha)	6,323.1	1,500.0	59,833.0	1.0	10,988.5	590

Heterogeneity Across Seasonal Rice Varieties

Table 3 presents the regression results of the baseline specification for all three seasonal rice varieties: autumn, winter, and summer rice. The coefficient estimates for the AC zone dummy variables were not reported. The results showed that an increase in mean daily temperature had a positive effect on autumn rice yield and a negative impact on winter and summer rice yield. However, none of these effects was statistically significant. In general, increased temperatures may decrease crop yield due to spikelet sterility. As Rahman et al. (2017) stated, "rice is hypersensitive to high-temperature stress during panicle development and meiosis causing anomalous pollen maturity and absolute sterility."[11] The fact that no evidence of significant impact

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[11] A situation in which there is no grain within the glumes of the rice plant.

Table 3. Median and panel OLS regression results for autumn, winter, and summer rice

Independent Variable	Median Regression						Panel OLS Regression					
	Autumn Rice		Winter Rice		Summer Rice		Autumn Rice		Winter Rice		Summer Rice	
	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat
Temperature	27.83	1.28	–15.97	–0.69	–5.00	–0.24	29.78	1.32	–9.88	–0.43	–26.71	–1.01
Temperature variability	72.88**	2.14	72.47**	2.15	6.01	0.35	63.49*	1.82	81.93***	2.43	23.66	1.48
Rainfall	–0.15	–0.19	1.19*	1.89	–1.18	–1.17	–0.76	–0.91	1.16*	1.82	–1.93	–1.53
Rainfall variability	–38.32	–0.96	–106.13***	–2.53	82.85	1.42	40.83	0.99	–113.85***	–2.67	74.07	1.04
Trend	15.25***	9.50	20.68***	13.83	32.44***	19.21	13.51***	8.11	21.73***	14.37	27.13***	12.26
Fertilizer	0.001	0.16	0.01	0.87	0.03***	3.42	–0.01	–0.88	0.001	0.23	0.04***	3.96
Area	–0.002**	–2.19	0.00	1.23	0.004*	1.75	–0.002***	–2.68	0.001	1.53	0.003	1.39
Flood dummy	–62.43**	–2.22	36.36	1.45	100.61***	3.80	–124.96***	–4.30	24.94	1.00	84.58***	2.42
Pseudo R-squared	0.39		0.36		0.34		0.57		0.57		0.49	
No. of observations	594		593		587		594		593		587	

Notes: *** Significant at 1 percent level of significance

** Significant at 5 percent level of sign¬ificance

* Significant at the 10 percent level of significance

was found might indicate that the increase in temperature does not yet represent the high-temperature stress that adversely affects the reproductive structure of rice in Assam.

Temperature variability had a positive impact on yield for all three seasonal varieties but statistically significant (at the 5% level) only for autumn and winter rice. One unit increase in temperature variability during the growing season raised the yield by more than 72 kg per hectare for both autumn and winter rice. As noted previously, day-to-day variations in weather conditions such as temperature and rainfall during the growing season have crucial effects on the growth and yield of crops (Mearns, Rosenzweig, and Goldberg 1996; Schlenker and Roberts 2009).

While the exact science behind these effects is under the purview of agrometeorology, the result indicated that increased day-to-day variations in temperature were beneficial for autumn and winter rice in Assam. Rainfall had a significant positive effect only on winter rice yield. A 1 cm increase in total rainfall during the growing season led to an increase of more than 1 kg in median yield of winter rice. In general, rice requires hot and humid conditions. Rainfall increases relative humidity, which in turn may contribute to higher rice yield. Rainfall variability is harmful to autumn and winter rice yield but beneficial to summer rice. However, the negative effect was statistically significant only for winter rice.

Among the control variables, technology trend had significant positive effects on yield for all three seasonal varieties. The yield increase was largest for summer rice. The effects of fertilizer consumption were positive but statistically significant only for summer rice. Note that these results might have been influenced by the fact that fertilizer data were not available separately for rice.[12]

Area had a statistically significant negative effect on the yield of autumn rice and a statistically significant positive effect on summer rice. Although no information about farm sizes was available, the negative (or positive) effect may be indicative of diseconomies (or economies) of scale. The significant negative coefficient for the flood dummy in case of autumn rice suggests that yield was significantly lower in the districts that were frequently and heavily affected by floods. However, flood seemed to be beneficial to other two seasonal varieties although the effect was statistically significant only for summer rice. The higher yield might be due to the fact that the flood water leaves behind soil nutrients beneficial to summer rice cultivation in the flood affected districts. It might also be due to the fact that farmers in flood affected districts put more intensive efforts to its cultivation in order to compensate for lower yields for the other two seasonal varieties.[13]

The panel OLS estimates were qualitatively similar but quantitatively different. Overall, results indicated significant heterogeneity in the effects of changes in temperature and rainfall on yield across seasonal varieties. Since these rice varieties were grown in three different seasons, the results also reflected seasonal heterogeneity of climatic impacts.

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[12] Barnwal and Kotani (2013) also noted this weakness of the fertilizer data for Andhra Pradesh. They also did not find any significant effects of fertilizer on rice yield.

[13] The findings from a field survey reported in Mandal (2014) showed that prolonged water logging from floods rendered winter rice cultivation impossible in the frequently flood-prone areas of Dhubri district. Hence, the farmers in these areas allocated a considerable proportion of total cropped area to summer rice and they put more intensive efforts to its cultivation.

Heterogeneity Across AC Zones

The estimation results of the model with interactions between the climate variables (temperature and rainfall) and AC zone dummies are presented in Table 4. For convenience of interpretation, the net effects of temperature and rainfall for each AC zone were reported. That is, for AC zone 1 (the base against which the impacts in other zones were evaluated), the estimated coefficient value of temperature (and rainfall) was reported, and for zones 2, 3, 4, 5, and 6, the sum of the estimated coefficients for zone 1 and those for the interaction terms between temperature (and rainfall) and the respective zone dummies were taken. The corresponding standard errors for the net effects that were not reported in the table were also calculated.[14] Instead, the t-statistics are indicated.

The results showed that temperature had a significant positive effect on autumn rice yield in zone 2 (Central Brahmaputra Valley zone). A 1°C increase in mean daily temperature led to about 177 kg/ha increase in median yield for this seasonal variety in that zone. Furthermore, it had a positive effect on autumn rice yield in zones 1, 3, and 4, and negative effects in zones 5 and 6; although, these effects were not statistically significant.

For winter rice, increase in temperature was harmful in all but zones 2 and 6. However, the negative effect was statistically significant only in zone 5 (Hill zone). In contrast, the positive effects in zones 2 and 6 were relatively large and statistically significant. Finally, an increase in temperature was beneficial to summer rice yield in zones 1, 2, and 4. The positive effect was not statistically significant in zone 4. In contrast, the negative effect was large and statistically significant only in zone 3.

Thus, an increase in temperature was found to be beneficial to all three seasonal varieties of rice in the Central Brahmaputra Valley zone, while it was harmful for all three varieties (although significantly so only for winter rice) in the Hill zone. Additionally, it was favorable to winter rice yield in the Barak Valley zone and detrimental to summer rice yield in the North Bank Plain zone.

The effect of an increase in total rainfall during the growing season on autumn rice yield was negative in all but zone 3. None of these effects was statistically significant. In contrast, rainfall had significant positive impacts on winter rice yield in zones 1, 3, and 6 where a 1 cm increase in total rainfall raised median yield by 1.43, 2.92, and 3.96 kg/ha, respectively. Finally, rainfall was beneficial for summer rice in zones 1 through 3 and harmful in zones 4 through 6. However, the effect was statistically significant only in zone 3. Thus, higher rainfall was beneficial to winter rice yield in the Lower Brahmaputra Valley and North Bank Plain zone (a contiguous geographic region to the north of the Brahmaputra River) and the Barak Valley zone in the southern part of Assam. The effects of temperature and rainfall variability, and other control variables were similar to those reported in the previous sub-section.

As before, the panel OLS estimates were qualitatively similar but there were quantitative differences. Overall, the results demonstrated substantial heterogeneity in terms of magnitude, direction, and statistical significance in the effects of temperature across various AC zones of Assam. The differences

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[14] The following formula was used to calculate the *SE*s of the net effects:

$$SE(net\ effect\ in\ zone\ j) = \sqrt{[SE(\hat{\beta}_{1q})]^2 + [SE(\hat{\beta}_{jq})]^2 + 2Cov(\hat{\beta}_{1q}, \hat{\beta}_{jq})}$$

where $SE(\hat{\beta}_{1q})$ is the estimated SE of the estimated coefficient of temperature for the *q*th quantile (*q* = 25th, 33rd, 50th, 67th, and 75th) in zone 1; $SE(\hat{\beta}_{jq})$ is the *SE* of the estimated coefficient of the interaction term between temperature and zone *j* dummy for the same quantile in agro-climatic zone *j* (*j* = 2, 3, 4, 5, and 6), and $Cov(\hat{\beta}_{1q}, \hat{\beta}_{jq})$ is the estimated covariance between $(\hat{\beta}_{1q})$ and $(\hat{\beta}_{jq})$.

Table 4. Median and panel OLS regression results for autumn, winter, and summer rice across AC zones

Independent Variable		Median Regression						Panel OLS Regression					
		Autumn Rice		Winter Rice		Summer Rice		Autumn Rice		Winter Rice		Summer Rice	
		Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat
Temperature													
	AC zone 1	36.99	1.05	−40.12	−0.95	68.57*	1.76	48.00	1.29	−16.27	−0.38	1.31	0.03
	AC zone 2	177.09***	2.56	200.84**	2.08	174.87**	1.96	96.79	1.34	253.04***	2.74	110.45	1.21
	AC zone 3	56.61	1.36	−56.72	−1.47	−144.51***	−3.11	29.83	0.68	−89.16**	−2.31	−160.91***	−2.97
	AC zone 4	27.81	0.62	−42.12	−0.84	17.58	0.37	−0.68	−0.01	−30.83	−0.63	29.01	0.52
	AC zone 5	−67.13	−1.08	−200.22***	−2.51	−59.95	−0.72	−23.52	−0.36	−93.92	−1.21	−116.55	−1.34
	AC zone 6	−41.95	−0.71	251.56***	3.24	−25.94	−0.35	−44.18	−0.70	264.55***	3.44	56.41	0.70
Temperature variability		76.51**	2.26	120.65***	3.42	4.28	0.25	50.79	1.40	100.56***	2.87	20.85	1.24
Rainfall	AC zone 1	−1.10	−0.84	1.43*	1.88	1.47	0.76	−1.81	−1.30	1.29*	1.71	0.86	0.36
	AC zone 2	−1.01	−0.40	−0.09	−0.04	5.61	1.17	−1.59	−0.61	−1.23	−0.64	6.07	1.20
	AC zone 3	0.65	0.57	2.92***	3.35	3.63**	2.19	−0.06	−0.05	2.58***	2.94	−1.00	−0.51
	AC zone 4	−0.91	−0.95	0.44	0.53	−0.62	−0.47	−0.93	−0.91	0.64	0.78	−1.87	−1.17
	AC zone 5	−4.23	−1.62	−0.03	−0.01	−2.38	−0.53	−2.32	−0.84	−0.42	−0.21	−2.58	−0.53
	AC zone 6	−0.82	−0.69	3.96***	2.92	−1.78	−1.12	−1.41	−1.12	3.79***	2.82	−2.80	−1.53
Rainfall variability		−8.41	−0.20	−117.38***	−2.73	34.86	0.59	56.85	1.30	−126.58***	−2.95	55.22	0.76
Trend		14.76***	9.43	20.81***	13.61	32.28***	18.43	13.81***	8.10	21.89***	14.12	27.24***	12.17
Fertilizer		0.001	0.10	−0.002	−0.30	0.02***	2.39	−0.006	−0.87	−0.005	−0.71	0.036***	3.27
Area		−0.001	−1.59	0.001**	2.08	0.004*	1.70	−0.002***	−2.71	0.001	1.43	0.004	1.62
Flood dummy		−74.04***	−2.67	65.74***	2.62	93.76***	3.27	−127.28***	−4.29	33.19	1.29	90.08***	2.50
Pseudo R-squared		0.40		0.38		0.35		0.56		0.58		0.49	
No. of observations		594		593		587		594		593		587	

Notes: *** Significant at 1 percent level of significance; ** Significant at 5 percent level of significance; * Significant at 10 percent level of significance in the effects of rainfall were relatively less pronounced. Since AC zones represented not only the spatial variations in climatic conditions but also the differences in soil quality, changes in temperature and rainfall and their variability interacted with the soil quality to produce the specific impacts as described above.

Heterogeneity Across Yield Distribution

The quantile regression results for the 20th, 40th, 60th, and 80th quantiles of the yield distribution are presented here. Only the estimated net effects of climate variables are reported separately for autumn, winter, and summer rice, respectively in Panels A, B, and C of Table 5.

The effect of temperature on autumn rice was positive for all quantiles in zones 1, 2, and 3 but statistically significant at conventional levels only for the 80th quantile in zone 1, the 40th and 60th quantile in zone 2, and the 40th quantile in zone 3. The significant positive effects were also quantitatively larger than those that were not significant. In contrast, the impact of increase in temperature was negative for the 20th and 80th quantiles in zone 4, all but the 80th quantile in zone 5, and all quantiles in zone 6. These negative effects were statistically significant at the conventional levels for all but the 40th quantile only in zone 6.

In contrast, significant negative effects of increase in temperature on winter rice yield was found for all but the 20th quantile in zone 3, and only the 60th quantile in zone 5. In these two zones along with zones 1 and 4, the effect of temperature was negative for almost all quantiles. However, temperature had significant positive effects on winter rice yield for all quantiles in zones 2 and 6. The positive effects were also quantitatively larger. Finally, temperature had significant negative impacts on summer rice yield for all four quantiles in zone 3 and the 20th quantile in zone 5. These negative effects were also quantitatively large. Furthermore, temperature had significantly large positive effects on summer rice yield for the 60th and 80th quantiles in zone 2, and for the 20th quantile in zone 6.

Temperature variability had statistically significant positive impact on autumn and winter rice yields for all four quantiles of their distributions considered here. However, there were quantitative differences across quantiles with relatively larger impact on the lower end of the distribution. Finally, the effect of temperature variability was significantly positive only for the 80th quantile of summer rice distribution. These results are broadly consistent with the earlier results reported in Tables 3 and 4 but highlighted the distributional heterogeneity in climatic impact.

The effects of total precipitation on autumn rice yield were positive for all quantiles in zone 3 and negative for most quantiles in other zones. However, the negative effects were statistically significant only for the 40th quantile in zone 5 and 60th quantile in zone 6. In the case of winter rice, rainfall had positive effects on yield for all four quantiles in zones 1, 3, and 6. However, these effects were statistically significant only for the 60th quantile in zone 1, for all but the 20th quantile in zone 3, and for the 20th and 60th quantiles in zone 6. The positive impact of rainfall was also statistically significant for the 60th quantile in zone 4. The negative effects of rainfall for all but the 60th quantile in zone 2, the 80th quantile in zone 4, and the 20th and 80th quantiles in zone 5 were not statistically significant. Finally, rainfall had positive effects across the yield distribution for summer rice in zone 2 and negative effects in zone 4, but these effects were statistically significant only for the 40th and 80th quantiles in zone 2. Moreover, the positive effects were statistically significant for the 80th quantile in zone 1 and for the 40th and 80th quantiles in zone 3, while the negative

Table 5. Quantile regression results for autumn, winter, and summer rice

Independent Variable		20th Quantile		40th Quantile		60th Quantile		80th Quantile	
		Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat
Panel A: Autumn Rice									
Temperature									
	AC zone 1	10.30	0.27	26.59	0.84	47.19	1.26	72.89**	1.96
	AC zone 2	69.11	0.86	140.61**	2.13	118.95*	1.64	114.72	1.45
	AC zone 3	12.21	0.27	63.46*	1.69	48.87	1.11	41.71	0.93
	AC zone 4	–17.54	−0.36	1.15	0.03	25.18	0.53	−51.16	−1.06
	AC zone 5	−72.31	−0.99	−96.67	−1.63	−47.53	−0.72	38.06	0.54
	AC zone 6	−131.39*	−1.95	−80.13	−1.47	−151.09***	−2.41	−158.94***	−2.41
Temperature variability		103.91***	2.88	84.33***	2.84	91.19***	2.54	90.72***	2.53
Rainfall	AC zone 1	−1.53	−1.06	−1.03	−0.88	−0.24	−0.17	0.52	0.36
	AC zone 2	−1.15	−0.40	−0.33	−0.14	−2.28	−0.87	−2.01	−0.70
	AC zone 3	0.27	0.22	0.56	0.54	0.62	0.52	1.40	1.13
	AC zone 4	−0.61	−0.59	−0.45	−0.53	−0.40	−0.39	0.57	0.54
	AC zone 5	−2.72	−0.88	−4.85*	−1.97	−2.25	−0.82	−0.68	−0.23
	AC zone 6	−0.99	−0.74	−0.90	−0.82	−2.14*	−1.68	−1.14	−0.87
Rainfall variability		21.12	0.47	−0.79	−0.02	−7.43	−0.17	−25.30	−0.56
Panel B: Winter Rice									
Temperature									
	AC zone 1	9.90	0.23	−37.33	−0.81	−41.68	−1.13	3.77	0.08
	AC zone 2	234.05**	2.25	178.36*	1.73	207.85**	2.30	302.57***	2.71
	AC zone 3	−22.66	−0.56	−72.25*	−1.72	−65.95*	−1.90	−107.03***	−2.36
	AC zone 4	57.64	1.09	−6.21	−0.11	−48.33	−1.07	−88.76	−1.54
	AC zone 5	−11.70	−0.14	−112.49	−1.32	−189.73***	−2.50	−66.42	−0.72
	AC zone 6	292.76***	3.50	258.53***	3.09	292.72***	4.08	382.20***	4.21
Temperature variability		109.31***	3.10	103.51***	2.71	106.26***	3.49	70.42*	1.76
Rainfall	AC zone 1	0.83	1.06	0.84	1.02	1.57***	2.33	1.13	1.29
	AC zone 2	−2.75	−1.26	−1.21	−0.57	0.31	0.16	−1.42	−0.61
	AC zone 3	0.08	0.09	1.95**	2.05	2.83***	3.65	3.33***	3.25
	AC zone 4	0.36	0.42	0.27	0.30	1.18*	1.65	−0.32	−0.33
	AC zone 5	−2.11	−0.93	0.62	0.28	2.50	1.27	−1.76	−0.73
	AC zone 6	7.12***	5.00	2.40	1.63	2.61**	2.13	1.00	0.64
Rainfall variability		−83.08*	−1.89	−87.97*	−1.87	−148.87***	−3.96	−128.06***	−2.58

Notes: *** Significant at 1 percent level of significance
** Significant at 5 percent level of significance
* Significant at 10 percent level of significance

Table 5. Continuation

Independent Variable	20th Quantile		40th Quantile		60th Quantile		80th Quantile	
	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat	Est. coeff	t-stat
Panel C: Summer Rice								
Temperature								
AC zone 1	25.65	0.55	55.38	1.34	1.27	0.04	–4.47	–0.12
AC zone 2	42.75	0.39	140.52	1.48	161.98**	1.98	189.92**	2.21
AC zone 3	–209.06***	–3.68	–172.06***	–3.39	–173.48***	–4.08	–107.97***	–2.45
AC zone 4	15.42	0.27	–13.84	–0.27	46.60	1.07	23.15	0.53
AC zone 5	–220.33**	–2.15	–59.49	–0.67	–38.42	–0.51	–69.75	–0.88
AC zone 6	155.16*	1.73	–12.92	–0.16	–23.22	–0.35	–90.35	–1.30
Temperature variability	10.47	0.54	11.57	0.66	–3.13	–0.18	112.32***	6.38
Rainfall								
AC zone 1	–0.20	–0.09	0.40	0.19	0.75	0.41	4.96***	2.75
AC zone 2	3.37	0.57	10.04**	1.96	5.30	1.23	13.16***	2.90
AC zone 3	–3.29	–1.62	3.34*	1.86	1.19	0.78	3.28**	2.11
AC zone 4	–1.66	–1.05	–1.85	–1.31	–1.04	–0.85	–0.45	–0.36
AC zone 5	–6.17	–1.12	–2.94	–0.61	–0.97	–0.24	3.09	0.72
AC zone 6	–4.00**	–2.08	–3.90**	–2.29	–0.63	–0.43	1.45	0.98
Rainfall variability	83.70	1.19	78.56	1.24	28.18	0.51	–140.38***	–2.51

Notes: *** Significant at 1 percent level of significance
** Significant at 5 percent level of significance
* Significant at 10 percent level of significance

effects were significant only for the 20th and 40th quantiles in zone 6.

The effects (positive or negative) of rainfall variability on autumn rice yield were not statistically significant for the four quantiles. For winter rice, significant negative impact of rainfall variability was robust across different quantiles. In contrast, the positive effects of rainfall variability on summer rice yield for first three quantiles of its distribution were not statistically significant. However, the negative effect on the 80th quantile was large in magnitude and highly significant. While these results clearly demonstrate heterogeneous impacts of climate change on rice yields along different dimensions, the explanation for these results would require in-depth investigation in the fields of agronomy and agrometeorology, which is beyond the scope of this paper.

To summarize, of the 24 cases (6 AC zones × 4 quantiles) for each seasonal variety, a change in temperature had statistically significant impacts on yield in seven cases (4 positive and 3 negative) for autumn rice, in 12 instances (8 positive and 4 negative) for winter rice, and in 8 cases (3 positive and 5 negative) for summer rice. Similarly, a change in total rainfall had significant impacts on yield in only 2 cases (both negative) for autumn rice, in 7 cases (all positive) for winter rice, and in 7 cases (5 positive and 2 negative) for summer rice. These results demonstrate substantial heterogeneity in the impacts of temperature and rainfall on yield across seasonal rice varieties, AC zones, and the yield distribution of each variety in all six zones.[15]

To gain a clear overall perspective on these heterogeneities, the estimated coefficients (net effects) for different quantiles for all zones and all seasonal rice varieties were plotted (Figure 2). For easy comparison across seasonal rice varieties, the scale on the vertical axis was kept constant across varieties. This represents changes in rice yield per hectare. Each chart in the figure clearly shows the differences in the impact of temperature and rainfall across yield distribution and AC zones for each seasonal variety of rice. Looking across charts, substantial variations can be seen in the effects of temperature and rainfall across seasonal rice varieties without losing sight of within-variety heterogeneities.

That evidence of positive effects of temperature and rainfall in several instances was found is interesting, as people would generally expect, and some other studies (e.g., Barnwal and Kotani 2013) have shown these to have negative impacts. However, the results seem to be quite consistent with the relatively recent findings that the effects of climate variables are non-linear. For example, studies showed that temperature has a positive impact on crop yield until it reaches a threshold, after which, there is a decline in crop yield. In the instances where positive impact was found, the temperature might not have reached the critical threshold and, as such, positive effect was still observed. A similar explanation may apply to the effects of rainfall as well.

CONCLUSIONS AND IMPLICATIONS

This paper presented evidence of heterogeneity in climatic impacts on agricultural yield. Applying the non-parametric quantile regression technique to district-level data from 1978 to 2005, it examined heterogeneity in the impacts of temperature and rainfall across rice varieties grown in different seasons of the year, AC zones, and distribution of rice yield in Assam, India. The results suggested that, in general, the effects of temperature on yield were not statistically significant for any of the three seasonal rice varieties. However, these effects were not uniform in their magnitudes, signs, and statistical significance across AC zones and yield distribution for each variety of rice. Similarly, there were wide variations in the effects of total precipitation across seasonal varieties, AC zones, and yield distribution. The results also suggested that an increase in temperature variability is beneficial and that rainfall variability is harmful to autumn and winter rice yield. For summer rice, although the effects of these two variables were positive, these were statistically insignificant.

Given the importance of rice yield for food security and poverty alleviation in Assam, these results could be informative in designing appropriate adaptation strategies and public policies to counter the adverse impacts of climate change on agriculture in the state. Furthermore, since most people in rural areas are engaged in agriculture, these results are important for the sustainability of rural economies as well. For example, while positive impacts of rising temperature should encourage farmers in most parts of the Brahmaputra Valley to grow more autumn rice, the adverse impacts should discourage them to do so in the Hill zone and in the Barak Valley zone.

In contrast, since temperature has significant beneficial effects on winter rice yield in the Barak Valley, the farmers should

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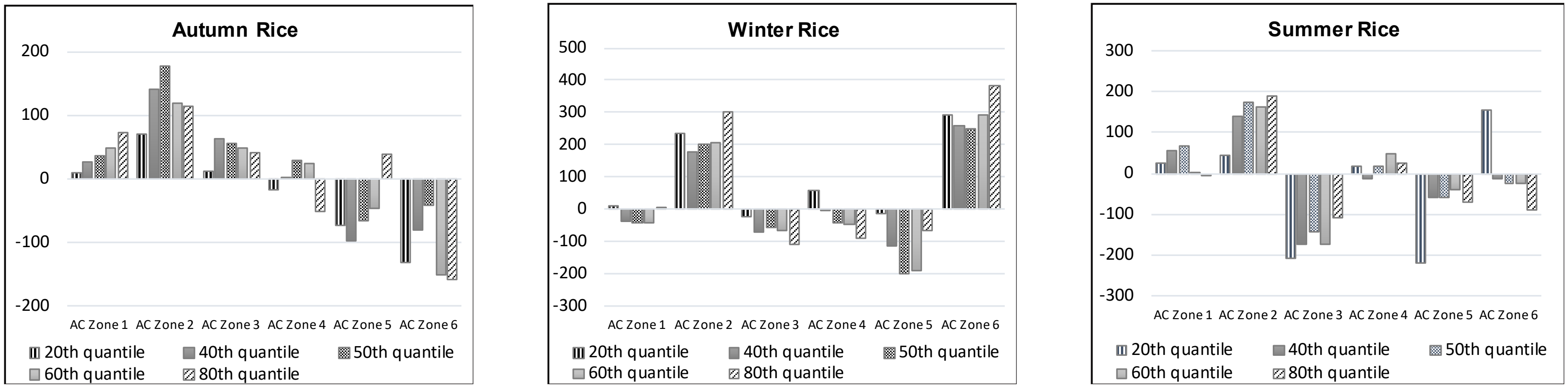
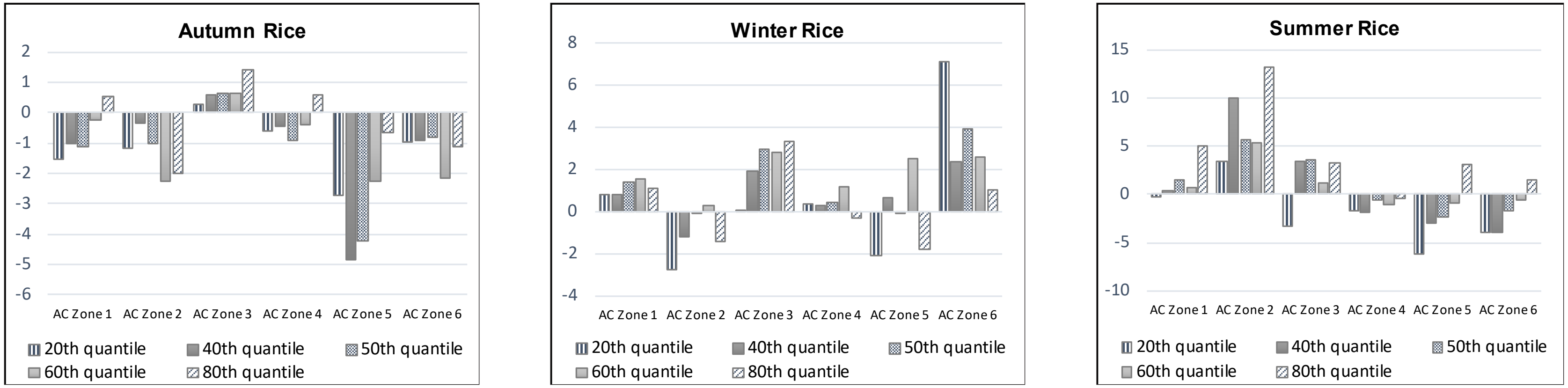
[15] The alternative specifications for each of the three seasonal rice varieties with additional variables for irrigation, the use of high yielding variety (HYV) seeds, and drought were estimated. In general, the results with respect to the effects of temperature and rainfall on rice yield were qualitatively not different. To save space, these results were not included in this paper.

Figure 2. Relative variations in the effects of temperature and rainfall on the distribution of rice yield

Effects of temperature: change in yield (kg/ha) due to an increase in mean daily temperature by 1º C during the growing season



Effects of rainfall: change in yield (kg/ha) due to an increase in total rainfall by 1 cm during the growing season



focus more on this seasonal variety of rice. Similarly, temperature had adverse effects on the yield of winter and summer rice in the Central Brahmaputra zone but favorable effects on autumn rice yield. Therefore, the farmers in that zone may focus more on growing autumn rice. Further, while increasing precipitation is beneficial only for winter rice in the Barak Valley zone, it is favorable only for summer rice in the North Bank Plain zone. Thus, these findings not only provide guidance as to which cropping pattern to choose in order to ensure food security but also inform the policymakers to design relevant public policies that provide incentives and necessary help to the farmers to adopt the appropriate cropping strategies.

Finally, there are caveats that need to be noted. First, and as earlier noted, it has been beyond the scope of this paper to determine and explain the possible agronomic reasons for the directions and magnitude of temperature and rainfall effects across ACs and seasonal rice varieties. Second, the effects of climate change may vary at different stages of rice production: sowing/planting, growing, and harvesting. By considering the period between sowing/planting and harvesting, the growing period, which is an important stage in rice production, was primarily covered. Thus, there is scope for examining climatic impacts on rice yield during sowing/planting and harvesting period as well. However, as discussed above, there are substantial variations in sowing and harvesting time across districts and locations. It would be an onerous task to examine the climatic impacts at these stages with so much heterogeneity. This is a limitation of the present study and would be a worthwhile subject for future research.

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