Analysing the Impact of Climate Change on Cotton Productivity in Punjab and Sindh, Pakistan

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ABSTRACT

The study analyses the impact of climate change on productivity of cotton in Pakistan using the district level disintegrated data of yield, area, fertilizer, climate variables (temperature and precipitation) from 1981-2010. Twenty years moving average of each climate variable is used. Production function approach is used to analyse the relationship between the crop yield and climate change. This approach takes all the explanatory variables as exogenous so the chance endogenity may also be minimized.

Separate analysis for each province (Punjab and Sindh) is performed in the study. Mean temperature, precipitation and quadratic terms of both variables are used as climatic variables. Fixed Effect Model, which is also validated by Hausman Test, was used for econometric estimations. The results show significant impact of temperature and precipitation on cotton yields. The impacts of climate change are slightly different across provinces—Punjab and Sindh. The negative impacts of temperature are more striking for Sindh. The impacts of physical variables—area, fertilizer, P/NPK ration and technology, are positive and highly significant. The results imply educating farmers about the balance use of fertilizer and generating awareness about the climate change could be feasible and executable strategies to moderate the adverse impacts of climate change to a reasonable extent.

Keywords: Climate Change, Cotton Productivity, Production Function, Fixed Effect Model, Linear Effects and Marginal Effects

1. INTRODUCTION

Anthropogenic activities are a source of rising concentration of greenhouse gases which in turn are the major reasons of global warming and other changes in climate [Zilberman, *et al*. (2004)]. The climate change is characterised by rising temperature, erratic and lower rainfall—declined frequency but with greater intensity, changing seasons, and occurrence of extreme events—floods and droughts. These changes pose serious threats to various sectors of economies. However, the agriculture sector is more vulnerable to these changes, since around 60 percent of agricultural production is determined by the suitability of weather conditions [Deshmukh and Lunge (2012)]. Therefore, this sector has gained particular attention of the researchers to analyse its impacts on agriculture and adaptation options. It has been argued that adaptations to climate change have the potential to lower the adverse impacts. Low income countries—particularly having higher dependence on agriculture, likely to be affected more in future because of low adaptive capacity [Holst, *et al*. (2010) and Schlenker, *et al*. (2006)]. It is crucial to understand the dynamics of climate change and its impacts on agriculture.

Pakistan's economy is semi-industrialised and agriculture stands as the third largest sector[1] of the economy [Henneberry, *et al.* (2000)]. However, the importance of agriculture cannot be negated as it is the largest source of food and fibre. This sector plays an important role in poverty alleviation and ensuring food security. Recent statistics show that the sector contributes around 21 percent to GDP, employs 44 percent of labour force, and directly or indirectly provides livelihood to 60 percent of the rural population. Agriculture includes livestock, major crops, minor crops, forestry, and fisheries. The share of important crops[2] is 25.2 percent in agriculture value addition. Production of crops is primarily affected by the availability of water, which in turn mainly depends on the precipitation (monsoon seasons). Crops like rice and cotton (*Kharif* season) are grown in summer which is characterised by very high temperature in most areas of Pakistan [Pakistan (2013)].

Pakistan's Agriculture is both rain-fed and irrigated but cotton crop is normally sown in the irrigated and semi-arid areas due to its water requirement

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[1]After services and Industrial sectors

[2]Important crops include the wheat, rice, maize, cotton, and sugarcane.

for proper growth [Naheed and Rasul (2010)]. Cotton is grown in the areas of Punjab and Sindh which receive low seasonal precipitation and have high temperature. As climate change is a threat to water resources so it also imperils the production of food and fibre [Zhu, *et al*. (2013)]. Though cotton is not high water consuming crop but low public awareness and technical inability makes Pakistan more prone to climate change [Sayed (2011)]. Cotton crop of Pakistan has faced many challenges like pest attack, climatic variation and price volatility. Although, the problem of pest attack has considerably been reduced by the introduction of Bt. (*Bacillus thuringiensis*) cotton but the climatic variations which have been independent of this new cotton innovation do have serious implications for the cotton production system [Huang, *et al*. (2003)].

Although, Pakistan is not a very active contributor in greenhouse gas emission but is highly vulnerable[3] to climate change due to its geographical location [Sayed (2011)]. Cotton is contributor, by pesticide residuals, as well as victim of climate change. Escalating temperature causes high evapotranspiration which results in water stress thus reduce the plant growth and also crop productivity. The impact of high variations in precipitation from mean value negatively impacts cotton productivity [Iqbal (2011)].

Pakistan is the fourth major producer of cotton in the world[4] [Pakistan (2013)]. The cotton belt is spread over the 1200km of Indus delta. The soil characteristics vary from sandy loam to clay loam. Irrigation is adapted to meet the primary water requirement of crop in high temperature and low rainfall as a supplementary source. Climate change may also impact the availability of irrigational water which also impacts the crop productivity negatively [Zhu, *et al.* (2013)] especially for food crops. However, limited literature is available on fibre crops' analysis. In Pakistan, cotton average fibre content and boll weight are low due to high temperature. Cotton crop in Pakistan is grown under irrigated to semi-arid, mostly in high temperature and low rainfall conditions, and is tolerant to high temperature and water stress to some extent due to its vertical tap root system. However, the crop is sensitive to water availability at flowering and boll formation [ITC (2011)]. High temperature also makes the crop more vulnerable to pest attack and usual response of crop is loss of vegetative and fruiting parts[5] [ITC (2011)].

International Trade Centre's Technical Paper [ICT (2011)] states that cotton is grown successfully under the temperature ranging from 28.2^0C in China to 41.8^0C in Sudan—in Punjab (Pakistan) average seasonal temperature is around 36.8^0C. The historical experience, however shows that the heat stress is a major constraint in production of cotton in various countries including Pakistan, India and Syria, and further rise in temperature could damage the cotton economy in

[3]Pakistan ranked as 8th in the global vulnerability risk Index 2013.
[4]1st is China, 2nd India and 3rd USA.
[5]Flowers and bolls.

countries/regions where it is already grown at a temperature close to 40^0C (ICT, 2011). Unfortunately, Pakistan falls in that category. The livelihood of millions of farmers and industrial labourers depend upon cotton economy in Pakistan. Therefore, the understanding of cotton-climate relationship is important for their welfare.

A number of studies have already analysed the impact of climate change on cotton crop for different countries and regions. However, in Pakistan almost all studies focused on the impact of climate change on food crops like Shakoor, *et al*. (2011), Ashfaq, *et al*. (2011), and Ahmad, *et al*. (2014a and 2014b)]. Siddiqui, *et al*. (2012) analysed the impact of climate change on major crops including cotton but took only selected districts from Punjab. Some of them are even minor producers of cotton, and included only climatic variables—took only the average temperature and precipitation from May to September which does not cover the whole season. The present study is thus particularly designed to quantify the impacts of climate change and weather shocks on cotton productivity in major cotton producing areas of Pakistan.

2. DATA AND EMPIRICAL MODEL

2.1. The Data

Climatic data—temperature and precipitation is obtained from the Pakistan Meteorological Department and data on production and inputs are obtained from various published sources including Agriculture Statistics of Pakistan and NFDC fertiliser surveys. Thirty districts have been included for the purpose analysis.[6] The bases of including these districts in the analysis have been the 'major cotton producing districts' and availability of data for at least 30 years—1981 to 2010.[7]

Variables

Cotton Productivity (Y) is defined as production of seed cotton per hectare which is used as a target variable to evaluate the impact of climate change variables on cotton crop. Empirical studies like Dherty (2003) and Sankaranarayanan, *et al*. (2010) used this variable to analyse the productivity and climate change relationship.

Input variables include cultivable area of the district, area under cotton crop, chemical fertiliser, pesticide, machinery, etc. Due to some data limitations, some variables are not available at the district level, like irrigation. However, the

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[6]Bhakhar, Bahawalpur, Bahawalnagar, D G Khan, Faisalabad, Jhelum, Jhang, Khushab, Kasur, Layyah, Mianwali, Muzafar Gharh, Multan, Okara, Rajanpur, Rahim Yar Khan, Sargodha, Sahiwal, Toba-take Singh, and Vehari from Punjab. Badin, Dadu, Hyderabad, Jacobabad, Khairpur, Larkana, Nawabshah, Sukhur, Sanghar, and Thatta from Sindh.

[7]Because for climate change analysis at least 30 year data of climate variable is required [Mendelsohn, *et al.* (1994)].

construction of panel for the analysis will capture the effect of omitted variables. Following You, *et al*. (2009) and Schlenker, *et al.* (2006), the study also assumes the homogeneity of cultural practices—like ploughing, drilling and other field operations, within district for cotton crop.

Area under the Cotton Crop (Land) is an important variable that helps identify the return to scale in production of the crop [Kaufman (1997); and Ahmad and Ahmad (1998)]. The variable is measured in hectares.

Fertiliser includes Nitrogen, Potash, and Phosphorus (NPK) in nutrient tonnes per hectare. As fertiliser data available at the district level is in aggregated form used all crops, we extracted data of fertiliser applied to cotton crop using the following formulation:

$$FCC = share\,\mathrm{FC} \times \mathrm{TAF}$$

Where FCC is fertiliser applied to cotton crop at the district level, while *share FC* is the share of fertiliser consumption at various time periods obtained from various reports of the National Fertiliser Development Centre and TAF represents total off take of fertiliser in each district.

Regional Production Specialisation (RPS): This variable is constructed by taking a ratio between 'cotton cropped area at the farm' divided by 'total farm cropped area'. This variable acts as a proxy measure of the suitability of land and environment [You, *et al*. (2009)].

Climate Change Variables relate to mean monthly temperature and precipitation. The effect of temperature differs at every stage of plant growth [Schlenker, *et al.* (2006); Tsiros (2008); and Deshmukh and Lunge (2012)]. Therefore, the total production period of cotton is divided into four stages based on phenological properties of the plant. The first is the *germination stage (VG)* requiring higher temperature—that is why the sowing is done in May. The second is the *vegetative stage*—the formation of stem and broadening of leave, requiring moderate temperature with some level of humidity. However, very high temperature and humidity will result in shedding of leaves and pest attack. This stage covers the months of June-July which are the most critical months for harvesting a good crop. *Flowering and fruit formation (FFF)* is the third stage, which covers the months of August and September and requires moderate temperature and low rainfall. During this stage cotton plants are more prone to pest attack and any increase in temperature or rainfall will cause greater invasion of pests, and flower and boll shedding. Fourth stage is *picking*—during this period the process of lint formation also continues. Lint quality is highly affected by the higher temperature. Therefore, during this stage, crop usually requires moderate temperature ranging between 27^0C to 30^0C, and therefore, exposure of cotton crop to higher temperature normally results in reduced thread length affecting yield and quality as well. This stage is normally spanned over the months of October and November.

We have also introduced a dummy variable (D_{bt}) to capture the effects of Bt cotton grown in the area. The cotton growers have been facing various challenges in its production—like pest attack, high variations in temperature, erratic rainfalls, and water stresses, since long. However, the problems of pest attack and cotton leaf curl virus have been very serious. The issue of pest attack has got resolved to a great extent by the introduction of Bt cotton since it has special genotype that causes the death of boll warm-chewing pests—but the crop remained prone to sucking pests [Abid (2011)]. In May 2005, NIBGE[8] officially approved Bt cotton and introduced six of its varieties. Its cultivation remained low initially; however, with the passage of time the adoption of Bt varieties increased exponentially—raising the area under these varieties to over 85 percent of the total cotton area in Pakistan. Sowing time of Bt cotton differs from conventional varieties and is normally grown earlier than the traditional varieties [Abdullah (2010)]. To tackle this issue, we divided the data period into two groups—D_{bt} variable assumes the value of 1 for the period 2006 and after, while zero otherwise. The D_{bt} is then interacted with temperature and precipitation at the time of its sowing—March to April.

Following Cabas, *et al*. (2010), Ahmad, *et al*. (2014a and 2014b), we use 20 years moving averages of mean temperature and total precipitation during different phonological stages to capture the impacts of climatic variables in the long-run. The effects of climatic shocks are captured by taking the deviations of climatic variables from the respective long-term means [Cheng and Chang (2002); Ahmad, *et al.* (2014a and 2014b)].

2.2. Methodology

2.2.1. *Methodological Framework*

Analysis of crop productivity and climate change has been greatly debated in literature. Three different kinds of methodologies are reported in the literature. Mundlak, *et al*. (1978 and 1999), Cabas, *et al*. (2010) and Holst, *et al*. (2010) used production function approach. Mendelsohn, *et al*. (1994) applied Ricardian approach. Reddy, *et al.* (2002) used agronomic crop simulation model for such analyses.

Ricardian approach is used to measure the effect of climate change on agricultural land values. This framework uses the land value or net revenue as dependent variable so any impact of climate change on crop production will be reflected by the change in the net revenue or land value. This model has specific advantage as it incorporates the adaptive response of farmers and crop substitution effect of climate change [Mendelsohn, *et al*. (1994)]. However, this methodology normally uses farm level cross-sectional data and thus may face omitted variable

[8]National Institute for Biotechnology and Genetic Engineering, Faisalabad.

problem. Since variables like soil characteristics[9] and irrigation practices are spatially correlated with the climate of that area. Therefore, correlation among these variables may result in omitting these variables. Nonetheless, the effect of these variables shall reflect in the coefficients of climate variables which lead to biased estimates [Schlenker, *et al*. (2006)]. Moreover, this approach assumes perfect foresight and thus adaptations to climate change accordingly. However, if the predicted climate change is much larger than that yielded by this approach that may not capture the adaptation completely, besides it also uses constant price assumption and zero adjustment cost; therefore, yields lower bound of estimates [Kumar (2011)]. Furthermore, this methodology analyses the impact of climate change on land value or net revenue for a specific area instead of quantifying its impact on yield. The land markets of developing countries may not reflect the productivity of crops because of market imperfections [Haim and Berliner (2008)].

Although, agronomic models are mostly used in analysing the impact of climate change on crop production, these models are not free of criticism and limitations. They use the data of physiological processes and most variability is explained by non-linear forms of these variables [Schlenker, *et al.* (2006)]. The physiological process of plant growth is very complex and dynamic in nature which may not be easily captured by regression analysis [Schlenker, *et al*. (2009)].

Another application for analysis is the use of production function. Production function can be defined as "relationship between the maximal technical feasible output and input needed to achieve this output [Mishra (2007)]". Production function approach was introduced by Solow (1956) using aggregate economy level data. This was extended by many researchers for analysis of the panel data. Mundlak (1999 and 1978) estimated agricultural production function using environment as input in crops production process. The main feature of production function approach is that all the left hand side variables are exogenous and the error term has no relationship with these explanatory variables, and therefore the chances of endogeneity are minimised [Holst, *et al*. (2010)]. Moreover, the production function approach is based on the scientific experiment and thus this methodology is explicitly links the crop yield with climate. Production function approach also gives simple and conveniently interpretable results of analysis using the full set of available information [Haim and Berliner (2008)].

Two types of functional forms are normally used in agricultural production analyses studies including CD—Cobb-Douglas [Cobb and Douglas (1920)] and Transcedental (Translog) [Halter, *et al*. (1957)]. The latter is in fact an extension of the former and exhibits more flexibility, including the non-constant elasticity of production, while the CD yields the constant production elasticity. However,

[9]Which include the type of soil, texture and color etc.

the translog production function includes log-linear terms as well as square and interactions terms and therefore requires many parameters to be estimated.

The general form of a production function can be written as

$$Y_i = f(X_i) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Where i is the production unit—a district is assumed in this study, and i=1,2,3,….,n. Y_i is output produced using X_i inputs. We assume production technology does not vary across the cross-sections of districts. Therefore, the introduction of technology variable will have almost the same impact in all districts (Ali, 2010). The efficiency of input use and technology is affected by the climatic conditions and the soil characteristics of the specific area [Deressa (2011)]. Solow (1956) examined economic growth of an economy by introducing broader definitions of capital and labour as inputs. In agriculture, these broad terms are disaggregated into various inputs which have great importance for agricultural production [Mundlak (1999)].

The present study uses panel data and assumes homogenous technology across districts [Ali (2010)]. The production function using district level panel can be written as

$$Y_{it} = f(X_{it} C_{it}) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

where i represents cross-section i=1,2,3,…..n and t represents time t=1,2,3,….,T. Y_{it} represents seed cotton output per hectare of land. X_{it} is vector of physical input variables, while C_{it} is vector of climate related variables.

In studies related to climate change, climate variables are normally taken in linear form while the other physical input variables used in function are converted into log forms [Kaufmann and Snell (1997)]. For brevity, we would use modified form of Cobb-Douglas production function that can be written as [Halter, *et al*. (1957)].

$$Y_{it} = f(X_{it}^{\beta_i} e^{b_i c_{it}}) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

Equation 3 can be rewritten as [Kaufman and Snell (2007)]

$$\ln(Y_{it}) = \beta_i \ln(X_{it}) + b_i C_{it} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

The marginal contribution of climate variables in crop yield can be estimated by differentiating the Equation 4 with respect to climate variables [You, *et al*. (2009); and Kurukulasuriya, *et al.* (2006)].

2.2.2. *Econometric Model*

Empirical explanation of econometric methodology starts with defining the properties of panel data [Wooldridge (2002)]. The motivation behind the panel formation is the problem of the omitted variable effect which leads to unobserved effect in the panel data. The models chosen to capture these effects are based on the nature of the effect—fixed effects and random effects models.

Fixed Effects Model (FEM)

These unobserved effects could be time-wise or cross-section wise depending upon the characteristics of the sample and the objective of the research. The cotton producing districts are in fact heterogeneous in nature; therefore, cross-section wise effects may yield better results. Econometrically this can be written as [Wooldridge (2002)]

$$Y_{it} = \beta_0 + \beta_i X_{it} + U_{it} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

$$U_{it} = \alpha_i D_i + \varepsilon_{it} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

Substituting Equation 6 in 5 would result in

$$Y_{it} = \beta_0 + \beta_i X_{it} + \alpha_i D_i + \varepsilon_{it} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

Where X_{it} contain the explanatory variables like land, fertiliser and climatic effects etc., α_i are cross-section specific effects which vary across the cross-section but not across time. The district[10] specific scalar constant are denoted by $D_{i,}$ α_i is also called as individual effect or individual heterogeneity and dummy (D) captures the characteristics which are specific to district soil attributes and other knowledge of farm practices which makes the district different from others (Bell and Jones, 2012; and [Mundlak, *et al.* (1999)]. Fixed effects model shows that the effects in equation are correlated with explanatory variables (cross-section specific characteristics). In agriculture, the use of fixed effects model [Lee, *et al*. (2012)] is very common while using the panel data if the sample is not chosen randomly [Wooldridge (2002)].

Random Effect Model

The selection of fixed or random effects model is determined by how the unobserved effects are viewed: if unobserved effects are considered as random variable then the random effects model is applied [Hsiao (2003); and Wooldridge (2002)]. Fixed effects models are free from heterogeneity bias [Mundlak (1961)]. When the unobserved effects are random, which require the assumption of orthogonality in v_i and X_{it}, then the random effects model is applied. This can be written as

$$Y_{it} = \beta_0 + \beta_i X_{it} + U_{it} \quad \ldots. \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

$$U_{it} = \nu_i + \varepsilon_{it} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (9)$$

[10]District is used as cross-section.

Substituting Equation 9 in 8 would result into

$$Y_{it} = \beta_0 + \beta_i X_{it} + \nu_i + \varepsilon_{it} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (10)$$

The random effects model requires a strong assumption that the correlation between explanatory variables and random effects must be equal to zero [Wooldridge (2002)]. Exogeneity is thus violated in the random effects model because of measurement or sample selection error. Sometimes, it may exist because of omitted variable problem. If exogeneity is violated then the model will be estimated using instrumental variable approach [Mandlak (1978)].

This study uses time series districts level data. Since, the cross-sectional heterogeneity exists in the data; therefore, the fixed effects model shall be preferred as suggested by the literature as well. However, we prefer to perform Hausman (1978) test to support our argument for using Fixed Effects technique. The formulation of Hausman test can be written as:

$$H = (\beta^{FE} - \beta^{RE})[var(\beta^{FE}) - var(\beta^{RE})]^{-1}(\beta^{FE} - \beta^{RE}) \sim \chi^2 \quad \ldots \quad (11)$$

The Hausman specification test usually checks the existence of fixed or random effect in the model. To apply test, we estimate our model using both Random Effects and Fixed Effects techniques. Hausman test is based on the idea under the hypothesis of no correlation between explanatory variables and the error term—if chi-square statistic is significantly different from the critical value then we reject the null hypothesis that validates the Fixed Effect Models (FEM)—and FEM is considered as more appropriate for analysis.

2.2.3. *Empirical Model*

The detailed empirical production function being followed in the present study can be written as:

$$\begin{aligned}
\ln Y_{it} &= \beta_0 + \beta_{TM}(TEMP_M) + \beta_{\mathrm{TJJ}}(TEMP_{\mathrm{JJ}}) + \beta_{\mathrm{TAS}}(TEMP_{\mathrm{AS}}) + \\
&\beta_{\mathrm{TO}}(TEMP_{ON}) + \beta_{\mathrm{PM}}(PRECP_M) + \beta_{\mathrm{PJJ}}(PRECP_{\mathrm{JJ}}) + \beta_{\mathrm{PAS}}(PRECP_{\mathrm{AS}}) + \\
&\beta_{\mathrm{PO}}(PRECP_{\mathrm{ON}}) + \beta_{\mathrm{VTM}}(VTEMP_M) + \beta_{\mathrm{VTJJ}}(VTEMP_{\mathrm{JJ}}) + \\
&\beta_{\mathrm{VTAS}}(VTEMP_{\mathrm{AS}}) + \beta_{\mathrm{VTO}}(VTEMP_{\mathrm{ON}}) + \beta_{VPM}(VPRECP_M) + \\
&\beta_{\mathrm{VPJJ}}(VPRECP_{\mathrm{JJ}}) + \beta_{VPAS}(VPRECP_{\mathrm{AS}}) + \beta_{VPO}(VPRECP_{ON}) + \\
&\beta_{\mathrm{TM2}}(TEMP_M)^2 + \beta_{TJJ2}(TEMP_{JJ})^2 + \beta_{TAS2}(TEMP_{AS})^2 + \\
&\beta_{TO2}(TEMP_{ON})^2 + \beta_{\mathrm{PM2}}(PRECP_M)^2 + \beta_{\mathrm{PJJ2}}(PRECP_{\mathrm{JJ}})^2 + \\
&\beta_{PAS2}(PRECP_{\mathrm{AS}})^2 + \beta_{PO2}(PRECP_{ON})^2 + \beta_{TPM}(TEMP_M) * \\
&(PRECP_M) + \beta_{\mathrm{TPJJ}}(TEMP_{\mathrm{JJ}}) * (PRECP_{\mathrm{JJ}}) + \beta_{\mathrm{TPAS}}(TEMP_{\mathrm{AS}}) * \\
&(PRECP_{\mathrm{AS}}) + \beta_{\mathrm{TPON}}(TEMP_{ON}) * (PRECP_{\mathrm{ON}}) + \beta_{Bt} D_{Bt} + \\
&\beta_{\mathrm{TMhA}}(TEMP_{MA}) * D_{Bt} + \beta_{\mathrm{PM}}(PRECP_{MA}) + \beta_{ar} \ln(\text{land}) + \\
&\beta_{\mathrm{f}} \ln(\text{npk}) + \beta_{\mathrm{g}} Tt + \beta_{\mathrm{i}} \textstyle\sum_i D_i + u_{it} \quad \ldots \quad \ldots \quad \ldots \quad (12)
\end{aligned}$$

Where,

lnY_{it} is natural log *(ln)* of cotton yield—production per hectare.
$TEMP_M$ is 20 years moving average temperature for the month of May.
$TEMP_{JJ}$ is 20 years moving average temperature during June-July.
$TEMP_{AS}$ is 20 years moving average temperature during August-September.
$TEMP_{ON}$ is 20 years moving average temperature during October-November.
$PRECP_M$ is 20 years moving average precipitation for May.
$PRECP_{JJ}$ is 20 years moving average precipitation during June-July.
$PRECP_{AS}$ is 20 years moving average precipitation during August-September.
$PRECP_{ON}$ is 20 years moving average precipitation during October-November.
$VTEMP_?$ is deviation of temperature from respective log-term mean for various stages.
$VPRECP_?$ shows deviation of precipitation from log-term means for various stages.
D*bt* is dummy variable introduced for Bt-cotton.
Land denotes area under cotton
npk indicates fertiliser nutrients off take per acre of cotton
T_t= time trend
D_i= district dummy

The square and interaction terms of climatic variables are introduced in the model to see if there exists any nonlinearity in the impacts of these variables on productivity of cotton.

3. RESULTS AND DISCUSSIONS

The intensity of impact of climate change on crop production depends on the environment under which the crop is currently being grown. Cotton is grown in the hot areas of Pakistan. The adverse impacts of climate change on productivity vary according to the occurrence of events during different growth stages of the plant [Doherty, *et al.* (2003)]. Agronomic studies show that cotton is water stress-tolerant crop due to its tap root system. The impacts of water stress can be reduced by irrigating the cotton fields. There is no denying the fact that the cotton yield has increased over time mainly due to the improvements in technologies—varietal development, improved production practices and increased use of fertiliser and pesticides. However, the agronomic work shows that if the current trend in climate change continues, the productivity of cotton would adversely be impacted. The cotton growing areas of Pakistan are already experiencing heat stress and reduced as well as erratic rainfall. The wellbeing of the cotton growers as well as farm workers would adversely be affected in days to come.

For the purpose of analysis, we estimated separate models for Sindh and Punjab provinces since the time of sowing and harvesting as well the climate differs to varied extent. The impact of climate change on crops is different in different scenarios and may differ according to the spatial properties of the region. The means of temperature and precipitation is reported in Appendix Table 1. The mean values of temperature in all districts vary between 26 ^{0}C to 36 ^{0}C throughout the four crop growth stages—sowing and germination (I-stage), vegetative growth (II-stage), flowering and fruit formation (III-stage) and picking (IV-stage).

The effect of climate change on crop productivity is estimated including the physical inputs variables—fertiliser use, area under cotton and time trend representing technological progress and the climate related variables which are 20 years moving average of temperature and of total precipitation during different stages of growth—their linear terms, quadratic terms and the deviations from long-term means. Panel data[11] modelling techniques—Fixed Effects Model (FEM), and Random Effects Model (REM) were used, considering the heterogeneity of sample against every growth stage. None of the variables has perfect collinearity, although temperature and precipitation of each season have high correlation. Furthermore, multicollinearity among variables may not be a serious problem in the panel data analysis.[12]

Before, presenting the econometric model estimation results, we need to understand the pattern of temperature and precipitation variables. For this purpose, 20 years moving average of the climate data—temperature and precipitation normals are regressed on time. Only the slope coefficients along with their statistical significance are reported in Table 1. The temperature generally shows rising trend during the cotton growing season. However, the precipitation normals display opposite trend—it declined in March, April and May in almost all districts, only with few exceptions. The temperature in the month of May shows a statistically significant increase in almost all districts during the last three decades, while these changes during other stages of the growth cycle of cotton are insignificant in most of the districts.

First we estimate full model given in Equation 12 for *Punjab*[13] province using fixed effects technique[14] and the results are reported in Table 3. To choose appropriate specification of model variables, we performed WALD tests and tests results are provided in Table 2. The first hypothesis, i.e. $\beta_{TPMAP}=\beta_{TPMP}=\beta_{TPJJP}=\beta_{TPASP}=\beta_{TPONP}=0$, implies that interaction between temperature and precipitation normals jointly have no

[11]To check unit root Im Pesaran Shin (IPS) was applied and results reported in Appendix Table 2 show all variables are stationary.

[12]Wooldridge (2002) pp. 104

[13]Punjab covers about 80 percent cotton area and shares 70 percent of the total cotton production in the country.

[14]Hausman test could not be performed while estimating full model to choose whether Random Effects Technique or Fixed Effects technique is more appropriate because of number of cross-section is lesser than the number of variables, and therefore, it was performed only for the final model.

impact on cotton productivity. The hypothesis is accepted. Given the result of this hypothesis, the second hypothesis tested relates to "$\beta_{VTMAP}= \beta_{VTMP}= \beta_{VTJJP}= \beta_{VTASP}= \beta_{VTONP}=0$" that implies that temperature deviations from their long-run mean jointly have no impact on cotton productivity. This hypothesis is rejected which implies that deviation in temperature from temperature normals impacts the crop yield significantly. The third tested hypothesis, i.e. $\beta_{VPMAP}= \beta_{VPMP}= \beta_{VPJJP}= \beta_{VPASP}= \beta_{VPONP}=0$, implies that deviations of precipitation from their long-term means have no significant impact on cotton productivity, which was accepted. Given the results of first three hypotheses, the fourth and fifth hypotheses relate to testing the nonlinearity of the impacts of climate normal-temperature and precipitation. The respective hypotheses can be written as"$\beta_{TMA2P}=\beta_{TM2P}=\beta_{TJJ2P}=\beta_{TAS2P}=\beta_{TON2P}=0$" and "$\beta_{PMA2P}=\beta_{PM2P} =\beta_{PJJ2P} =\beta_{PAS2P} =\beta_{PON2P}=0$". These hypotheses specify that square of temperature and precipitation normals terms coefficients are equal to zero implying no significant impact on cotton productivity. Both of these hypotheses were rejected indicating that the climate normals affect cotton productivity non-linearly.

Table 1

Slope Coefficients of Climate Normals

	Temperature Normal (Slope Coefficients)					Precipitation Normal (Slope Coefficients)				
District	March and April	May	June and July	August and Septem-ber	Novem-ber and October	March and April	May	June and July	August and Septem-ber	Novem-ber and October
Punjab										
Bhakkar	0.017	0.035*	0.05*	0.003	0.04	-0.9*	-0.448	0.127	-0.084	-0.003
Bawalpur	0.085**	0.038*	-0.005	-0.011	0.038***	-0.14	-0.078	-0.36*	0.742*	-0.008
Bwl Nagar	0.067	0.053*	0.005	0.015*	0.034*	-0.425	0.901*	0.846	-0.095*	-0.072**
D.G. Khan	0.03	0.034*	0.081*	0.047*	0.045*	-0.792**	-0.704*	0.967*	0.221	-0.036
Faisalabad	0.108**	0.08**	0.002	0.008	0.048**	-0.493*	-0.027	0.238	0.931	0.071
Jhelum	0.037	-0.015**	0.02**	0.011**	0.045**	-1.901**	-0.426	0.855	-0.141	0.092
Jhang	0.011	0.032*	0.064	0.045*	0.057*	-0.493*	-0.027	0.238	0.913	0.0711
Khushab	0.14*	0.034*	0.035	0.018	0.027	-1.177*	1.393**	0.769	-0.868	0.019
Kasur	0.003	-0.04*	0.048	0.032	0.107*	-1.079	-0.297	0.46	-0.856	-0.32
Layyah	0.018**	0.028	0.058	0.052	0.061*	-0.797**	-0.704	0.967	0.221	-0.036
Mianwali	0.095**	0.073*	0.012	0.022*	0.046**	-0.908*	-0.448*	0.127	0.084	-0.003
M. Garh	0.026	0.03*	0.078	0.06	0.039	-0.172	-0.347	-0.254	0.141	-0.026
Multan	0.104*	0.031*	0.07	0.004	0.024*	-0.172	-0.347	-0.254	0.141	-0.026
Okara	0.013	0.032*	0.07	0.052	0.006*	-0.493*	-0.027	0.238	0.913	0.71
Rajanpur	0.03	0.031*	0.04	0.065*	0.029	0.0181	-0.331*	0.034	1.532	0.076
R.Y Khan	0.035	0.022*	0.065*	0.065	0.003	0.01	-0.332*	0.034	1.532	0.076
Sargodha	0.259**	0.304**	0.12**	0.046	0.054	-1.177**	1.39**	0.749	-0.868	0.091
Sahiwal	0.021	0.025*	0.041	0.063	0.029*	-0.493*	-0.027	0.238	0.931	0.071
T Tsingh	0.015	-0.304	0.071	0.053	0.092*	-0.493*	-0.027	0.238	0.931	0.071
Vehari	0.032	0.032*	0.08*	0.076	0.032*	-0.425*	0.901*	0.84	-0.095	-0.072
Sindh										
Badin	0.006**	0.023*	0.019*	0.026*	0.035***	-0.042	0.17	-0.775	-1.408	0.271
Dadu	0.04	-0.006	0.074*	0.067*	0.029*	0.15	0.152	-0.325	-0.034	0.058
Hyderabad	0.034*	0.008	0.022*	0.006	0.015	-0.002	0.095	1.463*	-0.0117	0.144
Jacobabad	0.082**	0.07***	0.003	0.015	0.031*	-0.117	0.019	-0.169	-0.341	-0.0416
Khairpur	0.043	0.0063*	0.055	0.052	0.021*	0.028	0.08	-0.293	-0.336	0.014
Larkana	-0.088*	0.18***	0.181**	0.223**	0.007**	0.15*	0.152	-0.325	-0.034	-0.058
Nawabshah	0.078*	0.048**	0.001	0.022	0.038*	-0.008	-0.047	0.336	1.387	-0.014
Sukkur	0.03	0.0313	0.014	0.029	0.025	-0.117	-0.018	-0.042	-0.361	-0.042
Sanghar	0.038	0.011	0.03	0.052	0.003	-0.008	-0.049	0.363	1.386	-0.0223
Thatta	0.18	0.023	0.011	0.023*	0.002*	-0.001	0.225	-0.017	-0.857	0.143*
Average	0.052	0.031	0.047	0.041	0.045	-0.415	0.025	0.243	0.187	0.039

In summary the results of Wald tests show that interaction of temperature and precipitation normals and annual shocks in precipitation have no significant impact on cotton productivity. However, the temperature shocks influence the productivity significantly. The results have also demonstrated that cotton productivity and climate change exhibit nonlinear relationship. Based on these results, Model 3 in Table 3 is preferred for results discussion. Just for curiosity we performed Hausman test whether Fixed Effects was the appropriate technique while estimating the Model 3 (see Table 2). This test favoured the application of Fixed Effects technique—as χ^2_{Cal} (86.07) was higher than the χ^2_{Crit}(61.91).

Table 2

Results of Specification Tests for Model selection (Punjab Province)

	Null Hypothesis	F/χ^2—test		F/χ^2—critical		Decision
1	$\beta_{TPMAP}= \beta_{TPMP}= \beta_{TPJJP}= \beta_{TPASP}= \beta_{TPONP}=0$	F=1.655	χ^2=8.274	F=2.21	χ^2=11.07	Accepted
2	$\beta_{VTMAP}= \beta_{VTMP}= \beta_{VTJJP}= \beta_{VTASP}= \beta_{VTONP}=0$	F=8.143	χ^2=40.715	F=2.21	χ^2=11.07	Rejected
3	$\beta_{VPMAP}= \beta_{VPMP}= \beta_{VPJJP}= \beta_{VPASP}= \beta_{VPONP}=0$	F=0.456	χ^2=2.279	F=2.21	χ^2=11.07	Accepted
4	$\beta_{TMA2P}=\beta_{TM2P}=\beta_{TJJ2P}=\beta_{TAS2P}=\beta_{TON2P}=0$	F=6.126	χ^2=30.628	F=2.21	χ^2=11.07	Rejected
5	$\beta_{PMA2P}=\beta_{PM2P} =\beta_{PJJ2P} =\beta_{PAS2P} =\beta_{PON2P}=0$	F= 3.356	χ^2=16.782	F=2.21	χ^2=11.07	Rejected

The coefficients of the estimated Model 3 (Table 3) show that the impacts of all non-climate variables on cotton productivity are positive and statistically highly significant. The positive coefficient of area under cotton shows increasing returns to scale. The fertiliser (NPK) coefficient indicates that 1 percent increase in use of NPK will improve the cotton yield by 0.19 percent. The coefficient of P/NPK ratio variable is of particular interest. The coefficient is positive and statistically highly significant implying that as P to NPK ratio improves it would raise cotton productivity significantly—normally the use of fertiliser is highly imbalanced in Pakistan because of costly phosphatic based fertilisers, and often is in short supply. The coefficient of time is positive and statistically highly significant having magnitude of 0.0128 indicating increase in cotton yield by 1.3 percent every year during the last 30 years due mainly to the changes in technological improvement—new seeds, improved inputs and better agronomic practices.

The greater variations in temperature[15] during the sowing and vegetative growth stages influence cotton productivity negatively and the impacts are statistically significant. The impact of temperature deviation for March and April has turned out to be positive. Though the temperature variations during the flowering and maturity stages influence cotton yield positively, the impacts however are statistically non-significant.

[15]Variations in current temperature from long-term respective means.

Table 3

Fixed Effect Model Results for Punjab Province

		Model 1		Model 2		Model 3	
	Variable	Coefficient	S.E	Coefficient	S.E	Coefficient	S.E
β_{ARP}	Area	0.3647***	0.0490	0.3519***	0.0483	0.3625***	0.0494
β_{FP}	Fertiliser	0.1863***	0.0488	0.1785***	0.0488	0.1973***	0.0498
β_{PP}	P/NPK	0.0067***	0.0019	0.0063***	0.0019	0.0076***	0.0019
β_{GP}	Time trend	0.0146***	0.0047	0.0163***	0.0045	0.0128***	0.0046
β_{TMAP}	Temp Bt. Cotton *(march and April)*	-0.0014	0.0100	-0.0379	0.0271	-0.0304*	0.0175
β_{TMP}	Temp *(May)*	0.1241*	0.0617	0.2580	0.3410	0.5159*	0.3135
β_{TJJP}	Temp *(June and July)*	0.5390*	0.2461	0.9320***	0.3307	1.2000***	0.3311
β_{TASP}	Temp *(August and September)*	0.3302*	0.1705	0.6313	0.3469	0.6686**	0.3545
β_{TONP}	Temp *(October and November)*	0.2250	0.1269	0.1840	0.3409	0.1775	0.3474
β_{PMAP}	Precip Bt. Cotton *(march and April)*	-0.0261	0.0304	0.0104	0.0067	0.0109*	0.0068
β_{PMP}	Precip *(May)*	-0.0952*	0.0566	-0.0114	0.0137	0.0010	0.0137
β_{PJJP}	Precip *(June and July)*	-0.2059**	0.0460	-0.0032	0.0052	-0.0035	0.0053
β_{PASP}	Precip *(August and September)*	-0.0721	0.0405	0.0033	0.0046	0.0010	0.0047
β_{PONP}	Precip *(October and November)*	0.0034	0.1539	-0.0450	0.0114	-0.0442***	0.0116
β_{TMA2P}	Sq. Temp Bt. Cotton *(march and April)*	-0.0003	0.0014	0.0011*	0.0010	0.0090*	0.0010
β_{TM2P}	Sq. Temp *(May)*	-0.0001	0.0053	-0.0019*	0.0052	-0.0063*	0.0052
β_{TJJ2P}	Sq. Temp *(June and July)*	-0.0121**	0.0052	-0.0164***	0.0048	-0.0203***	0.0047
β_{TAS2P}	Sq. Temp *(August and September)*	-0.063***	0.0060	-0.0098*	0.0057	-0.0118*	0.0058
β_{TON2P}	Sq. Temp *(October and November)*	-0.0005	0.0070	0.0000	0.0067	0.0017	0.0069
β_{PMA2P}	Sq. Precip Bt. Cotton *(march and April)*	-0.0001	0.0001	-0.0001*	0.0001	-0.0002*	0.0001
β_{PM2P}	Sq. Precip *(May)*	0.0006	0.0004	0.0004*	0.0004	0.0002	0.0004
β_{PJJ2P}	Sq. Precip *(June and July)*	0.0001	0.0000	0.0001**	0.0000	0.0001*	0.0000
β_{PAS2P}	Sq. Precip *(August and September)*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
β_{PON2P}	Sq. Precip *(October and November)*	0.0011*	0.0006	0.0013***	0.0004	0.0014***	0.0004
β_{VTMAP}	Temp. Deviation Bt. *(march and April)*	0.0325	0.0241	0.0343**	0.0120	0.0303***	0.0113
β_{VTMP}	Temp. Deviation *(May)*	-0.0282*	0.0183	-0.0301**	0.0082	-0.0312**	0.0104
β_{VTJJP}	Temp. Deviation *(June and July)*	-0.0242*	0.0177	-0.0263***	0.0076	-0.0249**	0.0074
β_{VTASP}	Temp. Dev.*(August and September)*	0.0188	0.0116	0.0246	0.0093	0.0261	0.0190
β_{VTONP}	Temp. Dev.*(October and November)*	0.0281	0.0191	0.0247	0.0060	0.0211	0.0158
β_{VPMAP}	Precip. Dev. Bt. *(march and April)*	0.0012	0.0020	0.0010	0.0020		
β_{VPMP}	Precip. Deviation *(May)*	0.0008	0.0006	0.0006	0.0005		
β_{VPJJP}	Precip. Deviation *(June and July)*	-0.0002	0.0003	-0.0002	0.0005		
β_{VPASP}	Precip. Dev.*(August and September)*	-0.0001	0.0003	-0.0001	0.0003		
β_{VPONP}	Precip. Dev.*(October and November)*	0.0003	0.0006	0.0001	0.0006		
β_{TPMAP}	Temp.* Precip.*(march and April)*	0.0013	0.0010				
β_{TPMP}	Temp.* Precip. *(May)*	0.0023	0.0014				
β_{TPJJP}	Temp.* Precip.*(June and July)*	0.0005	0.0012				
β_{TPASP}	Temp.* Precip.*(August and September)*	0.0011	0.0012				
β_{TPONP}	Temp.* Precip*(October and November)*	-0.0018	0.0056				
	R^2	0.7770		0.7588		0.7548	

Note: ***, ** and * represent the level of significance ate 1 percent, 5 percent, and 10 percent.

Table 4

Marginal Impacts of Climate Change on Cotton Yield in Punjab Province

No.	Variable name	Marginal Impact
1	Temperature For Bt. Cotton *(March and April)*	0.0165
2	Temperature *(May)*	0.0657
3	Temperature *(June and July)*	-0.2414
4	Temperature *(August and September)*	-0.0804
5	Temperature *(October and November)*	0.2654
6	Precipitation For Bt. Cotton *(March and April)*	0.0006
7	Precipitation *(May)*	0.0070
8	Precipitation *(June and July)*	0.0093
9	Precipitation *(August and September)*	0.0010
10	Precipitation *(October and November)*	-0.0243

Our results show that climate change variables do influence the productivity. Following Kurukulasuriya, *et al.* (2006), the marginal impacts[16] of climate related variables on cotton productivity are quantified and the results are reported in Table 4. The magnitudes of the marginal impacts show that 1^0C increase in temperature during the sowing period of cotton would encourage yield by 1.65 percent and 6.57 percent in cases of Bt and conventional varieties, respectively. However, the rise in temperature by 1^0C during vegetative and flowering-fruiting stages of growth would reduce yield by 24.14 percent and 8 percent, respectively. The warmer temperature during the maturity and picking stage would help in harvesting good cotton crop—1^0C rise in temperature increases yield by 26.54 percent in Punjab. Since cotton is a heat-tolerant crop, warming up of weather during the sowing and maturity-picking stages help in getting better harvest, while further warming of the climate during the months of vegetation and flowering-fruit formation stages impacts negatively because the weather is already very hot during these months.

The impacts of precipitation normals are very small as shown by the coefficients of marginal analyses—the reason could be that cotton is grown in irrigated areas using various supplementary water sources [Naheed and Rasul (2010)]. The sum of the marginal impact coefficients is -0.0064 showing greater precipitation reduces overall yield of cotton—precipitation during maturity stage has been particularly not good for the crop. The marginal analyses reported in Table-4 highlights the fact that warming up of weather is beneficial for the cotton crop; the aggregate impact, however is marginal—that is less than 1 percent. Including the March-April months, the results indicate that 1^0C increase in temperature during cotton growing season—March to November, would increase cotton productivity by 2.6 percent.

[16] The marginal effects are evaluated using the mean of the variables.

The ***Sindh*** province is the second largest cotton producing province, sharing 28 percent of the total, in the country after Punjab—sharing 70 percent. The remaining 2 percent is produced by the other provinces [Pakistan (2013-2014)]. Cotton cultivation in Sindh is done in areas with high temperature and low precipitation—located in the neighbourhood of Rajasthan Desert. Canal irrigation is the major source for the water requirements of the crop.

For the purpose of impact evaluation of climatic variables on cotton productivity in Sindh, we again estimate full model given in Equation 12 using Fixed Effects technique. The WALD test was then applied to choose the final model and the results are reported in Table-5. In this regard, the first hypothesis relates to '$\beta_{TPMAP}= \beta_{TPMP}= \beta_{TPJJP}= \beta_{TPASP}= \beta_{TPONP}=0$' which implies that interaction between temperature and precipitation normals jointly have no significant impact on cotton productivity. The hypothesis was accepted. Given this result, the second hypothesis tested was "$\beta_{VTMAP}= \beta_{VTMP}= \beta_{VTJJP}= \beta_{VTASP}= \beta_{VTONP}=0$" that specifies that the temperature deviations from their respective long-turn means jointly have no significant impact on cotton productivity. This hypothesis was rejected implying significant role of temperature deviation in crop yield in Sindh. The third tested hypothesis, i.e. $\beta_{VPMAP}= \beta_{VPMP}= \beta_{VPJJP}= \beta_{VPASP}= \beta_{VPONP}=0$, implies deviations of precipitation from their respective long-term means have no significant impact on cotton productivity. This hypothesis was accepted. The fourth and fifth hypotheses which were tested are '$\beta_{TMA2P}=\beta_{TM2P}=\beta_{TJJ2P}=\beta_{TAS2P}=\beta_{TON2P}=0$' and '$\beta_{PMA2P}=\beta_{PM2P}=\beta_{PJJ2P}=\beta_{PAS2P}=\beta_{PON2P}=0$'. These hypotheses respectively specify that temperature and precipitation normals impact cotton productivity linearly. Both of these hypotheses were rejected implying that temperature and precipitation normal influence cotton productivity non-linearly. The specification tests results reported in Table-5 lead us to conclude that interaction terms between temperature and precipitation normals during various stages of growth, and annual shocks in precipitation have no significant impact on cotton productivity in Sindh. However, the temperature shocks significantly influence cotton productivity, and the impacts of temperature and precipitation on cotton productivity are nonlinear. Model-3 in Table-6 is the preferred model.

The results of this model show that all non-climatic variables have positive and statistically significant influence on crop productivity. The value of land coefficient shows that there exists increasing return to scale in cotton production. The fertiliser coefficient shows that 10 percent increase in fertiliser use shall result 2.6 percent increase in crop productivity. This results further highlights the fact that cotton crop in Sindh is more responsive to phosphatic fertilisers use than the nitrogenous fertilisers. Time trend is used as proxy for technology which shows that productivity of cotton increases more than 4 percent per annum due to the changes in technologies and production practices. It is worth mentioning here that Bt. varieties were introduced much earlier than that of in the Punjab; however, the impacts of climatic variables during March-April were statistically non-significant.

Table 5

Results of Specification test for Model selection (Sindh Province)

	Null Hypothesis	F/χ^2—test	F/χ^2--critical	Decision
1	$\beta_{TPMAPS}= \beta_{TPMPS}= \beta_{TPJJPS}= \beta_{TPASPS}= \beta_{TPONPS}=0$	F=1.51 χ^2=7.56	F=2.21 χ^2=11.07	Accepted
2	$\beta_{VTMAPS}= \beta_{VTMPS}= \beta_{VTJJPS}= \beta_{VTASPS}= \beta_{VTONPS}=0$	F=2.69 χ^2=13.43	F=2.21 χ^2=11.07	Rejected
3	$\beta_{VPMAPS}= \beta_{VPMPS}= \beta_{VPJJPS}= \beta_{VPASPS}= \beta_{VPONPS}=0$	F=1.99 χ^2=9.98	F=2.21 χ^2=11.07	Accepted
4	$\beta_{TMA2PS}=\beta_{TM2PS}=\beta_{TJJ2PS}=\beta_{TAS2PS}=\beta_{TON2PS}=0$	F=3.87 χ^2=19.33	F=2.21 χ^2=11.07	Rejected
5	$\beta_{PMA2PS}=\beta_{PM2PS} =\beta_{PJJ2PS} =\beta_{PAS2PS} =\beta_{PON2PS}=0$	F=2.84 χ^2=28.39	F=2.21 χ^2=11.07	Rejected

Table 6

Fixed Effect Model Results with Log of Yield as Dependent Variable (Sindh)

		Model 1		Model 2		Model 3	
	Variable	Coefficient	S.E	Coefficient	S.E	Coefficient	S.E
β_{ARS}	Area	0.0122**	0.0747	0.1961***	0.0739	0.1896***	0.0733
β_{FS}	Fertiliser	0.0480***	0.0754	0.0181***	0.0093	0.0263**	0.0131
β_{PS}	P/NPK	0.0212	0.0205	0.0885**	0.0576	0.0898**	0.0521
β_{GS}	Time trend	0.0468***	0.0055	0.0418***	0.0054	0.0435***	0.0053
β_{TMAS}	Temp For Bt. Cotton *(march and April)*	0.1610	0.1274	0.0398	0.0462	0.0393	0.0456
β_{TMS}	Temp *(May)*	1.0588**	0.5217	1.2830**	0.5283	1.2861**	0.5263
β_{TJJS}	Temp *(June and July)*	1.0633**	0.5831	1.0026*	0.5783	1.0251***	0.5725
β_{TASS}	Temp *(August and September)*	0.6632	0.5552	0.9464*	0.5580	0.8448**	0.5520
β_{TONS}	Temp *(October and November)*	-0.0388	0.5222	0.2110	0.5371	0.1764	0.5337
β_{PMAS}	Precip For Bt. Cotton *(March and April)*	-1.2854*	0.6905	-0.0261	0.1914	0.0234	0.1853
β_{PMS}	Precip *(May)*	1.0882**	0.4420	-0.0006	0.0515	-0.0089	0.0509
β_{PJJS}	Precip *(June and July)*	0.2640*	0.1603	-0.0053	0.0202	-0.0003	0.0196
β_{PASS}	Precip *(August and September)*	-0.3141***	0.0919	-0.0297**	0.0111	-0.0311**	0.0109
β_{PONS}	Precip *(October and November)*	-0.2635	0.3025	0.1242**	0.0336	0.1026**	0.0329
β_{TMA2S}	Sq. Temp For Bt. Cotton *(March and April)*	-0.0056	0.0044	-0.0014	0.0015	-0.0015	0.0015
β_{TM2S}	Sq. Temp *(May)*	-0.0124*	0.0077	-0.0163*	0.0077	-0.0162**	0.0077
β_{TJJ2S}	Sq. Temp *(June and July)*	-0.0184**	0.0085	-0.0186**	0.0086	-0.0186**	0.0085
β_{TAS2S}	Sq. Temp *(August and September)*	-0.0064	0.0088	-0.0096*	0.0090	-0.0086*	0.0049
β_{TON2S}	Sq. Temp *(October and November)*	-0.0082	0.0092	-0.0096	0.0094	-0.0088	0.0093
β_{PMA2S}	Sq. Precip For Bt. Cotton *(March and April)*	0.0328*	0.0229	0.0003	0.0222	-0.0062	0.0215
β_{PM2S}	Sq. Precip *(May)*	-0.0080	0.0073	-0.0032*	0.0007	-0.0026	0.0056
β_{PJJ2S}	Sq. Precip *(June and July)*	-0.0003	0.0005	0.0002**	0.0001	0.0002	0.0003
β_{PAS2S}	Sq. Precip *(August and September)*	0.0005***	0.0001	0.0003**	0.0001	0.0004**	0.0001
β_{PON2S}	Sq. Precip *(October and November)*	-0.0035	0.0034	-0.0042*	0.0035	-0.0109**	0.0015
β_{VTMAS}	Temp Deviation For Bt. Cotton *(March and April)*	-0.0209	0.0280	-0.0017	0.0284	0.0060	0.0274
β_{VTMS}	Temp Deviation *(May)*	-0.0079	0.0163	-0.0021	0.0163	-0.0024	0.0159
β_{VTJJS}	Temp Deviation *(June and July)*	0.0291*	0.0164	0.0391*	0.0167	0.0389**	0.0165
β_{VTASS}	Temp Deviation *(August and September)*	-0.0382*	0.0206	-0.0448*	0.0211	-0.0429**	0.0206
β_{VTONS}	Temp Deviation *(October and November)*	0.0222*	0.0132	0.0131	0.0135	0.0147	0.0133
β_{VPMAS}	Precip Deviation For Bt. Cotton *(March and April)*	-0.0104*	0.0057	-0.0090	0.0059		
β_{VPMS}	Precip Deviation *(May)*	-0.0002	0.0016	-0.0001	0.0017		
β_{VPJJS}	Precip Deviation *(June and July)*	0.0006	0.0006	0.0009	0.0006		
β_{VPASS}	Precip Deviation *(August and September)*	-0.0002	0.0002	-0.0002	0.0002		
β_{VPONS}	Precip Deviation *(October and November)*	0.0014	0.0016	0.0002	0.0016		
β_{TPMAS}	Temp.* Precip.*(March and April)*	0.0382	0.0295				
β_{TPMS}	Temp.* Precip.*(May)*	-0.0317	0.0223				
β_{TPJJS}	Temp.* Precip. *(June and July)*	-0.0069	0.0047				
β_{TPASS}	Temp.* Precip *(August and September)*	0.0083	0.0062				
β_{TPONS}	Temp.* Precip *(October and November)*	0.0122	0.0104				
	R^2	0.8538		0.8192		0.8192	

Note: ***, ** and * represent the level of significance ate 1 percent, 5 percent, and 10 percent.

Marginal impacts of the climatic variables used in the Model for Sindh province (Table 6) have also computed and the outcomes are reported in Table 7. The results are somewhat different than those of Punjab. For Bt. Sowing stage, March and April, temperature change impacts cotton productivity insignificantly. This result is an unexpected outcome. The Bt. varieties have special characteristics of sowing earlier and in relatively lower temperature than that of the conventional cultivars. Furthermore, the average temperature during March-April is more than 2^0C higher than the average in cotton growing districts of Punjab that may lead to conclude that further rise in March-April may affect Bt cotton sowing adversely. The month of May is the most suitable month for sowing cotton [Ayaz, *et al*. (2012) and Kakar, *et al.* (2012)], particularly for the conventional varieties; however, the early sown varieties also require higher temperature in latter month. Therefore, 1^0C increase in temperature during May is beneficial for cotton productivity.

Table 7

Marginal Impacts of Climate Change on Log of Yield (Sindh Province)

No.	Variable name	Marginal Impact
1	Temperature For Bt. Cotton *(March and April)*	-0.0457
2	Temperature *(May)*	0.1526
3	Temperature *(June and July)*	-0.1522
4	Temperature *(August and September)*	0.3080
5	Temperature *(October and November)*	-0.2853
6	Precipitation For Bt. Cotton *(March and April)*	-0.0230
7	Precipitation *(May)*	-0.0203
8	Precipitation *(June and July)*	0.0165
9	Precipitation *(August and September)*	-0.0058
10	Precipitation *(October and November)*	0.0342

The impact of temperature increases during vegetative stage is negative; the result is similar to the findings in the case of Punjab. During flowering and fruit formation stage, 1^0C increase in temperature may cause about 31 percent improvement in the cotton yield, while the effect of temperature in full picking impacts cotton productivity negatively. One of the major reasons of such impacts could be that temperature has relatively declined in most of the cotton growing districts of Sindh during flowering and fruit formation stage (August-September), while during the full picking season (October-November) started rising—particularly in the month of November. The cumulative impact, i.e. sum of all stages, came out to be reduced yield by -2.26 percent with 1^0C increase in temperature during the growing season of cotton in Sindh—that is March to November. The marginal impact of precipitation is negative for sowing stage of crop and positive for vegetative stage of crop as the crop water requirement is high in this stage [Ayaz, *et al*. (2012)] and negative for boll formation and picking stage. The overall impact of precipitation is positive on crop yield.

4. SUMMARY AND CONCLUSIONS

The major objective of this paper has been to analyse the relationship between cotton yield and climate change variables. Agricultural production has strong relationship with the climate and its anomalies because of the nature of production. Furthermore, studies done on the subject in Pakistan used current climate related variables which only capture the impacts of weather shocks. This study tries to capture both long- and short-run effects of climate related variables on cotton productivity.

The results suggest that climatic change influences cotton production significantly. However, the impacts differ across crop's growth cycle. For Punjab, the results indicate that 1^0C increase in temperature during the sowing period of cotton would encourage yield by 1.65 percent and 6.57 percent in cases of Bt. and conventional varieties, respectively. The rise in temperature by 1^0C during vegetative and flowering-fruiting stages of growth would reduce yield by 24.14 percent and 8 percent, respectively. The warmer temperature during the maturity and picking stage would help in harvesting good cotton crop—1^0C rise in temperature increases yield by 26.54 percent in Punjab. Since cotton is a heat tolerant crop, warming up of weather during the sowing and maturity-picking stages help in getting better harvest, while further warming of the climate during the months of vegetation and flowering-fruit formation stages impacts negatively because the weather is already very hot during these months. The net impact of 1^0C increase in average temperature during growth cycle of crop in Punjab—i.e., March to November, would increase productivity by 2.6 percent.

The results are somewhat different in Sindh than the outcomes of Punjab. March-April temperature had unexpectedly negative impact on cotton productivity, but statistically insignificant. Higher temperature in May turned out to be beneficial for cotton productivity, while further rise in temperature during vegetative stage (June-July) is harmful for cotton. During flowering and fruit-formation stage—August and September, 1^0C increase in temperature may lead to about 31 percent improvement in the cotton yield while the effect of temperature in full picking impacts cotton productivity negatively almost of the same magnitude. One of the major reasons of such impacts could be that temperature has relatively declined in most of the cotton growing districts of Sindh during flowering and fruit formation stage (August-September), while during the full picking season (October-November) remained either high or started rising again—particularly in the month of November. The cumulative impact, i.e. sum of all stages, came out to be reduced yield by -2.26 percent with 1^0C increase in temperature during the growing season of cotton in Sindh—that is March to November. This result is opposite to the findings in Punjab. The reason of this divergent impact is that most of the cotton producing districts of Sindh become very hot—having higher temperature by 1-3^0C as compared to the Punjab. The effect of rainfall on cotton production is mostly insignificant or negligible for cotton production due to irrigated nature of crop in both provinces.

The changing pattern of climate would have serious implications for the cotton economy of Pakistan. This crop is a very labour and capital intensive enterprise in Pakistan on one hand and 2/3rd of our total exports are dependent on this crop on the other. Poverty is relatively high in cotton growing areas of Pakistan. Further rise in temperature in areas where the crop is already under heat stress and facing irrigation water shortage will jeopardise not only the wellbeing of the communities related to cotton economy but also the overall economy of the country because of its contribution. Therefore, agricultural research efforts should be concentrated on developing heat tolerant verities—having high productive potential as well as resistant to insect pests' attacks and to diseases.

APPENDIX Table 1

Mean Value of Temperature and Precipitation Across the Panel Districts

	Mean Temperature (^{0}C)					Mean Precipitation (mm)				
District	March and April	May	June and July	August and September	October and November	March and April	May	June and July	August and September	October and November
Bhakkar	26.02	37.07	36.06	30.19	23.38	56.51	22.84	79.73	84.16	14.00
Bawalpur	24.53	32.88	34.54	31.73	26.29	9.73	7.80	34.62	25.35	3.67
Bwl Nagar	24.45	32.64	33.97	31.45	26.36	13.39	9.97	52.37	26.06	6.41
D.G. Khan	28.26	38.52	37.86	33.80	27.41	30.59	15.82	39.95	41.82	5.53
Faisalabad	22.68	30.97	32.83	30.56	25.00	23.15	14.03	73.80	60.62	4.32
Jhelum	22.12	30.17	31.51	29.06	24.76	53.51	28.70	154.16	157.30	17.74
Jhang	27.11	37.71	36.55	31.68	25.22	23.15	14.03	73.80	60.62	4.32
Khushab	26.15	36.99	35.22	29.56	23.47	31.95	20.56	74.09	76.74	9.97
Kasur	27.31	37.60	34.64	30.02	24.25	30.79	22.38	126.42	123.76	14.07
Layyah	27.16	37.92	37.01	32.40	25.53	30.59	15.82	39.95	41.82	5.53
Mianwali	22.26	31.10	33.95	31.33	24.99	56.62	22.89	79.80	84.22	14.03
M. Garh	27.62	38.21	37.72	33.19	26.39	16.27	11.63	37.00	30.46	4.33
Multan	24.36	32.81	34.67	31.67	26.34	16.27	11.63	37.00	30.46	4.33
Okara	27.38	37.76	35.78	31.34	25.29	23.15	14.03	73.53	60.62	4.32
Rajanpur	28.79	38.56	37.55	34.33	28.77	4.06	4.54	15.35	18.44	2.20
R.Y Khan	28.93	38.15	36.65	34.14	29.39	4.07	4.54	15.50	18.28	2.14
Sargodha	23.41	31.94	33.79	31.16	25.29	31.95	20.56	74.08	76.74	9.97
Sahiwal	27.55	37.87	36.39	32.15	26.03	23.15	14.03	73.63	60.62	4.32
T Tsingh	27.32	37.82	36.63	32.03	25.69	23.15	14.03	73.80	60.62	4.32
Vehari	27.84	37.93	36.76	32.97	26.98	13.64	10.23	54.18	27.34	6.53
Badin	27.64	32.55	31.85	29.53	28.58	1.54	4.04	41.82	60.50	5.49
Dadu	29.10	37.56	35.70	33.80	29.67	2.52	1.46	21.69	18.22	2.72
Hyderabad	28.48	33.51	33.30	31.12	29.65	4.78	3.62	30.53	39.74	3.44
Jacobabad	26.95	35.22	35.88	32.20	27.72	6.61	2.88	21.80	21.92	2.35
Khairpur	29.91	38.11	35.88	33.86	30.83	3.53	1.50	22.33	25.39	2.16
Larkana	30.07	39.36	38.33	35.88	30.76	2.52	1.46	21.69	18.22	2.72
Nawabshah	26.59	34.19	34.82	31.76	27.75	2.79	1.41	29.38	38.25	4.51
Sukkur	24.49	31.93	34.85	31.61	24.35	6.61	2.88	22.18	21.92	2.35
Sanghar	29.26	35.39	32.62	31.15	30.25	2.80	1.42	30.14	38.12	4.57
Thatta	27.54	31.96	30.16	28.85	29.04	4.55	1.39	38.51	33.81	1.10

Appendix Table 2

IM Pesaran Shin (IPS) Test of Unit Root at Level

Variable	Statistics	Probability	Conclusion
Yield	-2.6400	0.0040	stationary
Area	-2.1097	0.0175	stationary
Fertiliser	-3.6500	0.0450	stationary
P/NPK	-4.5600	0.0000	stationary
Temperature Bt. Cotton *(March-April)*	-2.2700	0.0800	stationary
Temperature *(May)*	-2.8600	0.0079	stationary
Temperature *(June and July)*	-2.6600	0.0039	stationary
Temperature *(August and September)*	-2.0100	0.0500	stationary
Temperature *(October and November)*	-6.3300	0.0000	stationary
Precipitation Bt. Cotton *(March-April)*	-2.0700	0.0400	stationary
Precipitation *(May)*	-2.5900	0.0870	stationary
Precipitation *(June and July)*	-3.4800	0.0100	stationary
Precipitation *(August and September)*	-2.3800	0.0200	stationary
Precipitation *(October and November)*	-2.0430	0.0790	stationary
Sq. Temp Bt. Cotton *(March-April)*	-2.6400	0.0900	stationary
Sq. Temperature *(May)*	-2.8600	0.0079	stationary
Sq. Temperature *(June and July)*	-3.0500	0.0011	stationary
Sq. Temperature *(August-September)*	-2.4600	0.0300	stationary
Sq. Temperature *(October-November)*	-6.0100	0.0000	stationary
Sq. Precip Bt. Cotton *(March-April)*	-2.4900	0.0300	stationary
Sq. Precipitation *(May)*	-1.9700	0.0760	stationary
Sq. Precipitation *(June and July)*	-3.7800	0.0100	stationary
Sq. Precip *(August and September)*	-2.0400	0.0400	stationary
Sq. Precip *(October and November)*	-2.7020	0.0800	stationary
Temp. Dev. Bt. Cotton *(March-April)*	15.0700	0.0000	stationary
Temp. Deviation *(May)*	-15.0800	0.0000	stationary
Temp. Deviation *(June and July)*	-18.0480	0.0000	stationary
Temp. Dev. *(August and September)*	-15.4000	0.0000	stationary
Temp. Dev. *(October and November)*	-12.8100	0.0000	stationary
Precip. Dev. Bt. Cotton *(March-April)*	-12.8400	0.0000	stationary
Precip. Deviation *(May)*	-16.0870	0.0000	stationary
Precip. Deviation *(June and July)*	-15.1300	0.0000	stationary
Precip. Dev. *(August and September)*	-11.9400	0.0000	stationary
Precip. Dev. *(October and November)*	-10.5819	0.0000	stationary

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This series of papers is an outcome of a joint research project of PIDE and IDRC. Transnational financing of developmental projects by donor agencies has emerged to be a notable phenomenon around the globe. Amongst others, International Development and Research Centre (IDRC) Canada remains one of the leading agencies providing funds for multifaceted developmental projects being implemented in developing countries. The project "***Climate Change Agriculture and Food Security in Pakistan: Adaptation Options and Strategies***" is one such an endeavor of PIDE and IDRC. Broadly speaking, the project aims at exploring responses of crop yields to changing climate and analyzing the adaptation efforts undertaken by farmers. The issue of climate change bears a special importance for Pakistan's economy being heavily dependent on agriculture sector both in terms of its contribution to GDP and employment. This project involves two strands of empirical undertakings: i) studies based on districts-level panel; and ii) studies based on Rapid Rural Appraisal (RRA) and household level survey data. The outcomes of the studies based on panel and cross-sectional data are being reported in working paper series of the project whereas findings of RRA have been published as a policy brief. However, for information of readers, the salient upshots of RRA are summarized in the following.

The evidence from RRA is suggestive that the farming communities in various regions of Pakistan widely perceive that climate is changing and is adapting accordingly through undertaking a wide range of adaptation strategies. Some of the adaptations in rainfed areas include use of deep tillage for rainwater harvesting and preserving moisture, building of small check dams, shifting away from shallow rooted to deep rooted crops, and delayed sowing of wheat and mustard by 15-30 days etc. While adaptations in irrigated agriculture include, in major, increased installation of tube-wells, increased area under low-delta/low-input requiring crops like canola and mustard as alternative to wheat in water scarce areas and substitution of other crop (guar seed and cotton crops being replaced with mungbean in low intensity zone), delayed wheat sowing by 15-21 days, and sowing of cotton on ridges to manage water scarcity etc.

Surprisingly, however, notwithstanding the changing climate, the research institutions and extension department still keep recommending completion of wheat sowing by 20th of November irrespective of regional climate variations. The sowing of rice nursery before 20th of May is prohibited according to the Punjab Agricultural Pest Ordinance, 1959 in order to control multiplication of harmful pests on early sown rice nurseries. Further, canal closure schedules do not match with the adaptation needs of farmers confronting climate changes (especially wheat in Punjab and rice in Sindh. The farmers have an urgent need of support from agricultural research and extension as well as other government departments to enhance their adaptive capacities.

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