IMPACT OF CLIMATE CHANGE ON PRODUCTIVITY OF COTTON IN PAKISTAN; A DISTRICT LEVEL ANALYSIS

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CERTIFICATE

This is to certify that this thesis by Mr. Amar Raza is accepted in its present form by the Department of Economics, Pakistan Institute of Development Economics, Islamabad, as satisfying the thesis requirements for the degree of Master of Philosophy in Economics.

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Dedicated to My

Mother

(Whose prayers always enlightened my way to success)

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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 against the each cotton yield. Neo-classical production function approach is used to analyze the relationship between the crop yield and climate change. Production function approach takes all the explanatory variables as exogenous so the chance endogenity may also minimize.

Separate analysis for each province (Punjab and Sindh) is also included in the study. Mean temperature, precipitation and quadratic term of both variables are used as climatic variables. Since research uses district level data for the analysis, each district has different management and Agro-ecological characteristics, so Fixed Effect Model, which also validated by Hausman Test, used for econometric estimations. The results suggest the marginal negative and significant impact of temperature and precipitation on cotton yield. The induction of Bt. Cotton has positive impact on yield in climate change. The impacts of climate change are slightly different across the provinces—Punjab and Sindh. The negative impacts of temperature are more striking for Sindh. The impacts of physical variables area, fertilizer and technology are positive and highly significant. Educating the farmers about the balance use of fertilizer and generating awareness about the climate change would be executable mitigation strategy to combat this phenomenon.

Keywords: climate change, cotton productivity, production function, fixed effect model, linear effects and marginal effects.

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CHAPTER 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 threat to various sectors of the economies. However, the agriculture 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 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-industrialized and agriculture stands as 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 staple fiber for textile industry that has 50.1% contribution in export earnings. This sector plays an important role in poverty alleviation and ensuring food security. Recent statistics show that the sector contributes around 21% to GDP, employs 44% of labour force, and directly or indirectly provide livelihood to 60% of the rural population. Agriculture includes livestock, major crops,

[1] After services and Industrial sectors

minor crops, forestry, and fisheries. Share of important crops[2] is 25.2% 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 characterized by very high temperature in most of the areas of Pakistan (GoP, 2013).

Pakistan's Agriculture is both rain-fed and irrigated but cotton crop is normally sown in the irrigated and semi-arid areas[3] due to its water requirement 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 fiber (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 have faced many challenges like pest attack, climatic variation and price volatility[4]. Although the problem of pest attack has considerably 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[5] 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

[2]Important crops include the wheat, rice, maize, cotton, and sugarcane.
[3] The graph of area under cotton is given in Appendix A-1.
[4]Over the two decades there is gap between the domestic and export price of cotton so to reduce this gap government have to announce support price (Caroratan and Ordan , 2008).
[5]Pakistan ranked as 8th in the global vulnerability risk Index 2013.

reduce the plan growth and also crop productivity. While the impact of precipitation deviation from mean value is negative on cotton productivity (Iqbal, 2011).

Pakistan is fourth major producer of cotton in the world[6] (GoP, 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 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, up to our knowledge limited literature is available on fiber crops. In Pakistan, cotton average fiber content and boll weight is low due to high temperature. Cotton crop in Pakistan is grown under irrigated to semi-arid, mostly high temperature and low rainfall conditions. Cotton plant is tolerant to high temperature and water stress to some extent due to its vertical tap root system but is however very 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[7] (ITC Technical paper, 2011).

International Trade Centre's Technical Paper (ICT, 2011) cites ICAC (2009) and states that cotton is being grown successfully from 28.2^0C in China to 41.8^0C in Sudan while in Punjab (Pakistan) the average seasonal temperature has been cited as 36.8^0C. However, the historical experience shows that the heat stress is a major constraint in production of cotton in various countries including Pakistan, India and Syria (ICT, 2011). Further rise in temperature may damage the cotton economy in countries/regions where it is already grown at a temperature close to 40^0C (ICAC, 2009). Unfortunately, Pakistan falls in that category.

[6] 1st is China, 2nd India and 3rd USA
[7] Flowers and bolls

The livelihood of millions of farmers and industrial labourers depends upon cotton economy in Pakistan. Therefore, the understanding of cotton-climate relationship is important for their social welfare. The present study is designed to quantifying the impacts of climate change on cotton productivity.

1.1 Research Gap

A number of studies have already analysed the impact of climate change on cotton crop for different countries and regions. For 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 and Schmitz (2011).[8] 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 producer of cotton, and included only climatic variables—took average temperature and precipitation from May to September which does not cover the whole season. Therefore, the coverage and scope of the study are limited and results of the study need to be explained carefully. The impact of climatic variables on plant growth and crop productivity differs at different stages of the plant cycle—seedling, leaves formation, vegetative growth, boll formation and boll size is sensitive to temperature variation (Reddy *et al*, (1993). Therefore, this study divides the crop season into two stages and each stage is further divided in two sub-stages on the basis of phenology of the crop—sowing and germination, vegetative stage, flowering and boll formation, and maturity/picking stages. The present study makes a real contribution to the literature by incorporating climatic and non-climatic variables and differentiating between climate change and weather shocks. Moreover, the climate change and weather shocks variables

[8]Because the country comprises great heterogeneity in the area of crop production as the temperature and precipitation variability is very high so climatic condition cannot be homogenized for country level production.

are introduced in the impact analysis keeping in view the phenological stages of cotton crop.

1.2 Objectives of the Study

The major objective of the study is to analyse the impact of climate change on productivity of cotton crop in major cotton growing areas of Pakistan. The specific objectives are:

1. To analyse the impacts of climate change on the yield of cotton crop in major cotton growing areas of Punjab;
2. To analyse the impacts of climate change on the yield of cotton crop in major cotton growing areas of Sindh;
3. To draw some policy implications from the results obtained from objectives 1-2 above, and suggest some recommendations.

1.3 Hypothesis

The study is conducted to empirically estimate the impacts of climate change and weather shocks. The following null hypotheses shall be tested in this study

- **H_0:** climate change has no effect on yield of cotton crop.
- **H_0:** climate shocks do not influence yield of cotton crop.

1.4 Organization of study

The remaining document is organized as follows. Second chapter reviews the literature related to the effects of climate change on crop production in general and on cotton production in particular. The third chapter includes the theoretical framework. The forth chapter covers the description of data and methodology used for the analysis. The fifth chapter provides results and discussion. The last chapter gives summary, conclusion, policy recommendation and some possible future research directions.

CHAPTER 2

Literature Review

David Ricardo (1772-1823) viewed the value of land as net productive potential of the land—more is the productive land higher shall be its value which can be estimated by value of discounted profits earned from land. The profit of any crop is affected by the levels of input use, climatic properties of Agro-ecological Zone, properties of soil and other socioeconomic variables. Production function and Ricardian framework are being commonly used to analyse the relationship between climate change and crop productivity[9].

Salam (1976) analysed agriculture productivity for Punjab using the production function approach. The study used cross-sectional data for two districts, which were selected using the multistage sampling technique, one each from Rice-Wheat and Cotton-Wheat systems. Production function was estimated using OLS regression analysis technique. The marginal productivity of each input was derived by differentiating the production function with respect to a specific input.

Adam *et al*. (1988) stated that climate change is a phenomenon of increase in CO_2 and trace gas emission which cause the greenhouse effects that crops productivity. The study uses the spatial equilibrium model and shows that the territorial alteration in agriculture affects the resource utilization. CO_2 concentration, temperature and precipitation used as climate variables. It was found that doubling the concentration of CO_2 may cause 4-5C^0 increase in temperature and annual precipitation may also increase. Effects on crop production were estimated using crop growth simulation models and found significant decline in yields of Wheat, Corn and Soybean.

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[9] Ricardian is a special case production function when farmer have information about the climatic variable. (Holst and Grun, 2010)

Reddy, *et al* (1992) conducted an experimental study to examine the impact of temperature variation on crop production using General Linear Models. Study found that every growth stage in cotton (*Gossypium hirsutum*) is affected by the increase in temperature beyond a certain optimal limit. The study used controlled climate for experiments in which the crop is exposed to the variety of temperature scenarios and found that elongation of vegetative parts is highly responsive to increase in temperature. The study also found that responsiveness of crop to temperature change is same for all cultivars. The study also confirmed the nexus of non-linearity in plant growth due to the response in temperature especially for the fruit bearing branches. The research shows that plants have different temperature requirement at the different development stages.

Mendelsohn *et al*. (1994) studied the impact of climate change on agricultural production using Ricardian framework. Thirty years average of each climate variable was used to determine the normal climatological variables. To minimize the chance of multicollinarity study divided the year into four seasons, thirty years average of each season is used in the cross-sectional analysis. The climate has a taxonomic nonlinear effect on agricultural production and thus on agricultural rent. The rise in temperature had a negative association with production while the precipitation had a positive effect on US agriculture.

Dixon *et al*. (1995) studied the impact of climate change on corn production using a yield response function in Illinois in USA. Time series and cross sectional data was used for the purpose. Besides using the traditional climatic variables—temperature and rainfall, the paper also uses the growing degree days for estimating the impact of solar radiation and moisture content as climate variables under the district level data. The corn crop is divided into four growth stages and effects of climate variables are studies for each stage. Four model specifications were used by incorporating climatic variable systematically and estimated the model using feasible generalized least square. The results found that soil moisture which has a close correlation with precipitation is most significantly affecting the crop yield and solar radiation is also significant. The research suggests that use of climate variable according to the growth stage improve the forecasting power.

Kaufmann and Snell (1997) used the pooled data for different surveys analysed the impact of economic environment, site characteristics and climate change on corn yield in U.S.A. The study used the temperature and precipitation as climate variables in linear and quadratic forms. The climatic variables are introduced according to the physiological characteristics of the crop. The results show that the linear form of every variable has a positive effect on crop but the quadratic form has a negative effect on the crop yield.

Mundlak *et al*. (1999) using panel data estimated agricultural production function by applying panel data estimation technique. The study used output and revenue (dependent) and input (fertilizer, labour, fixed capital, human capital and technology as independent variables) using the data of 37 countries for the period of 1970-1990. The effect of technology was found to be most significant. Potential dry matter and water deficit were used as proxy for environment variables but these variables were not found significant.

Doherty *et al*. (2003) examined the impact of different climate change scenario on productivity of cotton in USA. The study used detailed daily data of temperature and precipitation for growing season months, generated by GOSSYM model for cotton, under the stepwise regression analysis. The study validates the nonlinear relationship of plants growth with temperature, high temperature from start of May have positive impact on the germination of crop, up to certain limit elevated temperature in the month of June and July have positive impact on growth after which it starts depressing the plant growth and thus yield also. Study reported the mixed effect of precipitation on plant growth, rain reduces the water stress but also effect the light availability for photosynthesis, for some growth stages it has positive but negligible effect on yield. Study concluded that climate change is going to induce water stress on cotton which could be reduced irrigation and management adaptations.

Deressa *et al*. (2005) used Ricardian analytical framework to see the impact of climate change on sugarcane production in South Africa. The results show that the value of land is affected by the value of discounted profit which is influenced by the productivity of crops and the productivity of crops is affected by the climatic variations. Climate variables were included in linear and quadratic form (also used to include a 2nd order effects), the monthly average data in the form of three seasons used in the analysis. The study found that increase in winter temperature increases the net revenue up to a limit after which start decreasing or have negative effects. The same type of behaviour was found in case of summer temperature. These results were similar to the results found by the agronomic studies.

Eid *et al*. (2006) evaluated the impact of climate change on agriculture using Ricardian approach for different ecological zones of Egypt. This study incorporated the adaptation by farmers in response to the change in climatic conditions. The results have shown that temperature has the most significant effect on agriculture. The temperature was introduced as seasonal variables for each season. For summer and winter the relationship was found to be linear while for spring and fall it was quadratic. The most effective adaptation came out to be the setting up irrigation scheme and also changing the sowing dates and other cropping technologies.

Deschenes and Greenstone (2007) estimated the economic impact of climate change on agricultural crop yield and profit for USA agriculture. The study used climate data from 1970-2000 for 2268 counties to develop a balanced panel. The study estimated the impact of climate change under the theoretical framework of Hedonic pricing. Farm Profit and crop yield of corn and soybean crops are used as dependent variable. Seasonal climate variables (temperature and precipitation) with some variables related to the land characteristics are included in the analysis as dependent variables. Panel Fixed effect (time-wise and Cross-section wise) was used for econometric estimation. The study found that climate change has modest impact on Agricultural profit and crop Yield. But in simulation it will effect negatively to agricultural profits and crop yield.

Seo and Mendelsohn (2008) applied Ricardian analysis technique on data from 2300 farms from South America. The study used thirty years' moving average of climate variables for four seasons. The study divided farms in 5 categories—all farms, small farms, large commercial farms, arid farms and irrigated farms and separate regression for each farm data. Temperature, rainfall, soil characteristic data used as explanatory variables for farm value. Different climate change scenarios from high to medium were used for simulation analysis. The results have shown that the farm value has an inverse relationship with temperature and rainfall but only arid farms values increase with increase in rainfall.

Haim and Berliner (2008) used production function approach to study the impact of climate change on the production of wheat and cotton crop in Israel. Maximum temperature, minimum temperature, rainfall, humidity level and solar radiation were used as climatic variables to evaluate the climatic stress on plants. The crop yield was used as dependent variable for analysis. It was found that increase in temperature and decrease in rainfall will effect negatively to cotton yield and use of nitrogenous fertilizers and changing the sowing date were identified as the best adaptations to climate change.

You *et al*. (2009) examined the impact of temperature on wheat yield in china. The study used panel data for the analysis for all wheat growing provinces for the period of 1978-2000. In addition to some important physical variables, climate variables were used in nonlinear form in the function. The results of analysis showed that 4.7% decline in crop yield was due to climate change (4.5% by temperature and 0.2% of rainfall). Regional production specialization variable was used as proxy to capture the land characteristics and other governmental interventions used to promote the production of the crops which show the positive effect on wheat productivity with increase in the specialization of production.

Huang and Khanna (2010) studied the impact of climate change on crop yield and acreage allocation of crops for wheat, corn, and soybean using county level panel data. Monthly mean precipitation and its square and monthly mean temperature and deviations in temperature are used as variables for climate change and time trend is used as the proxy for technology innovations. The study used instrumental fixed effect method for econometric estimation. The results show that in climate change scenarios of IPCC (2001) effect of increase in temperature will effect negatively to the crop yield for all three crops while the effect of rainfall is positive for corn and soybean and ambiguous for wheat.

Ayinde *et al*. (2010) analysed the impact of climate change on agricultural production in Nigeria. The study showed that climate change (global warming) benefits the temperate zones because an increase in temperature will lengthen the growing season for these areas. The article used time series of temperature and precipitation for 22 years.

The area was divided into seven Agro-ecological zones. Analysis was conducted using simple statistical techniques of Granger causality tests after applying required techniques of time series analysis. The study concluded that temperature has no impact on crop production but rainfall has some positive impacts.

Cabas *et al*. (2010) analysed the impacts of climate change on crops (corn, soybean and wheat) yield in Ontario (Canada) using the time series data for 26 years. The study found that length of the growing season was the main determinant of crop yield. The paper used stochastic frontier approach to measure the effect of climate change using the panel data. Yield of crops used as dependent while site characteristics, economic characteristics, monthly temperature and precipitation and coefficient of variation (to capture the extreme events) variables were used as independent variables—both in linear and quadratic forms. The paper has estimated the impacts using the production function approach using the feasible general least square and also estimated the impact of climate change on variance of yield. The results of research prove the nexus of nonlinearity between climate variable and yield.

Le (2010) used counties' level panel data of the 3000 US counties for five crops[10] including cotton. Thirty years' moving average temperature, precipitation and diurnal temperature range were included as climate variables for the analysis. Fixed effects technique was used in the analysis. To examine the impact of nonlinearity on yield the quadratic terms of climatic variable were also included in the analysis. The study found positive impact of linear term of temperature on cotton crop but negative for the quadratic term. The impact of precipitation reported as negative which shows the water stress tolerance nature of crop. Study also captured the effect of marginal lands on yield of crops

[10] The other crop which are include in the analysis Wheat, corn, sorghum, soybean

which was reported as negative. So the overall impact of climate change was negative on most crops except cotton.

Sankaranarayanan *et al*. (2010) studied the impact of climate change on cotton crop in India using CO2, monthly average of temperature and precipitation as climate variables with some control variables[11]. The study found that CO2 has nothing to do with growth sensitivity of the crop but enhance the efficiency of inputs used for growth. The study confirms quadratic impact of climate variables on the crop production. The study reports the occurrence of more vegetative growth if crop is exposed to high temperature and lesser number of fruit formation in crop that reduced yield. The study also suggest adaptive precaution to remain protected from the climate change impacts by developing heat tolerant cultivars and intercropping with suitable crops.

Owusu *et al*. (2011) studied the contribution of climate change in determining the yield of crop using daily average of all climate variables[12] for 20 years. The research predicted that changing temperature and quantity of rainfall effect soil as well as crop production and also determine the sowing timing of crop by affecting the proper moisture condition. Decline in rainfall and increase in temperature decreased the Yield of crops but the overall results of this result remain inconclusive

Rowhani *et al*. (2011) measured the effect of climate variability on the yield of crops in East Africa—with a special focus on the variability of climate in between the seasons for production of Maize, Sorghum and Rice in Tanzania. Using time series data for mean seasonal temperature and rainfall, and seasonal variability of these two was used as climate variables. Coefficient of variation (CV) was used to capture the variability of climate variables across the seasons. Data was collected from Meteorological stations and

[11] Irrigation, soil moisture, soil nutrients and pesticide used etc.
[12] Temperature, rainfall, relative humidity, evaporation, and sunshine.

interpolated using Thin Plate Spline to increase the dataset so that we can get more idea about the geographical variations of climate. The Panel Fixed effect is used by incorporating the linear and quadratic terms of temperature and precipitation. The result of study showed the increase in seasonal variability other than mean value of climate variable will also reduce the crop yield

Passel *et al.* (2012) study relies on the Ricardian analysis which is a log linear model to study the impact of climate change on European Agriculture. The paper used 30 year time period by using the climate variables (30 years seasonal average of temperature and precipitation), socioeconomic indicators as exogenous variables and dummy for each country. Median regression was used to get coefficient which is less sensitive in the original model. The model shows linear relation of temperature with crop yield because all quadratic forms of temperature were insignificant but for precipitation both linear and quadratic forms were found statistically significant. Simulation results from model shows that land value throughout Europe was affected negatively by climate change. Robustness of model also implies that climate change will effect negatively to crop in climate change scenario.

From the aforementioned studies it can be concluded that climate has non-linear relationship with crop production. The effect of climate variable is accumulative in nature, affects the crop during every growth stage, and thus reflected in the yield. Cotton crop is highly responsive to temperature at the vegetative stage. The above cited literature also shows that the cotton has non-linear relationship with the climate variables.

CHAPTER 3

DATA AND METHODOLOGY

Testing the hypothesis of climate change and crop yield relationship that needs empirical analysis is a primary objective of this study. This chapter deals with the data and model specification.

3.1 Data and its Sources

Climatic data—mean temperature and mean 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 fertilizer surveys. Thirty districts have been included for the purpose analysis (See appendix A-3 for detail of districts). The bases of including these districts in the analysis are: be a major cotton producing district; and the data for production and inputs be available for at least 30 years—1981 to 2010[13].

3.2 Variables

The variables that are used in analysis are as following

3.2.1 Cotton Yield (Y)[14]

Cotton crop is source of lint and cotton seed, both of these have different uses in different industries—textile consumes lint as fiber while cotton seed is used in feed manufacturing industry and edible oil industries. As seed cotton (phutti) is main product of cotton, yield of the seed cotton is used as dependent variable for each district. Yield of crop has been used by Dherty (2003) and Sankaranarayanan *et al*. (2010) for the analysis of crop

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

[14] Short names/abbreviations shall be used in the empirical model

productivity and climate change relationship. Log transformation is used in the analysis for all physical variables including yield for the sake of convenience in interpreting the results.

3.2.2 Input variables

The set of variables includes all variables that are important and directly utilized in the production process like total cultivable area of the district, area under cotton crop, chemical fertilizer, pesticide, machinery, irrigation and other physical inputs. Due to some data limitations some variables are not available at the district level, like irrigation. However, the construction of panel for the analysis will capture the effect of omitted variables. The study also assumes the homogeneity of cultural practices[15] within district for cotton crop (You *et al*, 2009 and Schlenker *et al*, 2006).

Area under the Cotton Crop (Land): It is an important variable it helps in determining the return to scale in production of crop (Kaufman, 1997; Ahmad and Azkar, 1998). The variable is measured in hectares.

Fertilizer (NPK): Fertilizer includes Nitrogen, Potash, and Phosphorus (NPK) in nutrient tonnes. As fertilizer is available at the district level aggregated for all crops, we extracted data for cotton using share of fertilizer used for cotton crop. Share of fertilizer uptake for the crop was obtained from different publications of NFDC on 'National Fertilizer Use Survey'. The formula for fertilizer use in cotton is as follows

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

[15]Cultural practices include the ploughing, drilling and other field operation for the cultivation of crop.

The FCC is fertilizer consumption by cotton crop at district level, *Share FC* is the share of fertilizer consumption at various time periods—NFDC conducts fertilizer use survey after every five years. The TAF is total fertilizer off take in each district.

Climate Change Variables: According to Schlenker *et al* (2006), the effect of temperature differs at every stage of plant growth. The total effect is a consequence of accumulation of affects over time of the plant growth cycle of. Therefore, the effect of climate on yield is outcome of total effects that are added over the life span of plant. Crop production is usually sensitive to temperature and precipitation fluctuations. Deshmukh and Lunge (2012) explained that 60% yield variation in cotton is because of climatic effects. Although temperature values usually do not vary too much during the cotton production season; however, the optimal temperature changes for each growth stage. According to Tsiros (2008) cotton crop season can be divided into various growth stages based on phenological properties of the cotton plant. Deshmukh and Lunge (2012) study used time series data from 1991 to 2008 period and divided the cotton crop season into 5 growth stages. All the stages were found affected by growing degree day's temperature. Precipitation also had significant impact on vegetative growth.

In the present study, we divided cotton growth cycle into two major stages—vegetative and reproductive stage, since the response of cotton plant to changes in climate varies from one stage to another (Reddy *et al*, 1992). Each stage is divided into two sub-stages. To evaluate the impacts of temperature and rainfall, linear and quadratic terms of climate change related variables are used—the later is to capture the nexus of nonlinearity with yield.

Germination: Southern Punjab and Indus delta for Sindh are the major producing regions of cotton in Pakistan. Both regions have characteristics of low rainfall and high temperature in growing season of cotton. Sowing usually starts in May—very hot month.

Vegetative growth (VG): Vegetative stage includes the formation of stem and broadening of leave. This growth stage requires moderate temperature and humidity. Very high temperature and humidity will result in shedding of leaves and pest attack on the plant. This stage includes the months of June-July which are the most critical months for harvesting good yield.

Flowering and fruit formation (FFF): This is also a critical stage for obtaining good cotton yield which comprises flowering, boll formation and lint formation. This stage requires a 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. This stage includes the months of August and September.

Picking: *During* most of the picking period the process of lint formation 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 ^{0}C, 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 month of October and November.

Structural break for Bt Cotton. Cotton is the white gold of Pakistan and contributes significantly in export earnings from Pakistan. For the number of year's cotton producing farmers were facing many challenges in its production like pest attack, high temperature, and water stress but the problem of pest attack has been very serious. This problem 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 pest. However, it remained prone to sucking pests (Abid, 2011)

In May 2005, NIBGE[16] 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 70%. Presently, unofficial estimates indicate that Bt cotton varieties are grown over 85% of the total cotton area in Pakistan. Sowing time of Bt cotton differ from conventional cotton and is normally grown earlier than the traditional varieties (Abdullah, 2010). To tackle this issue, we have introduced dummy variable for Bt cotton—D_{bt} is equal to 1 after 2006 and zero otherwise. Then D_{bt} is interacted with temperature and precipitation at the time of its sowing. The sowing time of Bt is normally between March to April.

3.3 Theoretical 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*. (1988),[17] Cabas *et al*. (2010) and Holst *et al*. (2010) used production function approach, Mendelsohn *et al*. (1994)[18] used Ricardian approach and Reddy, *et al.* (2002) used agronomic crop simulation models for such analyses. All the methods have strengths and weaknesses. This chapter discusses these models and proceeds with the application of production function approach for evaluating the impact of climate change on productivity.

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

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[16]National institute for Biotechnology and Genetic Engineering, Faisalabad.
[17] Mundlak *et al*. (1999 and 2008)
[18] Mendelsohn *et al*. (1996 and 2001)

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 incorporate 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 problem. Since variables like soil characteristics[19] 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, approach assume perfect foresight and thus adaptations according however, if predicted climate change is much larger than this approach may not capture the adaptation completely, besides it also use constant price assumption and zero adjustment cost therefore, give 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. These models 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

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

and input needed to achieve this output (Mishra, 2007)". Production function approach was used by Solow (1956) using aggregate economy level data. This was extended by many researchers to analyse the panel data. Mundlak (1999, 2001 and 2011) 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 endogeniety are minimized (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).

3.3.1 The Basic Model

The idea of production function dates back to the publication of Turgot in 1767 who pioneered this idea and described the production process and optimal conditions of a production function. Malthus (1798) extended this model to logarithmic form while Ricardo (1817) contributed to this extension by including quadratic terms in the function. According to Ricardo, any variable can be represented in quadratic form in agricultural production function because of diminishing marginal return to the factors of production. Thünen (1824) introduced the production function for the first time for his own agricultural farm in exponential form and it was considered a real contribution in the marginal productivity theory. He proposed exponential marginal productivity and also disintegrated the complex input bundle of agricultural production function into distinct input sets and used calculus for marginal productivity analysis (Mishra, 2007). Later on there have been series of modifications in the production function until the Cobb and

Douglas (1920) discovered the production function for neoclassical economics, which was called as Cobb-Douglas (CD) production function. Lloyd (1969) rediscovered and proved that the Thünen (1824) exponential production function was nothing but a special case of CD function (Humphrey, 1997). Halter *et al.*, (1957) proposed the concept of Transcedental form for agricultural production which included linear as well as exponential form of the variables. This function was also modified form of Cobb-Douglas production function and exhibited more flexibility, including the non-constant elasticities of production.

Cobb-Douglas production function found to be the most important discovery of the neoclassical economics. This production function has number of implications in agriculture and productivity analyses (Mishra, 2007). The relationship between the output and input is accomplished by the inclusion of technology factor which is adapted during the production process. The general form for a production function can be written as

$$Y_i = f(X_i) \tag{3.1}$$

Where *i* is the number of observation i=1,2,3,….,n. Y_i is output produced using X_i inputs. For this analysis, we assume that 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

$$Y_{it} = f(X_{it} C_{it}) \qquad (3.2)$$

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 variable are normally taken in linear form while the other physical input variables used in function are converted into log forms (Kaufmann and Snell, 1997). We would use modified form of Cobb-Douglas production function that can be written as (Halter *et al*, 1957).

$$Y_{it} = f(X_{it}^{\beta_i} e^{b_i c_{it}}) \qquad (3.4)$$

Equation 3.4 can be rewritten as (Kaufman and Snell, 2007)

$$\ln(Y_{it}) = \beta_i \ln(X_{it}) + b_i C_{it} \qquad (3.5)$$

The marginal contribution of climate variables in crop yield can be estimated by differentiating the equation (3.5) with respect to climate variables (You *et al*, 2009 & Kurukulasuria *et al*, 2006).

3.4 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 model and random effects model.

3.4.1 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 research. The cotton producing districts are in fact heterogeneous in nature; therefore, cross-section wise effects may give better results. Econometrically these can be written as (Wooldridge, 2002)

$$Y_{it} = \beta_0 + \beta_i X_{it} + U_{it} \quad (4.1)$$

where

$$U_{it} = \alpha_i D_i + \varepsilon_{it} \quad (4.2)$$

Substituting Equation 4.2 in 4.1 would result in Equation 4.3

$$Y_{it} = \beta_0 + \beta_i X_{it} + \alpha_i D_i + \varepsilon_{it} \quad (4.3)$$

where X_{it} contain the explanatory variables like land, fertilizer and climatic effects etc., α_i are cross-section specific effect which vary across the cross-section but not across the time. The district[20] specific scalar constant are denoted by D_i[21], α_i is also called as individual effect or individual heterogeneity and dummy (D) capture 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 the 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).

[20] District is used as cross-section.
[21](Mundlak, 1978)

3.4.2 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

$$Y_{it} = \beta_0 + \beta_i X_{it} + U_{it} \quad (4.4)$$

where

$$U_{it} = \nu_i + \varepsilon_{it} \quad (4.5)$$

Substituting Equation 4.5 in 4.4 would result into

$$Y_{it} = \beta_0 + \beta_i X_{it} + \nu_i + \varepsilon_{it} \quad (4.6)$$

To reiterate, the random effects model requires a strong assumption that the correlation between explanatory variables and random effects must be equal to zero (Wooldridge, 2002). Exogeniety 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 exogeniety is violated then the model will be estimated using instrumental variable approach (Mandlak, 1978).

In the present study time series districts level data is pooled. Since, the cross-sectional heterogeneity exists in the data; therefore, the fixed effects model shall be preferred as suggest by the literature as well. However, the final decision about which model is most appropriate the Hausman (1978) test will be applied.

Although the fixed effects are introduced in this model, we will use Hausman test for final selection of model (Green, 2003).

$$H = (\beta^{FE} - \beta^{RE})[\text{var}(\beta^{FE}) - \text{var}(\beta^{RE})]^{-1}(\beta^{FE} - \beta^{RE}) \sim \chi^2 \qquad (4.7)$$

The Hausman specification test usually checks the existence of fixed or random effect in the model. For test application first we estimate the model using the Random Effects model after which we apply the test. Hausman[22] 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 which validates the Fixed Effect Models (FEM) are more appropriate than Random Effect Model (REM).

3.4.3 Empirical Model

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

$$\begin{aligned}
\ln Y_{it} = {} & \beta_0 + \beta_{TM}(TEMP_M) + \beta_{\mathrm{TJJ}}(TEMP_{\mathrm{JJ}}) + \beta_{\mathrm{TAS}}(TEMP_{\mathrm{AS}}) + \beta_{\mathrm{TO}}(TEMP_{ON}) + \beta_{\mathrm{PM}}(PRECP_M) + \beta_{\mathrm{PJJ}}(PRECP_{\mathrm{JJ}}) + \\
& \beta_{\mathrm{PAS}}(PRECP_{\mathrm{AS}}) + \beta_{\mathrm{PO}}(PRECP_{\mathrm{ON}}) + \beta_{\mathrm{VTM}}(VTEMP_M) + \beta_{\mathrm{VTJJ}}(VTEMP_{\mathrm{JJ}}) + \beta_{\mathrm{VTAS}}(VTEMP_{\mathrm{AS}}) + \\
& \beta_{\mathrm{VTO}}(VTEMP_{\mathrm{ON}}) + \beta_{VPM}(VPRECP_M) + \beta_{\mathrm{VPJJ}}(VPRECP_{\mathrm{JJ}}) + \beta_{VPAS}(VPRECP_{\mathrm{AS}}) + \beta_{VPO}(VPRECP_{ON}) + \\
& \beta_{\mathrm{TM2}}(TEMP_M)^2 + \beta_{TJJ2}(TEMP_{JJ})^2 + \beta_{TAS2}(TEMP_{AS})^2 + \beta_{TO2}(TEMP_{ON})^2 + \beta_{\mathrm{PM2}}(PRECP_M)^2 + \\
& \beta_{\mathrm{PJJ2}}(PRECP_{\mathrm{JJ}})^2 + \beta_{PAS2}(PRECP_{\mathrm{AS}})^2 + \beta_{PO2}(PRECP_{ON})^2 + \beta_{TPM}(TEMP_M) * (PRECP_M) + \beta_{\mathrm{TPJJ}}(TEMP_{\mathrm{JJ}}) * \\
& (PRECP_{\mathrm{JJ}}) + \beta_{\mathrm{TPAS}}(TEMP_{\mathrm{AS}}) * (PRECP_{\mathrm{AS}}) + \beta_{\mathrm{TPON}}(TEMP_{ON}) * (PRECP_{\mathrm{ON}}) + \beta_{Bt}D_{Bt} + \beta_{\mathrm{TMhA}}(TEMP_{MA}) * D_{Bt} + \\
& \beta_{\mathrm{PM}}(PRECP_{MA}) + \beta_{ar}\ln(\text{land}) + \beta_{\mathrm{f}}\ln(\text{npk}) + \beta_{\mathrm{g}}Tt + \beta_{\mathrm{i}}\textstyle\sum_i D_i + u_{it} \qquad (4.8)
\end{aligned}$$

Where,

$\ln Y_{it}$ = log of cotton yield.

[22](Hausman, 1978)

$TEMP_M$ = 20 years moving average temperature of May.

$TEMP_{JJ}$ = 20 years moving average temperature of June and July.

$TEMP_{AS}$ = 20 years moving average temperature of August and September.

$TEMP_{ON}$ = 20 years moving average temperature of October and November.

$PRECP_M$ = 20 years moving average precipitation of May.

$PRECP_{JJ}$ = 20 years moving average precipitation of June and July.

$PRECP_{AS}$ = 20 years moving average precipitation of August and September.

$PRECP_{ON}$ = 20 years moving average precipitation of October and November.

$VTEMP_M$ = Deviation from 20 years moving average temperature of May.

$VTEMP_{JJ}$ = Deviation from 20 years moving average temperature of June and July.

$VTEMP_{AS}$ = Deviation from 20 years moving average temperature of August and September.

$VTEMP_{ON}$ = Deviation from 20 years moving average temperature of October and November.

$VPRECP_M$ = Deviation from 20 years moving average precipitation of May.

$VPRECP_{JJ}$ = Deviation from 20 years moving average precipitation of June and July.

$VPRECP_{AS}$ = Deviation from 20 years moving average precipitation of August and September.

$VPRECP_{ON}$ = Deviation from 20 years moving average precipitation of October and November.

$(TEMP_M)^2$ = Square of 20 years moving average temperature of May.

$(TEMP_{JJ})^2$ = Square of 20 years moving average temperature of June and July.

$(TEMP_{AS})^2$ = Square of 20 years moving average temperature of August and September.

$(TEMP_{ON})^2$ = Square of 20 years moving average temperature of October and November.

$(PRECP_M)^2$ = Square of 20 years moving average precipitation of May.

$(PRECP_{JJ})^2$ = Square of 20 years moving average precipitation of June and July.

$(PRECP_{AS})^2$ = Square of 20 years moving average precipitation of August and September.

$(PRECP_{ON})^2$ = Square of 20 years moving average precipitation of October and November.

$(TEMP*PRECP)_M$ = interaction term of 20 years moving average temperature and precipitation for May.

$(TEMP*PRECP)_{JJ}$ = interaction term of 20 years moving average temperature and precipitation for June and July.

$(TEMP*PRECP)_{AS}$ = interaction term of 20 years moving average temperature and precipitation for August and September.

$(TEMP*PRECP)_{ON}$ = interaction term of 20 years moving average temperature and precipitation for October and November.

Dbt = dummy variable introduced for Bt-cotton.

$TEMP_{MA}$= 20 years moving average for the month of March and April (the months of Bt. Cotton sowing)

$PRECP_{MA}$= 20 years moving average of precipitation for the month of March and April (the months of Bt-cotton sowing).

Ln(land)= natural log of area under cotton

Ln(npk)= natural log of fertilizer available for cotton

T_t= time trend

D_i= district dummy

The interaction terms are introduced in the analysis for some variables like temperature and precipitation which imply that high temperature will have an interaction effect on the rainfall. Three dummies are introduced in the equation, D_{Bt} shows the effect of Bt-cotton on the production as by the introduction of Bt-cotton the expenditure on crop has been reduced significantly and sowing time for Bt-cotton is different from conventional cotton varieties so interaction dummy is introduced for a temperature and rainfall, and other dummies are introduced to capture the cross-sectional effect.

CHAPTER 4

Results and Discussions

The intensity of impact of climate change on crop production depends on environment the crop is currently being grown. The 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 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[23] over time mainly due to the improvements in technologies—varietal development, improved production practices and increased use of fertilizer and pesticides. However, the agronomic work shows that if the current trend in climate change continues, the productivity of cotton would adversely be impacted. Since, cotton is grown in specific areas of Pakistan experiencing already very hot temperature and reduced and erratic rainfall, the wellbeing of the cotton growers as well as farm workers would adversely be affected in days to come.

The remaining chapter is divided into three sections. The first section explains the results obtained from estimation of production function using combined data from two major cotton zones—Punjab and Sindh, of Pakistan. The second and third sections provide the results from estimation of impact model for Punjab and Sindh provinces, respectively.

4.1 Pakistan—Punjab and Sindh Combined

The impact of climate change on crops is different in different scenarios and may differ according to the spatial properties of the region. The descriptive statistics of temperature and precipitation is reported in Appendix A-5. The mean values of

[23] See Appendix A-2 for yield trend.

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). To estimate the effects of climate change on productivity of cotton at country level, data from two major zones —Punjab and Sindh, was combined and Equation 4.8 was estimated using panel data technique. The effect of climate change on crop productivity is estimated including the physical inputs variables—fertilizer use, area under cotton and time trend representing technological progress and the climate related variables which are 20 years moving average temperature and 20 years moving average precipitation—their linear terms[24], quadratic terms[25] and the deviations from long-term means[26]. Panel data[27] modelling techniques—the Common Effects Model (CEM), 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[28].

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 4.1. The temperature generally shows rising trend during the cotton growing season. However, the precipitation normals show opposite trend—it declined in March, April and May in almost all districts, only with few exceptions. For the remaining

[24]Only linear terms of climate variables
[25]Linear and quadratic terms of climate variables
[26]Linear terms and deviation from the mean value of climate variables
[27] To check unit root Im Pesaran Shin (IPS) is applied and reported in appendex No. A-7
[28]Wooldridge (2002) pp. 104

Table 4.1: Slope coefficients of Climate Normals

District	Temperature Normal (Slope Coefficients)					Precipitation Normal (Slope Coefficients)				
	March & April	May	June & July	August & September	November & October	March & April	May	June & July	August & September	Novemb er & 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
Nawabsha h	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

cotton growth period, the precipitation shows mixed trends; however, the majority of the districts exhibit positive trends. From the level of significance it can be concluded that rising trend of temperature for the month of May is most significant in last three decades while the slope coefficients for vegetative and flowering and Fruit formation stages are mostly insignificant. Furthermore, the slope coefficients of rainfall are also insignificant with few exceptions—March, April and May. It can be said that the climate normals show some increasing temperature trends in the cotton growing areas (Table 4.1). Furthermore, statistically significant increase in temperature normals is more pronounced in Punjab than in Sindh.

Different techniques can be used to analyse the panel data to evaluate the impact of climate change on cotton productivity. We estimate the FEM and REM. To choose the most appropriate model, the Hausman test was applied. The test statistics given in Table 4.2 favours the application of fixed effects technique.

Table 4.2: Hausman Test

Null Hypothesis	Chi-square (cal)	Chi-square (crit)	Decision
Random effect is more appropriate	95.84	42.98	Rejected

Tables 4.3 and 4.4 show the results of production function estimated using FEM[29]. Table 4.3 provides results of the tests of hypotheses using WALD test statistics. Model 1 in Table 4.4 is a full model that includes the all climate related variables of temperature and precipitation—their linear terms, squared terms, deviations' variables and the interaction terms, and other physical variables including area under cotton, fertilizer use and time trend representing technological change. To test the joint significance of various blocks of variables including the non-linearity of the impacts of climate normal, interaction between precipitation and temperature normals, square terms of precipitation and temperature, and the climate shocks—deviations from long-term means, WALD test has been used and the tests results are reported in Table 4.4.

The first hypothesis we tested was that $\beta_{TPMAPS}= \beta_{TPMPS}= \beta_{TPJJPS}= \beta_{TPASPS}= \beta_{TPONPS}=0$. This hypothesis implies that interactions between precipitation and temperature normals do not jointly impact the productivity of cotton. This hypothesis was accepted indicating that interactions between climate normals variables during different growth stages pose no significant influence on yield of cotton. Given this result, the second hypothesis which was tested relate to that of the deviations of current temperature from the long term means during all five stages of variables have no impact on cotton productivity. This hypothesis can be written as $\beta_{VTMAPS}= \beta_{VTMPS}= \beta_{VTJJPS}= \beta_{VTASPS}= \beta_{VTONPS}=0$. This hypothesis was rejected

[29] To see districts effect see Appendix A-4

implying that the deviations in temperature from its long term means during five stages of growth influence cotton productivity statistically significantly. The third hypothesis which was tested was that the deviations in precipitation from their long-term means during all stages of growth do not impact the cotton productivity, i.e. $\beta_{VPMAPS}= \beta_{VPMPS}= \beta_{VPJJPS}= \beta_{VPASPS}= \beta_{VPONPS}=0$. This hypothesis was accepted implying that the annual shocks in terms of precipitation had no impact on the cotton yield. The fourth and fifth tests of hypotheses are: $\beta_{TMA2PS}=\beta_{TM2PS}=\beta_{TJJ2PS}=\beta_{TAS2PS}=\beta_{TON2PS}=0$ meaning that temperature normals' square terms of all five stages of growth jointly do not influence cotton productivity; and $\beta_{PMA2PS}=\beta_{PM2PS}=\beta_{PJJ2PS}=\beta_{PAS2PS}=\beta_{PON2PS}=0$ specifies that the square terms of precipitation normals have no joint impact on cotton productivity. Both of these hypotheses were rejected implying that the climate change—temperature normal and precipitation normals, impact cotton productivity non-linearly. In summary, the tests of hypotheses reported in Table 4.3 indicate that the interaction of climate normals variables did not cause any significant variation in cotton productivity, and the precipitation shocks had also not influenced cotton productivity statistically significantly during the study period. However, the variations in temperature from their long-term means impacted the cotton productivity significantly. Furthermore, the climate change affected the productivity statistically significantly and the relationship had been non-linear. Given the results of tests of the hypotheses, Model 3 is the preferred model (Table 4.4).

Table 4.3: Results of Specification test for Model selection (Pakistan)

	Null Hypothesis	F / χ^2--test	F / χ^2--critical	Decision
1	$\beta_{TPMAPS}= \beta_{TPMPS}= \beta_{TPJJPS}= \beta_{TPASPS}= \beta_{TPONPS}=0$	F= 1.5122 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=4.6315 χ^2=23.1577	F= 2.21 χ^2= 11.07	Rejected
3	$\beta_{VPMAPS}= \beta_{VPMPS}= \beta_{VPJJPS}= \beta_{VPASPS}= \beta_{VPONPS}=0$	F= 1.9957 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=3.8658 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= 2.8396 χ^2= 28.40	F= 2.21 χ^2= 11.07	Rejected

Table 4.4 : Fixed Effect Model results with log of Yield as dependent variable

		Model 1		Model 2		Model 3	
	Variable	**Coefficient**	**S.E**	**Coefficient**	**S.E**	**Coefficient**	**S.E**
β_{AR}	Area	0.37095***	0.03552	0.3588***	0.0357	0.2001***	0.0394
β_{F}	Fertilizer	0.24754***	0.02983	0.2392***	0.0299	0.0282***	0.0386
β_{P}	P/NPK	0.01000***	0.00147	0.0098***	0.0015	0.0026***	0.0017
β_{G}	Time trend	0.03021***	0.00320	0.0263***	0.0032	0.0266***	0.0032
β_{TMA}	Temperature Bt. Cotton *(March-April)*	0.06963***	0.02953	0.0227	0.0237	0.0041	0.0228
β_{TM}	Temperature *(May)*	0.46864*	0.30213	0.5655***	0.3040	0.643**	0.2924
β_{TJJ}	Temperature *(June & July)*	1.13719***	0.34493	1.2411***	0.3253	1.0652***	0.3130
β_{TAS}	Temperature *(August & September)*	0.32689	0.34678	0.6416***	0.3176	0.3614*	0.2454
β_{TON}	Temperature *(October & November)*	0.56726**	0.28829	0.8925***	0.2800	0.86***	0.2679
β_{PMA}	Precipitation Bt. Cotton *(March-April)*	-0.0838***	0.02882	-0.0253***	0.0058	-0.0212**	0.0055
β_{PM}	Precipitation *(May)*	0.00453	0.05189	0.0249***	0.0118	0.0103	0.0113
β_{PJJ}	Precipitation *(June & July)*	-0.01518	0.02864	-0.0072**	0.0046	-0.0079*	0.0044
β_{PAS}	Precipitation *(August & September)*	-0.04820	0.03479	-0.0008	0.0037	-0.0058*	0.0035
β_{PON}	Precipitation *(October & November)*	-0.6110***	0.09464	-0.0047	0.0091	-0.0071	0.0087
β_{TMA2}	Sq. Temp Bt. Cotton *(March-April)*	-0.00204**	0.00104	-0.0002	0.0008	0.0002	0.0008
β_{TM2}	Sq. Temperature *(May)*	-0.00433	0.00450	-0.0064*	0.0045	-0.0090**	0.0044
β_{TJJ2}	Sq. Temperature *(June & July)*	-0.0218***	0.00482	-0.0217***	0.0047	-0.0176***	0.0045
β_{TAS2}	Sq. Temperature *(August-September)*	-0.00546	0.00529	-0.0099**	0.0051	-0.0052*	0.0049
β_{TON2}	Sq. Temperature *(October-November)*	-0.01205**	0.00531	-0.0147***	0.0053	-0.0133***	0.0050
β_{PMA2}	Sq. Precip Bt. Cotton *(March-April)*	0.00037***	0.00010	0.0003***	0.0001	0.0002**	0.0001
β_{PM2}	Sq. Precipitation *(May)*	-0.00010	0.00034	-0.0006**	0.0003	-0.0003	0.0003
β_{PJJ2}	Sq. Precipitation *(June & July)*	0.00010***	0.00003	0.0001**	0.0000	0.0001***	0.0000
β_{PAS2}	Sq. Precip*(August & September)*	0.00004	0.00003	0.0000	0.0000	0.0000	0.0000
β_{PON2}	Sq. Precip*(October & November)*	0.00328***	0.00058	0.0003	0.0004	0.0001	0.0004
β_{VTMA}	Temp. Dev. Bt. Cotton *(March-April)*	0.01899	0.01229	0.0170	0.0126	0.0201*	0.0114
β_{VTM}	Temp. Deviation *(May)*	-0.0233***	0.00823	-0.0191*	0.0084	-0.0226***	0.0079
β_{VTJJ}	Temp. Deviation *(June & July)*	-0.00460	0.00768	-0.0059	0.0078	-0.0131*	0.0074
β_{VTAS}	Temp. Dev.*(August & September)*	-0.00212	0.00959	0.0026	0.0097	0.0093	0.0091
β_{VTON}	Temp. Dev.*(October & November)*	0.01828**	0.00605	0.0135*	0.0060	0.0117*	0.0058
β_{VPMA}	Temp. Dev. Bt. Cotton *(March-April)*	0.00062	0.00210	0.0005	0.0021		
β_{VPM}	Precip. Deviation *(May)*	0.00054	0.00060	0.0005	0.0006		
β_{VPJJ}	Precip. Deviation *(June & July)*	0.00041	0.00030	0.0004	0.0003		
β_{VPAS}	Precip. Dev.*(August & September)*	-0.00031*	0.00019	-0.0003	0.0002		
β_{VPON}	Precip. Dev.*(October & November)*	0.00089	0.00067	0.0004	0.0007		
β_{TPMA}	Temp.*precip*(March & April)*	0.00228*	0.00168				
β_{TPM}	Temp.* precip*(May)*	0.00020	0.00143				
β_{TPJJ}	Temp. *precip*(June & July)*	0.00013	0.00079				
β_{TPAS}	Temp.* precip*(August & September)*	0.00144	0.00105				
β_{TPON}	Temp.*precip *(October & November)*	0.02092	0.01328				
	R^2	0.76		0.71		0.74	

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

The results of Model 3 show that the cotton production faces increasing return to scale as the estimated coefficient of area under cotton is positive and statistically significant. The coefficient of fertilizer is positive and highly significant. Its magnitude indicates that 10 percent increase in fertilizer use shall encourage cotton productivity by 2.8 percent. The use of fertilizer nutrients in crops production is highly unbalanced—phosphoric and potash fertilizers are used significantly lower than the recommended doses. To see the response of phosphatic fertilizer (P), we used ratio of P to NPK. The coefficient of this ration is positive and highly statistically significant—highlighting the importance of phosphatic fertilizer to enhance cotton productivity.

Marginal impacts[30] of climate related variables have also been computed using approach of Kurukulasuriya *et al*, (2006) and the results are given in Table 4.5 the figures given in Table 4.5 are calculated using results from Model 3. On the basis of phenology of the crop, cotton can be divided into five growth stages (Reddy *et al*, 1992) starting from germination and early growth. Two types of cotton verities are grown in Pakistan: the first group includes the Bt. cotton[31] and the other group comprises of conventional cotton varieties. Sowing of Bt. Cotton starts earlier in March and April—the average temperature and precipitation of both months are used as variables. The results given in Table 4.5 show that 1^0C increase in temperature would improve yield of Bt. cotton by 1.5% while the increase in precipitation by 1mm would reduce its yield by 1.38%. The temperature in March and April is normally low and is not suitable for cotton sowing. However, with the changing climate the 20 years moving average of temperature in cotton growing districts is shown positive trend—though not statistically significantly. Since the cotton crop is heat loving plant and with the introduction of Bt. cotton varieties—long duration and early sowing, it has become possible to sow these varieties earlier than the conventional

[30]The marginal effects are evaluated on basis of mean temperature and precipitation for each growth stage.
[31] See A-6 for the result of Bt. Cotton dummy without interaction with climate variables.

cultivars. Therefore, the rising temperature in the months of March and April proved to be beneficial for the crop. The results are similar to those obtained by Doherty *et al* (2003) and Sankaranarayanan, *et al* (2010) for the same crop[32]. The conventional varieties of cotton are sown late and thus their cultivation starts in the month of May. The result given Table 4.5 implies that higher temperature would be beneficial for the crop output by improving the crop germination. The increase in temperature normal by 1^0C may increase the yield of cotton crop by 7.58%. The impact of precipitation on yield is lower but positive—i.e. 1mm increase in precipitation may improve the yields by 0.398%. These results are inline to the Doherty *et al* (2003) and Sankaranarayanan *et al* (2010) studies for cotton crop.

Table 4.5: Marginal impact of climate change variables on log of Yield

No.	Variable name	Marginal impact
1	Temperature For Bt. Cotton *(March & April)*	0.0148
2	Temperature *(May)*	0.0750
3	Temperature *(June & July)*	-0.2335
4	Temperature *(August & September)*	-0.0138
5	Temperature *(October & November)*	0.1418
6	Precipitation For Bt. Cotton *(march & April)*	-0.0138
7	Precipitation *(May)*	0.0039
8	Precipitation *(June & July)*	0.0026
9	Precipitation *(August & September)*	-0.0058
10	Precipitation *(October & November)*	-0.0059

The second growth stage covering June and July months—vegetative, development and flowering stage, yields the most dominant impact on crop productivity (Doherty *et al,* 2003; and Sankaranarayanan *et al.,* 2010). Although the linear term of temperature is positive but its square term is significantly negative, which indicates that productivity increases up to a certain level of temperature but starts declining thereafter. Our result

[32]The cotton crop is unresponsive to temperature variations during the first fortnight after sowing and in the second fortnight crop becomes sensitive to temperature (Sankaranarayanan *et al*, 2010). Precipitation normally has negative impact on germination of crop and early growth because moisture stress is usually low in March and precipitation may delay the process of sowing and germination.

shows that 1^0C increase in temperature above average (20 years moving average temperature during last thirty years) would reduce the crop yield by almost 23.35%—the crop is already under severe heat stress and any further increase in temperature would jeopardize the cotton economy of Pakistan[33]. The impact of precipitation increases during this stage would however be positive. This finding is similar to the findings of Doherty *et al.,* 2003; Sankaranarayanan *et al.*, 2010; and Le, 2010).

Third growth stage in the cotton production is characterized by boll setting, boll opening and lint formation, which covers the months of August and September. Boll setting is sensitive to temperature—the optimal temperature for boll setting ranges between 32 ^0C—36 ^0C. Our results show that 1^0C increase in temperature normal would reduce cotton yield by 1.3%. Impact of precipitation normal during this stage would be negative—however the magnitude of impact would be very marginal as the coefficient is very small. The negative impact may be due to the reason that higher rainfall with greater temperature increases the level of humidity that in turn induces invasion of pest on plants. The same types of results are reported by the Doherty *et al* (2003) and Sankaranarayanan *et al* (2010). The fourth growth stage—October and November months, is the cotton picking season. The maturation period actually covers the duration of crop from white flowers to open bolls and is influenced very strongly by the temperature. High temperature helps opening up of bolls and facilitates harvesting. The impact of precipitation is insignificant because it plays no important role as crop is at its maturity stage.

In summary, the results obtained from using full sample—over all Pakistan, imply that the impacts of temperature and precipitation vary according to the stages of growth. As crop yield is the cumulative outcome of crop growth for each growth stage (Schlenker*et al,* 2006) hence the sum of all impact coefficients of temperature—from 4

[33]By wilting and shedding of leaves.

stages, indicates that 1^0C rise in temperature throughout the cotton season would reduce cotton productivity by about 3.05%. If the months of March and April are included then these figures are -1.57% and -1.9% for rise in temperature and precipitation, respectively.

The impacts of temperature deviations from long-term mean are also statistically significant. From Model 3 for March and April show that with 1^0C deviation from the long term mean of temperature improve the cotton yield by 2%, however, for traditional varieties 1^0C deviation from long term mean of May temperature may cause 2.2% negative effect on cotton yield. Furthermore, the impact of June & July 1^0C deviation from long term mean may reduce the cotton yield by 1.3%, nevertheless, for October & November 1^0C deviation from long term mean temperature may improve the yield by 1.1%. In summary the overall impact of temperature deviation is negative, only 0.4%.

4.2 Punjab Province

Punjab includes about 80% cotton producing area of Pakistan (GoP, 2012-2013). A significant area under cotton is in districts of central Punjab, which has moderate to high temperature and precipitation. However, the most of the cotton producing belt includes southern Punjab which has high temperature and low precipitation. The Punjab has special characteristic for cotton production having significant area under cotton sharing and 70% of the total cotton production in the country.

Table 4.6 gives the results of WALD tests used to test the joint significance of variables in block in order to selection an appropriate model. For Punjab the array of hypotheses testing is similar to that of followed in Section 4.1 above. The first hypothesis, i.e. $\beta_{TPMAP}= \beta_{TPMP}= \beta_{TPJJP}= \beta_{TPASP}= \beta_{TPONP}=0$, implies that interaction between the temperature and precipitation normals jointly have no 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. The hypothesis is rejected which implies that deviation in temperature from temperature normal 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 normal 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.

On summarising the results of the Wald tests reported in Table 4.6, it can be concluded 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 4.7 is the preferred model.

Table 4.6: Results of Specification test 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=1.65481 χ^2=8.27405	F=2.21 χ^2=11.07	Accepted
2	$\beta_{VTMAP}= \beta_{VTMP}= \beta_{VTJJP}= \beta_{VTASP}= \beta_{VTONP}=0$	F=8.1431 χ^2=40.7155	F=2.21 χ^2=11.07	Rejected
3	$\beta_{VPMAP}= \beta_{VPMP}= \beta_{VPJJP}= \beta_{VPASP}= \beta_{VPONP}=0$	F=0.4559 χ^2=2.2797	F=2.21 χ^2=11.07	Accepted
4	$\beta_{TMA2P}=\beta_{TM2P}=\beta_{TJJ2P}=\beta_{TAS2P}=\beta_{TON2P}=0$	F=6.1256 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= 3.3563 χ^2=16.7816	F=2.21 χ^2=11.07	Rejected

Table4.7: Fixed effect Model results with log of Yield as dependent variable (Punjab)

		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}	Fertilizer	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}	Temperature Bt. Cotton *(march & April)*	-0.0014	0.0100	-0.0379	0.0271	-0.0304*	0.0175
β_{TMP}	Temperature *(May)*	0.1241*	0.0617	0.2580	0.3410	0.5159*	0.3135
β_{TJJP}	Temperature *(June & July)*	0.5390*	0.2461	0.9320***	0.3307	1.2000***	0.3311
β_{TASP}	Temperature *(August & September)*	0.3302*	0.1705	0.6313	0.3469	0.6686**	0.3545
β_{TONP}	Temperature *(October & November)*	0.2250	0.1269	0.1840	0.3409	0.1775	0.3474
β_{PMAP}	Precipitation Bt. Cotton *(march & April)*	-0.0261	0.0304	0.0104	0.0067	0.0109*	0.0068
β_{PMP}	Precipitation *(May)*	-0.0952*	0.0566	-0.0114	0.0137	0.0010	0.0137
β_{PJJP}	Precipitation *(June & July)*	-0.2059**	0.0460	-0.0032	0.0052	-0.0035	0.0053
β_{PASP}	Precipitation *(August & September)*	-0.0721	0.0405	0.0033	0.0046	0.0010	0.0047
β_{PONP}	Precipitation *(October & November)*	0.0034	0.1539	-0.0450	0.0114	-0.0442***	0.0116
β_{TMA2P}	Sq. Temperature Bt. Cotton *(march & April)*	-0.0003	0.0014	0.0011*	0.0010	0.0090*	0.0010
β_{TM2P}	Sq. Temperature *(May)*	-0.0001	0.0053	-0.0019*	0.0052	-0.0063*	0.0052
β_{TJJ2P}	Sq. Temperature *(June & July)*	-0.0121**	0.0052	-0.0164***	0.0048	-0.0203***	0.0047
β_{TAS2P}	Sq. Temperature *(August & September)*	-0.063***	0.0060	-0.0098*	0.0057	-0.0118*	0.0058
β_{TON2P}	Sq. Temperature *(October & November)*	-0.0005	0.0070	0.0000	0.0067	0.0017	0.0069
β_{PMA2P}	Sq. Precipitation Bt. Cotton *(march & April)*	-0.0001	0.0001	-0.0001*	0.0001	-0.0002*	0.0001
β_{PM2P}	Sq. Precipitation *(May)*	0.0006	0.0004	0.0004*	0.0004	0.0002	0.0004
β_{PJJ2P}	Sq. Precipitation *(June & July)*	0.0001	0.0000	0.0001**	0.0000	0.0001*	0.0000
β_{PAS2P}	Sq. Precipitation *(August & September)*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
β_{PON2P}	Sq. Precipitation *(October & November)*	0.0011*	0.0006	0.0013***	0.0004	0.0014***	0.0004
β_{VTMAP}	Temp. Deviation Bt. Cotton *(march & 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 & July)*	-0.0242*	0.0177	-0.0263***	0.0076	-0.0249**	0.0074
β_{VTASP}	Temp. Dev.*(August & September)*	0.0188	0.0116	0.0246	0.0093	0.0261	0.0190
β_{VTONP}	Temp. Dev.*(October & November)*	0.0281	0.0191	0.0247	0.0060	0.0211	0.0158
β_{VPMAP}	Precip. Dev. Bt. Cotton *(march & 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 & July)*	-0.0002	0.0003	-0.0002	0.0005		
β_{VPASP}	Precip. Dev.*(August & September)*	-0.0001	0.0003	-0.0001	0.0003		
β_{VPONP}	Precip. Dev.*(October & November)*	0.0003	0.0006	0.0001	0.0006		
β_{TPMAP}	Temp.* Precip.*(march & April)*	0.0013	0.0010				
β_{TPMP}	Temp.* Precip. *(May)*	0.0023	0.0014				
β_{TPJJP}	Temp.* Precip.*(June & July)*	0.0005	0.0012				
β_{TPASP}	Temp.* Precip.*(August & September)*	0.0011	0.0012				
β_{TPONP}	Temp.* Precip*(October & November)*	-0.0018	0.0056				
	R^2	0.7770		0.7588		0.7548	

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

The coefficients estimated in Model 3 (Table 4.7) 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 fertilizer (NPK) coefficient indicates that 1% increase in use of NPK will improve the cotton yield by 0.19%. The coefficient of P to 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 fertilizer is highly imbalanced in Pakistan because of costly phosphatic based fertilizers, 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% 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[34] 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

Table 4.8: Marginal impacts of climate change on log of Yield (Punjab Province)

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

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

The climate change impacts cotton productivity in Punjab follow almost the same pattern that was observed at the national level—Sindh and Punjab combined. The marginal impacts figures given in Table 4.8 show that 1^0C increase in temperature during the sowing period of cotton would encourage yield by 1.65% and 6.57% in cases of Bt seed and conventional seeds, respectively. However, the rise in temperature by 1^0C during vegetative and flowering-fruiting stages of growth would reduce yield by 24.14% and 8%, respectively. However, the warmer temperature during the maturity and picking stage would help in harvesting good yield of cotton—the marginal impact calculations show that with 1^0C rise in temperature increases yield by 26.54%. Since cotton is a heat tolerant crop, warming up of weather during the sowing and maturity-picking stages help harvest better cotton crop, 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 source (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 4.8 highlights the fact that warming up of weather is beneficial for the cotton crop; the impact however is marginal—that is less than 1%. 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%.

4.3 Sindh Province

Punjab produces about 70%[35] of the total cotton, while Sindh shares almost 28% of the total cotton crop in the country and remaining 2% is produced by the other provinces (GoP, 2013-2014). Cotton cultivation in Sindh is done in area with high temperature and low precipitation—located in the neighbourhood of Rajistan Desert. Canal irrigation is the major source for the water requirements of the crop.

On the same pattern as followed in Section 4.2 and 4.3, the WALD test statistics is applied to choose the final model and results are reported in Table 4.9. In this regard the first hypothesis, which was tested can be written as $\beta_{TPMAP}= \beta_{TPMP}= \beta_{TPJJP}= \beta_{TPASP}= \beta_{TPONP}=0$, 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 which was 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. 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 testes can be written as "$\beta_{TMA2P}=\beta_{TM2P}=\beta_{TJJ2P}=\beta_{TAS2P}=\beta_{TON2P}=0$" and "$\beta_{PMA2P}=\beta_{PM2P} =\beta_{PJJ2P} =\beta_{PAS2P} =\beta_{PON2P}=0$" respectively, these, hypotheses 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.

[35] PAK-SCMS Bulletin (2014)

In summary, the results reported in the Table 4.9 indicate 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. However, the temperature shocks of significantly influence cotton productivity, and the impacts of temperature and precipitation on cotton productivity are nonlinear On the basis of Joint WALD coefficient test Model 3[36] is considered to the preferred model. The impact of all physical variables is positive on crop. The positive and significant value of land coefficient shows that productivity of cotton has increasing return to scale. The fertilizer coefficient shows that 10% increase in fertilizer use may cause 2.6% increase in crop productivity. This result further highlights the fact that cotton crop in Sindh is more responsive to phosphatic fertilizers use than the nitrogenous fertilizers. Time trend is used as proxy for technology which shows that productivity of cotton increases more than 4% per annum due to the changes in technologies. It is worth mentioning here that Bt. verities were introduced much earlier than the in the Punjab.

Table 4.9: 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=1.5122 χ^2=7.5612	F=2.21 χ^2=11.07	Accepted
2	$\beta_{VTMAPS}= \beta_{VTMPS}= \beta_{VTJJPS}= \beta_{VTASPS}= \beta_{VTONPS}=0$	F=2.6860χ^2=13.4308	F=2.21 χ^2=11.07	Rejected
3	$\beta_{VPMAPS}= \beta_{VPMPS}= \beta_{VPJJPS}= \beta_{VPASPS}= \beta_{VPONPS}=0$	F=1.9957χ^2=9.9785	F=2.21 χ^2=11.07	Accepted
4	$\beta_{TMA2PS}=\beta_{TM2PS}=\beta_{TJJ2PS}=\beta_{TAS2PS}=\beta_{TON2PS}=0$	F=3.8658 χ^2=19.3293	F=2.21 χ^2=11.07	Rejected
5	$\beta_{PMA2PS}=\beta_{PM2PS}=\beta_{PJJ2PS}=\beta_{PAS2PS}=\beta_{PON2PS}=0$	F=2.8396 χ^2= 28.3961	F=2.21 χ^2=11.07	Rejected

[36] Table 4.10

Table 4.10: 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}	Fertilizer	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}	Temperature For Bt. Cotton *(march & April)*	0.1610	0.1274	0.0398	0.0462	0.0393	0.0456
β_{TMS}	Temperature *(May)*	1.0588**	0.5217	1.2830**	0.5283	1.2861**	0.5263
β_{TJJS}	Temperature *(June & July)*	1.0633**	0.5831	1.0026*	0.5783	1.0251***	0.5725
β_{TASS}	Temperature *(August & September)*	0.6632	0.5552	0.9464*	0.5580	0.8448**	0.5520
β_{TONS}	Temperature *(October & November)*	-0.0388	0.5222	0.2110	0.5371	0.1764	0.5337
β_{PMAS}	Precipitation For Bt. Cotton *(march & April)*	-1.2854*	0.6905	-0.0261	0.1914	0.0234	0.1853
β_{PMS}	Precipitation *(May)*	1.0882**	0.4420	-0.0006	0.0515	-0.0089	0.0509
β_{PJJS}	Precipitation *(June & July)*	0.2640*	0.1603	-0.0053	0.0202	-0.0003	0.0196
β_{PASS}	Precipitation *(August & September)*	-0.3141***	0.0919	-0.0297**	0.0111	-0.0311**	0.0109
β_{PONS}	Precipitation *(October & November)*	-0.2635	0.3025	0.1242**	0.0336	0.1026**	0.0329
β_{TMA2S}	Sq. Temperature For Bt. Cotton *(march & April)*	-0.0056	0.0044	-0.0014	0.0015	-0.0015	0.0015
β_{TM2S}	Sq. Temperature *(May)*	-0.0124*	0.0077	-0.0163*	0.0077	-0.0162**	0.0077
β_{TJJ2S}	Sq. Temperature *(June & July)*	-0.0184**	0.0085	-0.0186**	0.0086	-0.0186**	0.0085
β_{TAS2S}	Sq. Temperature *(August & September)*	-0.0064	0.0088	-0.0096*	0.0090	-0.0086*	0.0049
β_{TON2S}	Sq. Temperature *(October & November)*	-0.0082	0.0092	-0.0096	0.0094	-0.0088	0.0093
β_{PMA2S}	Sq. Precipitation For Bt. Cotton *(march & April)*	0.0328*	0.0229	0.0003	0.0222	-0.0062	0.0215
β_{PM2S}	Sq. Precipitation *(May)*	-0.0080	0.0073	-0.0032*	0.0007	-0.0026	0.0056
β_{PJJ2S}	Sq. Precipitation *(June & July)*	-0.0003	0.0005	0.0002**	0.0001	0.0002	0.0003
β_{PAS2S}	Sq. Precipitation *(August & September)*	0.0005***	0.0001	0.0003**	0.0001	0.0004**	0.0001
β_{PON2S}	Sq. Precipitation *(October & November)*	-0.0035	0.0034	-0.0042*	0.0035	-0.0109**	0.0015
β_{VTMAS}	Temperature Deviation For Bt. Cotton *(march & April)*	-0.0209	0.0280	-0.0017	0.0284	0.0060	0.0274
β_{VTMS}	Temperature Deviation *(May)*	-0.0079	0.0163	-0.0021	0.0163	-0.0024	0.0159
β_{VTJJS}	Temperature Deviation *(June & July)*	0.0291*	0.0164	0.0391*	0.0167	0.0389**	0.0165
β_{VTASS}	Temperature Deviation *(August & September)*	-0.0382*	0.0206	-0.0448*	0.0211	-0.0429**	0.0206
β_{VTONS}	Temperature Deviation *(October & November)*	0.0222*	0.0132	0.0131	0.0135	0.0147	0.0133
β_{VPMAS}	Precipitation Deviation For Bt. Cotton *(march & April)*	-0.0104*	0.0057	-0.0090	0.0059		
β_{VPMS}	Precipitation Deviation *(May)*	-0.0002	0.0016	-0.0001	0.0017		
β_{VPJJS}	Precipitation Deviation *(June & July)*	0.0006	0.0006	0.0009	0.0006		
β_{VPASS}	Precipitation Deviation *(August & September)*	-0.0002	0.0002	-0.0002	0.0002		
β_{VPONS}	Precipitation Deviation *(October & November)*	0.0014	0.0016	0.0002	0.0016		
β_{TPMAS}	Interaction of temp &precip*(march & April)*	0.0382	0.0295				
β_{TPMS}	Interaction of temp &precip. *(May)*	-0.0317	0.0223				
β_{TPJJS}	Interaction of temp &precip. *(June & July)*	-0.0069	0.0047				
β_{TPASS}	Interaction of temp &precip. *(August & September)*	0.0083	0.0062				
β_{TPONS}	Interaction of temp &precip. *(October & November)*	0.0122	0.0104				
	R^2	0.8538		0.8192		0.8192	

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

Marginal[37] impact analysis for these variables may give the more comprehensible relationship between the climate change and crop yield. For marginal analysis, Kurukulasuriya, *et al.* (2006) is followed to evaluate the impact of climate change on cotton yield. The results of marginal analysis are reported in Table 4.11. The results follow the almost same trend with little differences as of using the full sample—Punjab and Sindh. 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 ^{0}C higher than the average in cotton growing districts of Punjab. . The May is the most suitable month for cotton sowing (Ayaz *et al*, 2012 & Kakar *et al, 2012*), particularly for the conventional varieties as well as the early sown varieties also require higher temperature in latter month; therefore, 1^{0}C increase in temperature during May is beneficial for cotton productivity.

Table 4.11: Marginal impacts of climate change on log of Yield (Sindh Province)

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

The impact of temperature increases during vegetative stage is negative the result is similar to the findings in case of Punjab and full sample (Pakistan). During flowering and fruit formation stage, 10C increase in temperature may cause about 30 % improvement in the cotton yield while the effect of temperature in full picking impacts

[37]In table 4.11

cotton productivity negatively. Therefore, it may be inferred that the impact of temperature on cotton crop is different during different growth stages. The cumulative impact, i.e. sum of all stages, came out to be reduced yield by -2.26% with 10C increase in temperature during the growing season of cotton in Sindh—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. The positive impact of Bt. Cotton may be less as expected, for Sindh, this may be due to increase in the seed cost on adopting and farmer misperception that Bt. Cotton required no pesticide therefore, the optimal used pesticide was not practiced therefore, this may cause reduction in cotton yield [(Orphal, 2005) & (Nazli et al, 2012)].

Chapter 5

Summary, Conclusion and Policy Recommendation

The major objective of this thesis 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. This study is unique in literature because all the previous studies used only climatic variables and yield for analysis that may overestimate the climate effects on crop production. This study includes non-climatic variables in addition to climate related variables. Furthermore, studies done on the subject in Pakistan used current climate related variables which only capture the impacts of weather shocks. This study takes 30 years moving average of temperature and precipitation. To capture the impacts of climate change and to evaluate the impacts of shocks on cotton yield, we took deviations of current climatic variables fromtheir respective climate normal—temperature and precipitation.

District level data is used for the analysis. Since each district has different management and agro-ecological characteristics, Fixed Effects Model (FEM) is used. The results suggest that climatic variables influence cotton yield statistically significantly. Although, the statistically significant positive effects of linear temperature were seen during all the growth stages, while squared terms exhibited negative signs in most of the cases-- most of them were statistically significant indicating that climatic variables impact cotton yield non-linearly. The marginal impact analysis shows that increase in temperature during May, October and November may improve the yield while it reduces yield if rise is experienced in June, July, August and September months. The overall impact of 1^0C increase in temperature will reduce the cotton yield by 1.58%. The overall impact of increase in precipitation is either insignificant or negligible. For Punjab the marginal analysis follows same the trend as for whole country. The overall impact of temperature rise is positive, while the precipitation exhibited negative influence on cotton yield. Interestingly, Sindh showed slightly different impact of temperature according to crop growth stages while overall impact of 1^0C increase in temperature would reduce the cotton yields by 2.26% and the effect of precipitation is mostly insignificant but with little positive impact on cotton yield. One of the major reasons could be the higher temperature in May and October and November months. Physical variables' impacts remain positive and significant for the crop yield.

From the above study results following conclusions can be drawn. The climatic variables impact cotton productivity nonlinearly. The impact of climate change is negative for cotton yield especially marginal increase in temperature impact is most obvious. The effect of rainfall on cotton production is mostly insignificant or negligible for current crop production due irrigated nature of crop but this rainfall may also affect negatively in the climate change scenario but interestingly the precipitation impact is positive for Sindh cotton production in same scenario.

The evidence of negative impact of temperature and positive impact of precipitation, although merely, and positive impact of fertilizer and technological improvement suggest some policy measures to endure the challenge of climate change. Enhancing the extension services to educate the farmers about the crop management, use of fertilizer, would be the important coping strategy against the adverse impacts. Considering the negative impacts of temperature efforts of agricultural research should concentrate on developing the heat stress tolerant verities.

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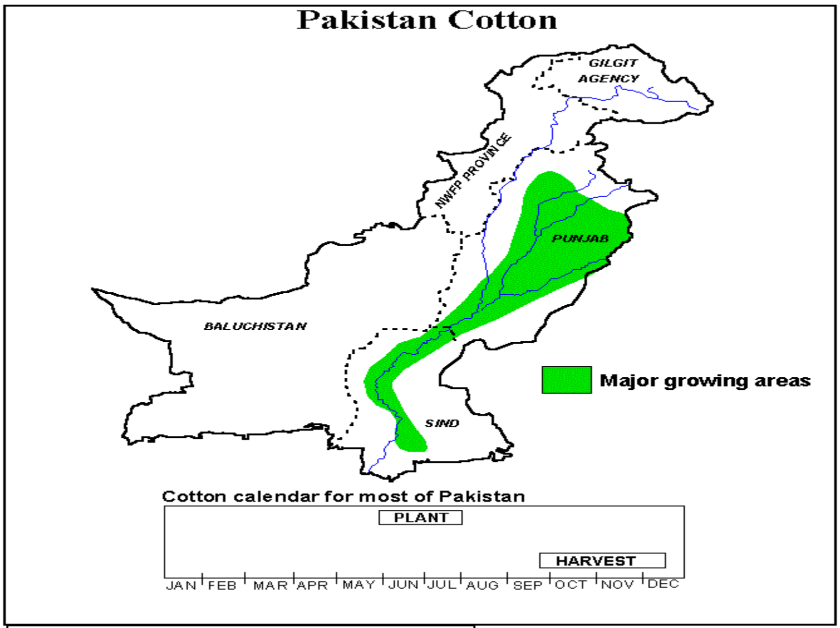
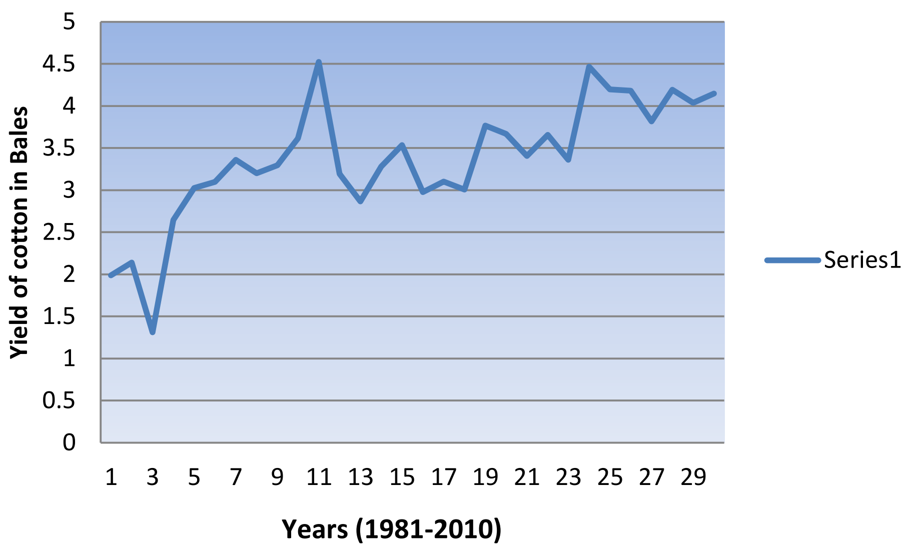
Appendices

Appendix A-1; Major Cotton growing areas of Pakistan



Source: Pakistan Agriculture Department.

Appendix A-2; Cotton Yield Trend of Pakistan



Year-wise Yield of Cotton

Appendix A-3: Districts selected in the analysis

Punjab	Sindh
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.	Badin, Dadu, Hyderabad, Jacobabad, Khairpur, Larkana, Nawabshah, Sukhur, Sanghar, and Thatta.

Appendix No.A-4 : **Cross-effects (District) for each district**

District	coefficient	District	coefficient
Bhakkar	0.7346***	R.Y Khan	-0.1844*
Bawalpur	-0.0194	Sargodha	-0.2483*
Bwl Nagar	-0.2216	Sahiwal	-0.3456***
D.G. Khan	0.7828	T Tsingh	0.1754***
Faisalabad	-0.3235	Vehari	0.1265**
Jhelum	-0.9947***	Badin	-0.5885*
Jhang	-0.0702***	Dadu	0.1570**
Khushab	0.3720***	Hyderabad	-0.3820**
Kasur	-0.9540***	Jacobabad	0.2469
Layyah	0.5076*	Khairpur	-0.0433*
Mianwali	0.5611	Larkana	0.5113
M. Garh	0.4002	Nawabshah	-0.0115
Multan	-0.3389**	Sukkur	0.8226**
Okara	-0.1663*	Sanghar	-0.8290**
Rajanpur	0.6012	Thatta	-0.2844***

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

APPENDIX A-5: Mean value of temperature and Precipitation across the panel districts

	Mean Temperature (^{0}C)					Mean Precipitation (mm)				
District	March & April	May	June & July	August & September	October & November	March & April	May	June & July	August & September	October & 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
Nawabsha h	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 No. A-6 Fixed effect Model results with log of Yield as dependent variable (Bt. Cotton)

	For Pakistan		For Punjab		For Sindh	
variables	**Coefficient**	**S.E**	**Coefficient**	**S.E**	**Coefficient**	**S.E**
Area	0.3508***	0.0349	0.4381***	0.0412	0.4452***	0.0685
Fertilizer	0.2213***	0.0289	0.3087***	0.0327	0.2923***	0.0633
P/NPK	0.0096***	0.0015	0.0112***	0.0014	0.4229***	0.2188
Dummy For Bt. Cotton	0.2001***	0.0336	0.0318***	0.0069	0.3042***	0.0703
Time trend	0.0260***	0.0032	0.0127**	0.0045	0.0445***	0.0051
Temperature *(May)*	0.3116*	0.1977	0.4455*	0.2418	0.7329*	0.4701
Temperature *(June & July)*	1.4340***	0.3236	1.1653***	0.3293	1.6061**	0.6321
Temperature *(August & September)*	0.7054***	0.3181	0.7088**	0.3553	0.4223*	0.2134
Temperature *(October & November)*	1.3242***	0.2715	0.0913	0.3373	0.4701	0.5881
Precipitation *(May)*	0.0447***	0.0113	-0.0061	0.0134	0.1384*	0.0527
Precipitation *(June & July)*	-0.0074*	0.0046	-0.0023	0.0052	-0.0118	0.0207[i]
Precipitation *(August & September)*	-0.0014	0.0037	0.0022	0.0046	-0.0015	0.0112
Precipitation *(October & November)*	-0.0047	0.0091	-0.0350*	0.0110	0.1245*	0.0292
Sq. Temperature *(May)*	-0.0030	0.0045	-0.0046	0.0052	-0.0086	0.0082
Sq. Temperature *(June & July)*	-0.0241***	0.0047	-0.0202***	0.0047	-0.0301**	0.0092
Sq. Temperature *(August & September)*	-0.0111***	0.0051	-0.0123**	0.0058	-0.0024*	0.0098
Sq. Temperature *(October & November)*	-0.0228***	0.0051	0.0024	0.0066	-0.0125	0.0103
Sq. Precipitation *(May)*	-0.0011***	0.0003	0.0003	0.0004	-0.0137*	0.0060
Sq. Precipitation *(June & July)*	0.0000**	0.0000	0.00005	0.0000	0.0003*	0.0003
Sq. Precipitation *(August & September)*	0.0000	0.0000	-0.00001	0.0000	0.0000	0.0001
Sq. Precipitation *(October & November)*	0.0001	0.0004	0.0012*	0.0004	-0.0048	0.0025
Temp. Deviation *(May)*	-0.01508**	0.0075	-0.0222**	0.0072	-0.0036	0.0157
Temp. Deviation *(June & July)*	-0.01348*	0.0073	-0.0224**	0.0070	0.0390**	0.0162
Temp. Dev.*(August & September)*	0.009269	0.0091	0.0224**	0.0088	-0.0449**	0.0200
Temp. Dev.*(October & November)*	0.013845**	0.0058	0.0196*	0.0057	0.0124	0.0130
R^2	0.705668		0.7499		0.7841	

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

Appendix No. A-7 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
Fertilizer	-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 & July)*	-2.6600	0.0039	stationary
Temperature *(August & September)*	-2.0100	0.0500	stationary
Temperature *(October & 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 & July)*	-3.4800	0.0100	stationary
Precipitation *(August & September)*	-2.3800	0.0200	stationary
Precipitation *(October & 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 & 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 & July)*	-3.7800	0.0100	stationary
Sq. Precip *(August & September)*	-2.0400	0.0400	stationary
Sq. Precip *(October & 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 & July)*	-18.0480	0.0000	stationary
Temp. Dev. *(August & September)*	-15.4000	0.0000	stationary
Temp. Dev. *(October & 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 & July)*	-15.1300	0.0000	stationary
Precip. Dev. *(August & September)*	-11.9400	0.0000	stationary
Precip. Dev. *(October & November)*	-10.5819	0.0000	stationary