Impact of Climate Change on Agriculture in Pakistan: A District Level Analysis

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ABSTRACT

This paper examines the impact of climate change and weather shocks on agriculture of Pakistan. Employing Fixed Effect (FE) and Instrumental variable (IV) estimations on district level panel data, this study finds evidence for significant impact of climatic variables on agriculture of the country. Warming is found harming the agriculture especially in warmer and rain-fed regions of the country. Increasing precipitation affects the agriculture produce positively. Findings are suggestive that agriculture production of previous year is a .ignificant determinant of current year s production of the sector. ertili er is found generating a statistically significant robust positive impact on agriculture production. Spatially varying impact of climate variables, both in magnitude and direction, is evident from the study. The results are robust to alternative specifications using agriculture output and revenue per hectare as dependent variable.

1. INTRODUCTION

Climate change remains one of the most celebrated areas of research and the vulnerability of agriculture to climatic change has earned a general consensus the world over [Cline (1996, 2007)].[1] The impact of climate change on agriculture, however, has emerged, and rightly so, to be more an empirical issue than the theoretical one generating voluminous literature standing far from being conclusive especially in context of the extent of impact varying both across the region and over time. High temperature and unfavourable rainfall (the precipitation) have emerged as the key determinants of agriculture sector produce across the globe[2] and agronomic models of climate change document a range of adverse climatic impact on agriculture of developing countries.

The issue bears special importance for developing economies for their maximum reliance on agriculture in terms of contribution to economic growth, exports[3] and employment share.[4] The agriculture of Pakistan stands poor when it comes to performance despite being a major shareholder both in contribution to GDP and provision of employment in the country. Along with trinity of socio-economic-politico factors, climate change is presumably one of the major factors underlying this poor performance. In Pakistan, water scarcity coupled with extended diversity of geographic conditions[5] turns climate an important predictor of the agriculture sector performance.[6] Amid lower water resources and higher water run-off, high temperatures push for maximum reliance on rainfalls. Higher rates of evapo-transpiration,[7] in Balochistan and northern

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[1] limate or climate normals refers to a location s weather averaged over long periods of time (this study uses 20 years average of temperature and precipitation as climatic variables).

[2]See Nicholson (1994 and 2000) for details on the issue. Gornall (2010) provides a comprehensive review of the literature on the impact of climate change on agriculture.

[3]See Christoplos (2009).

[4]Cline (2007) details the comprehensive estimates of lost output to change in climate with special focus on contribution of agriculture to GDP and employment.

[5]The geographical variation of availability of water may result in climate change impact varying spatially.

[6]Refer to Morrison (2009) for detail.

[7]A good control for the impact of temperature and precipitation though but data limitations preclude the use of the variable in this study.

Punjab, may further aggravate the situation. Again a major reliance on semi-arid areas for agriculture production increases the vulnerability of the sector to the temperature and rain falls further.[8]

In the long run, South Asia is expected to witness a wide range of variations in climate wherein temperature and precipitation may undergo an increase of 2.3 4.5° C and 10 17 percent by 2070-2099 resulting in large losses in agriculture.[9] The impact of climate change on agriculture, therefore, emerges as a future-driver of the agriculture produce. But the area remains least explored in Pakistan and the studies dealing the issue can be counted on fingers[10]. Available studies mostly cover only some specific regions of the country and use data on one or two crops. Against this backdrop, the present study, using district level data, extends the previous work in scope, coverage and estimation methods. Amid subsidised prices of the agriculture produce and inputs, Ricardian approach may produce erroneous results so the production function approach sets the bases of the present investigation[11]. Robustness of results, however, is confirmed by using both output and revenue as dependent variables. Fixed Effect (FE) and Instrumental Variable (IV) approaches are applied for the analysis. The remainder of the paper is structured as follows: next section details the conceptual underpinnings of the debate on models applied in empirical research on the issue along with estimation methodology and data used in the analysis at hand. Section 3 discusses the results while section 4 details the robustness of the estimates. Section 5 concludes the study.

2. THEORETICAL BACKGROUND

2.1. The Conceptual Underpinnings

An array of methodological issues involved in estimating impact of climate change on agriculture leaves no option for a generic model. Complexities of the relation, ranging from types of data used for analysis, functional form adopted, different geographical and policy variables, and region and time context heterogeneities[12] generate multistring empirical literature employing different methods of empirical estimations depending on nature and scope of the particular study.

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[8]See Final Report, Task Force on Climate Change, 2010 for details.

[9]Christensen, *et al*. (2007); IPCC (2007); Ruosteenoja, *et al.* (2003).

[10]Shakoor, *et al*. (2011); Muhammad, *et al.* (2011); Ahmed and Schmitz (2011); Ahmad and Ahmad (1998); Hausman (1978); Iqbal, *et al.* (2001); Shaw, *et al*. (1994); Farooqi, A., and A. H. K. (2008); Iqbal, *et al*. (2009).

[11]See Deschenes and Greenstone (2004) for detailed advantage of using production function approach.

[12]See Hoch (1958, 1962) and Mundlak (1961) for importance of immeasurable affecting agriculture.

Broadly speaking, methods and approaches applied in empirical literature on climate change-agriculture nexus can be categorised into structural and spatial analogue models with farmer being interdisciplinary in nature [Adams, *et al*. (1998); Schimmelpfennig, *et al.* (1996)]. Known as crop response models, structural models simulate potential yields of the specific crops under different climate scenarios. The experimental nature of structural models, an asset at micro level, turns into a liability when it comes to analyse the issue at macro level wherein inferences, obtained from few sample units, are to be generalised over large areas and production systems [Adams, *et al*. (1998)]. On the other hand, spatial analogue models, dealing with case studies, have widely been applied to study the cross-sectional variations in extent of climate impact across diverse geographical locations [Schimmelpfennig, *et al*. (1996)].

Largely relying on mathematical simulations, General Circulation Models (GCMs) belong to computer-based generation of models estimating likely impact of climate changes on agriculture (crop) production [Barron (1995)]. These models, by their very nature, are an expression of empirical relationships and mathematical equations dynamics generated by the interactions of soil characteristics and atmospheric changes. These models, analogously, allow simulating the future situation of climate change as well. The capacity of the computing programmes puts certain limits on the GCM. Notably, the accuracy of the outcome hugely depends on the precision of responses and process uploaded in the analysis.

Economic impact assessment models, having a special relevance in context of the study at hand, are generally classified into Agro-ecological Zone (AEZ), Crop Simulation, Production Function and the Ricardian models. Agro-Ecological Zones (AEZ) methodology is used to analyse the potential production under different rain-fed and irrigation conditions in different Agro-ecological context.[13] In context of Basic Linked System (BLS), against crop matching and environmental procedure, AEZ generates inventories predicting agro-ecological specific potential output.[14] The BLS, being an Applied General Equilibrium (AEG) in its very nature, demands huge amount of data with imposed balance on commodity and financial flows at local, national or international level depending on the scope of the analysis. Furthermore, data quality and reliability, with special reference to developing countries, limits the efficiency of these models.

Crop simulation models are controlled experiments estimating the impact of different climatic variations on crops grown under controlled environmental conditions. The models, fascinating apparently, fail to capture the impact of adaptability of farmers to the changing conditions of climate generating damage

[13]Fischer, *et al*. (1988) provides an excellent detail of the system.

[14]See Rosenzweig and Parry (1994), Fischer, *et al*. (1996), and Parry, *et al*. (1999) for application of BLS.

estimates biased upward [Mendelsohn and Dinar (1999)]. This generation of models, contrary to applied general equilibrium nature AEZ, belongs to partial equilibrium and adopts both controlled experiment and econometric procedures.

Production Function approach, for estimating impact of climate change on agricultural production, is the most widely used technique in extant literature in its different variants namely experimental or empirical production functions[15]. Empirical production function analysis allows direct estimation of the extent of impact of climate changes through incorporation of temperature and precipitation variables as direct inputs while controlling the outcome for physical and biological variables (inputs including technology, fertilisers etc.) using historical data. Amongst the critique on this approach, its intrinsic inability to handle the socio-economic characteristics of the farmer affecting, more importantly, his commitment and adaptability stands atop. This deficiency, in turn, may result in overstating the damage (yield reduction) [Mendelsohn, *et al.* (1994)].

Ricardian model, pioneered by Mendelsohn, *et al.* (1994), is more of a reaction to production function approach claiming the lead over all methods as instead of crop yield it uses economic variables data from country surveys or databases for the analysis.[16] Different versions of the Ricardian models use land value, land rent, net revenue or net profit on land as dependent variables to gauge the impact of climate variables on agriculture controlled for economic variables.[17] Worth mentioning, however, is that the model was first devised for U.S data and this point has a special relevance in context of our study as land value or rents amid ill-structured and semi-structured agriculture markets in the developing countries do not reflect true values rendering this method inefficient. Further non-integrated agriculture markets in developing countries may represent local rents and land values deviating from its true magnitude if the markets were integrated.[18] Of the non-exhausting list, development effect on land values, difficulties involved in allocating fixed cost to crop plots devoted to certain specific crops, multiple cropping seasons, household consumption of crops, especially that of food crops in developing countries and other issues involved in calculating cost of production are some of the major issues leaving the suitability of Ricardian analysis in developing countries skeptical.

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[15]See Deschenes and Greenstone (2006) on efficiency of the production function approach in estimating impact of climate change on agriculture.

[16]The nature of data in this study guides us toward using Production Function as Ricardian approach is more suitable for survey data at farm level.

[17]Cline (1996); Darwin (1999); Schlenker, *et al*. (2005) criticises the Mendelsohn, *et al*. (1994) for not controlling the irrigation factor. Also see Reilly, *et al.* (1994) for food price issues and Kaiser, *et al*. (1993a, 1993b); Kelly, *et al*. (2005) for cost of switching from one mode of production to other in Ricardian approach.

[18]Ricardo (1817) explicitly concludes that land rents are reflective of the land revenues in competitive markets .

2.2. The Model

Against this backdrop, the present study uses production function approach to estimate the impact of climate change on agriculture of Pakistan. The agriculture production (Q) is a function of climatic and non-climatic inputs. The vectors of inputs include capital (K), climate (C) and the other controls covered in (Z).

$$Q = f(K, C, Z)$$

In the present study, number of tube-wells (TWS) and tractors (TRS) is used as proxy capital (K).[19] Set of auxiliary climatic inputs (C) comprises temperature (TEMP) and precipitation (PREC)[20] variables which may affect the agricultural production while Z is the vector of other inputs including fertiliser (FER) and cultivated area (CA) etc.

The linear equation of the model can be written as:

$$Q_{it} = \alpha_i + \beta_1(TWS)_{it} + \beta_2(TRS)_{it} + \beta_3(FER)_{it} + \beta_4(CA)_{it} + \beta_5(TEMP)_{it} + \beta_6(PREC)_{it} + \eta_t + \mu_i + \varepsilon_{it} \quad (1)$$

Where Q_{it} is agricultural production of ith district at time t. η_t controls the effects common to the cross-section over the time i.e. improvements in agriculture practices and technology.[21] Any bias generated by time invarying unobserved factors is controlled by applying Fixed Effect Model (FEM). Square terms of climatic variables are introduced to capture the non-linearities involved in the climate change-agriculture production nexus. The inclusion of squared terms of climate indicators accounts for the fact that temperature and precipitation will have positive impact on output for a certain optimal limit and crossing that limit will adversely affect the output. Inclusion of squared terms gives Equation (2).

$$Q_{it} = \alpha_i + \beta_1(TWS)_{it} + \beta_2(TRS)_{it} + \beta_3(FER)_{it} + \beta_4(CA)_{it} + \beta_5(TEMP)_{it} + \beta_6(PREC)_{it} + \beta_7(TEMP)_{it}^{\ 2} + \beta_8(PREC)_{it}^{\ 2} + \eta_t + \mu_i + \varepsilon_{it} \quad (2)$$

It is argued that previous year s produce, to a larger extent, determines inputs level for the current year rendering output in the year t dependent on output of previous year (t_{-1}). Also the current prices are determined by the supply in previous year. These prices prevailing at time t, sets the expectations of farmers for the prices of the crops in time t_{+1} which operates as a signal for crop choice.[22] Also we argue that absence of credit market for the poor farmers, especially the small farm

[19]The selection of proxies was guided by data limitations.

[20]The data for temperature were generated by applying ECHAM5 GCM using Grid Analysis and Display System (GrADS while precipitation data were collected from Pakistan Metrological Department).

[21]To capture this, time trend was included in the estimations.

[22]Adaptive expectations.

holders, increases the reliance of farmer on its previous year s income. urther, lesser opportunities for off-farm income especially in rural part of the country leaves last year s production is ma or determinant of input use in current years. This lagged dependency is captured by introducing lagged production $[(Q)_{i(t-1)}]$ as explanatory variable making our model dynamic.

$$Q_{it} = \alpha_i + \beta_1(TWS)_{it} + \beta_2(TRS)_{it} + \beta_3(FER)_{it} + \beta_4(CA)_{it} + \beta_5(TEMP)_{it} + \beta_6(PREC)_{it}$$
$$+ \beta_7(TEMP^2)_{it} + \beta_8(PREC^2)_{it} + \beta_9(Q)_{i(t-1)} + \eta_t + \mu_i + \varepsilon_{it} \quad (3)$$

The lagged variable must enter positively and statistically significant if the argument built above hold. The inclusion of lagged output in Equation (3) induces dynamicity in the model making FE estimates biased. Further, sequential decision making by farmers makes the use of input an endogenous process wherein the decisions are revised at different stages of crop growth and not once for all.[23] Presumed endogeniety and dynamic nature of the Equation (3), makes Fixed Effect estimates inefficient (in addition to being biased) leading us to apply instrumental variable approach. Of the variants of IV, difference GMM remains the most used in dynamic panel data models.[24] Internal instrumentation is followed in this study.

2.3. Estimation Methodology and Data

Using district level panel data (i=67 districts, t=30 years [1980-2010]), this study envisages gauging the impact of climate change on agriculture in Pakistan[25]. Amid ill-structured and semi-structured agriculture markets in the developing countries, it is argued that land rent do not reflect true land values leaving Ricardian method inefficient.[26] Production Function approach, therefore, is employed for estimating impact of climate change on agriculture production of Pakistan to allow the direct estimation of the extent of climate change impact through incorporation of temperature and precipitation variables while controlling the outcome for physical inputs.[27]

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[23]Extensive literature is available on three stage production functions. The unavailability of data on decision making equation of farmer precludes the use of this function in the present study. See Zhou, *et al*. (2010) for sequential decision making in use of fertilisers.

[24]See Arrelano and Bond (1991) on GMM.

[25]Using panel data (actual/realised) spanned over long period in Fixed Effect framework minimises the omitting variable bias as unobservables such as soil quality and adaptation of farmers are captured through district dummies.

[26]Data limitations preclude use of Ricardian approach as no information is available on land rents. Further net profits cannot also be calculated as no data on costs are available. The robustness of the results, therefore, was confirmed by using total revenue per hectare (constant prices) as dependent variable.

[27]Standard disclaimer of inability of Production Function approach to account for adoption explicitly applies.

Equation (2) above involves no lagged dependent variables and can be estimated using Random/Fixed effect methods.[28] Heterogeneity concealed in both region and time invariant characteristics involved in panel data, guides towards using Fixed Effect (FE) model.[29] The acceptance of FE against Random Effect (RE) was confirmed by Hausman FE-RE test. Cross-section weights were applied and standard errors were corrected for panel to obtain efficient estimates. Estimations were undertaken for full sample as well as for all the four provinces. In order to gauge the impact of one set of variables on others, sensitivity analysis was performed by introduction of respective set of variables alternatively. Similar set of specification was estimated for full sample as well as at provincial level to perform some comparisons. Specifications, with different sets of physical inputs were also estimated where deemed necessary for example tube-wells and tractors appear only for Punjab and Balochistan as the data were available for these two provinces only. The presumed impact of lagged agriculture production on current year s production (Equation 3 above) may render FE suffer dynamic panel bias pushing us to the use of Arrelano and Bond s MM 1991 . Difference MM, preferred in purging fixed effects is used for the analysis. Standing with internal instrumentation, lagged values of endogenous variables were used as instruments. Weather variables, being strictly exogenous are used as instruments at level.

Starting from present number of 123 district level administrative units in Pakistan,[30] the data on physical inputs for the districts constituted after 1981 were merged with parent district data leaving us with a total of 67 districts for final analysis. A mix of 33 crops leads us to calculate Quantity Index (QI).[31] A representative QI corresponds to average of horizontal summation of individual indices calculated for each district against individual crops for respective year. Laspeyres Quantity index, at 1980-81 average prices was calculated purposefully as it conforms to, the central idea of total production; use of production function approach in this study and, at fixed price, any increase in QI must correspond to increase in produced quantities of crops.

Considering the persistence over the short time periods, the missing values for physical inputs were interpolated or extrapolated. The data on number

[28]This study estimates Equation 2 and Equation 3 by applying FE and IV separately to draw comparison.

[29]Heterogeneity is an integral part of panel data [Greene (2003)].

[30]Several new districts were created in Pakistan during the period 1981-2010, the statistics regarding these districts for the years prior to their creation were never worked out by the concerned quarters and therefore are not reported. This left us with no choice but to merge the available data in parent districts.

[31]Food and Agriculture Organisation (FAO) of the United Nations provides the similar index (Agriculture Production Index). Our index is different in way that it does not include data on live stocks. Further FAO does not provide index at disaggregate level.

of tube-wells and tractors were available only for Punjab and Balochistan while Sindh and Khyber Pakhtunkhwa (KP) respectively have data only on tube-wells and tractors. These variables were excluded from full sample analysis and the estimations for the respective provinces.

The determinants include, in addition to climate variables, data on inputs including fertilisers (nutrient tonnes of Nitrogen, Phosphorus and Potassium mix), tractors (numbers), and tube-wells (numbers) as well as total cultivated area (000 hectares)[32] and its irrigated proportion. The cultivated area represents the land input in production function. The mix of crops across the country and non-availability of daily data on temperature over the full period of study left us unable to use degree days as climate change measure. Guided by two main crop growing seasons in agricultural year[33] in Pakistan (Kharif and Rabi) and to cover important growth stages (crop phenology) for a mix of crops (in respective season), different sets of temperature and precipitation variables capturing long term climate change (20 years moving average),[34] and deviations from normal[35] were used alternatively to capture the impact.[36] This study reports the results for seasonal means of average monthly temperature and precipitation[37] for winter, spring, summer, and fall quarters.[38]

The descriptive statistics (mean values) of the variables used in the analysis are presented in Table 1. The lowest average QI is observed for KP while the highest is for Punjab. No significant variation in use of fertiliser nutrients per cultivated hectare (FER_CA) is observed across the provinces except KP which emerged to be the province using the lowest quantity of fertiliser nutrients. Balochistan cultivates the lowest area. Climatic variables show significant variation across the season and provinces. The lowest mean temperatures are observed for KP for all seasons while Sindh is found to be the warmest province. Across the seasons, summer remains the highest temperature season. Highest rain is observed in summer for all the provinces with Punjab having the highest precipitation while the Balochistan receives least rains. The

[32]The data are a mix of rain-fed and irrigated farms and information available incapacitates us to determine whether the farm is irrigated or not.

[33]Starting with Kharif season (Summer and Fall quarters of current calendar year) and completing by end of Rabi season (mostly Winter and Spring quarters of next calendar year).

[34]Wang, *et al*. (2009).

[35]We differ from Mendelsohn, *et al*. (1999) in constructing the climate variation variable(s). We calculate deviation of climate variables from their corresponding means over the long run while Mendelsohn, *et al*. (1999) constructed the variables using difference between highest and lowest monthly temperature. Our construction is similar to Chang (2002).

[36] his study reads climate as a long run pattern of weather. ee Deschenes and Greenstone (2007) for the distinction between climate and weather. Also refer to Mendelsohn, *et al*. (2007) on the impacts of climate normal and climate variance.

[37]Chang (2002) used same construction.

[38]Winter is the average of December to February; spring is the average of March to May; summer is the average of June to August; and fall is the average of September to November.

Table 1

Data Description

Regions	Statistics	QI	FER	FER_CA	CA	TMS	TMSR	TMF	TMW	PMS	PMSR	PMF	PMW	TR
	Mean	1060.25	29966.56	0.12	278.20	26.00	31.67	22.76	12.58	33.92	67.88	17.16	24.70	5686.33
Pakistan	Std. Dev.	3862.63	36596.03	0.27	208.01	7.29	5.28	5.82	6.33	37.79	60.89	16.51	25.39	6096.22
	N	**1890**	**1890**	**1890**	**1890**	**1890**	**1890**	**1890**	**1890**	**1890**	**1890**	**1890**	**1890**	**1890**
	Mean	1653.63	49958.12	0.13	405.76	29.69	34.58	25.10	14.79	26.96	100.30	20.00	17.90	5381.28
Punjab	Std. Dev.	5809.54	43097.82	0.11	151.44	4.12	2.85	2.56	2.87	13.79	64.47	11.54	10.61	4795.94
	N	**780**	**780**	**780**	**780**	**780**	**780**	**780**	**780**	**780**	**780**	**780**	**780**	**780**
	Mean	638.16	35423.92	0.12	372.25	30.22	33.44	27.18	17.91	3.74	38.38	6.45	4.40	5327.62
Sindh	Std. Dev.	1295.15	32707.91	0.10	224.03	1.74	2.53	1.89	1.76	1.61	13.83	3.30	2.05	7300.73
	N	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**
Khyber Pakhtunkhwa	Mean	570.02	8341.10	0.09	99.39	18.07	25.60	15.87	5.54	88.62	72.54	32.85	56.28	5528.50
(KP)	Std. Dev.	1011.58	11320.73	0.12	68.77	8.84	6.41	6.92	7.83	48.02	66.89	23.05	33.59	4521.00
	N	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**	**390**
	Mean	735.9	2942.8	0.10	76.9	21.7	29.9	20.1	9.4	21.4	20.6	4.6	27.4	7017.8
Balochistan	Std. Dev.	1058.8	6915.5	0.60	39.7	4.7	3.7	4.4	4.5	10.9	11.9	1.8	17.5	8339.7
	N	**330**	**330**	**330**	**330**	**330**	**330**	**330**	**330**	**330**	**330**	**330**	**330**	**330**

Note: QI denotes Laspeyres quantity index, while FER, FER_CA, CA respectively stand for fertilizer (nutrient tonnes), Fertilizer per cultivated hectare (nutrient tonnes) and total cultivated area (000, hectares). TMS, TMSR, TMF and TMW, denote 20 years moving average temperature (^{0}C) in Spring, Summer, Fall and Winter quarters respectively. Similar notation holds for Precipitation (mm).

Table 1

winter, spring, and fall are the direst quarters respectively in Punjab, Sindh and Balochistan. The incidence of precipitation exhibits more equitable patterns across the seasons in KP relative to that in other provinces.

3. RESULTS AND DISCUSSION

Table 2 and Table 3 respectively report estimates for Fixed Effect Model (Equation 2) and GMM (for Equation 3). The estimations start with inclusion of physical inputs only as explanatory variables (model M1 in Table 2). The models M2 and M3in Table 2 introduce climatic variables and squared terms of these variables respectively. The M4 concludes the FEM estimates by introducing irrigation area (IA) as percentage of cultivated area (CA). The results are suggestive of a significant impact of climate change on agriculture of the country. Almost similar patterns of the climatic impact are observed both for aggregate (full sample) as well as disaggregate (provincial) analyses. For full sample, long term temperature (20 years moving average), enters negatively and precipitation, with alternative signs across the seasons and regions, majorly enters statistically significant for KP, Sindh and Balochistan. These results may indicate the impact of climate because of higher reliance of these provinces on rain-fed cropping as compared to Punjab. Non linearity of climate and agriculture nexus is tested by incorporating squared terms of temperature and precipitation variables.[39] Quadratic terms of both precipitation and temperature, for full sample (Pakistan), except for summer temperatures (TMSR) and winter precipitation (PMW), confirm the hypothesis of non-linearity and enters significantly.[40] For an additional check-up, long term temperature and precipitation, controlled for the squared terms and climate variation were run and found behaving qualitatively similar as when controlled for physical inputs establishing the robustness of the climate change.[41]

A significant positive relation is documented for cultivated area and agriculture production and the nexus is robust to alternative specifications across the regions. Interestingly, however, CA carries negative sign for Sindh and KP. The plausible explanation for the result may be twofold. First, marginal lands (with low productivity) are brought under cultivation and second the additional area competes for resources amounting to shifting of resources from more productive lands to marginal lands. Fertilisers exert a

[39]Marginal impact of seasonal temperature and precipitation can also be calculated from the specification. A summation of the seasonal impacts totals to the annual impact of climate variables.

[40]Positive and negative quadratic terms suggesting U-shaped and hill shaped response function(s) [Mendelsohn, *et al*. (2007)] are hard to interpret considering the mix of crops in the study. Nonetheless it is helpful in establishing an overall impact direction.

[41]These results were robust qualitatively to the inclusion of variations of temperature and precipitation about respective long-run means.

Table 2

Fixed Effect Estimates Dependent Variable: Agriculture Production Index (QI)

Indicators	Pakistan M1	Pakistan M2	Pakistan M3	Pakistan M4	Punjab M1	Punjab M2	Punjab M3	Punjab M4	Sindh M1	Sindh M2	Sindh M3	Sindh M4	Khyber Pakhtunkhwa M1	Khyber Pakhtunkhwa M2	Khyber Pakhtunkhwa M3	Khyber Pakhtunkhwa M4	Balochistan M1	Balochistan M2	Balochistan M3	Balochistan M4
IA/CA				2361.10***				985.10				16.83				1503.97				2845.61****
				(330.36)				(711.26)				(52.67)				(407.55)				(461.57)
CA	0.47	1.42***	2.45***		5.25***	4.65***	7.29***		-0.81***	-0.59***	-0.43***		-2.79***	-5.22***	-4.71***		20.12**	1.56	6.20	
	(0.45)	(0.43)	(0.51)		(1.34)	(1.16)	(1.63)		(0.06)	(0.06)	(0.08)		(0.56)	(1.46)	(1.68)		(9.42)	(7.31)	(5.51)	
FER	0.04***	0.03***	0.03***	0.03***	0.02**	0.01*	0.02**	0.02**	0.002***	-0.004***	0.004***	-0.01***	0.001	0.004	0.003	0.00	0.05***	0.01	0.07***	0.02
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.0004)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)	(0.02)
TWS					-0.12***	-0.10***	-0.12***	-0.09***	0.01*	0.01***	0.02**	0.01					-0.20***	0.14	-0.02	-0.18**
					(0.03)	(0.02)	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)					(0.08)	(0.09)	(0.08)	(0.09)
TRS					0.58***	0.57***	0.52***	0.52***					0.16***	0.67***	0.66***	0.54	0.97***	-2.61***	-2.38***	-2.14***
					(0.11)	(0.11)	(0.12)	(0.12)					(0.05)	(0.13)	(0.13)	(0.12)	(0.26)	(0.48)	(0.52)	(0.51)
TMS		-1066.40***	-3004.65***	-3212.56***		-1917.37***	-7288.61***	-8534.67***		-223.87***	1378.33*	1083.18		-1219.68***	1325.56***	1100.69		-1398.27***	803.32	1212.58
		(252.27)	(524.32)	(536.55)		(638.25)	(2290.54)	(2268.55)		(33.91)	(727.14)	(786.84)		(251.90)	(494.66)	(500.33)		(379.76)	(976.95)	(987.42)
TMW		1258.03***	-396.94	-332.84		3342.86***	3245.24	3971.67**		1041.84***	3435.17***	3640.42***		750.40**	450.14	523.08		-2232.99***	-7339.19***	-6393.83***
		(223.51)	(288.36)	(270.37)		(810.40)	(2022.24)	(1869.80)		(48.63)	(496.40)	(520.25)		(299.42)	(274.22)	(283.29)		(511.67)	(1034.21)	(956.26)
TMF		690.12**	2097.83***	1487.67**		1285.33*	10929.28**	10255.05**		-488.36***	-3150.05***	-2674.94***		-678.70**	1093.70***	1057.91		4333.87***	11665.85***	9045.27***
		(320.52)	(731.20)	(658.61)		(761.26)	(4350.48)	(4085.37)		(47.44)	(590.02)	(672.68)		(276.67)	(421.21)	(413.90)		(626.54)	(2291.91)	(2138.12)
TMSR		-881.27***	-1004.85	100.10		-3467.51***	-39829.69***	-33327.44***		201.30***	-1250.65*	-1301.63*		1010.56***	610.95	367.54		-1439.17**	-12779.26***	-8092.96**
		(290.04)	(766.52)	(697.45)		(915.13)	(10010.05)	(8963.18)		(56.33)	(677.00)	(766.48)		(353.48)	(1029.56)	(1033.78)		(601.99)	(3506.30)	(3427.61)
PMS		6.23	-1.16	8.03		23.43	133.83	128.11		-39.76***	-268.46***	-255.37***		15.29**	42.90*	50.91		-114.69***	-228.31**	-139.96
		(6.71)	(21.43)	(22.04)		(40.50)	(210.67)	(206.85)		(8.38)	(30.53)	(32.41)		(7.70)	(25.14)	(24.01)		(38.37)	(112.07)	(97.75)
PMW		11.53	27.78	37.62*		-30.28	545.44**	601.95***		23.28***	-23.51	-19.89		-23.12*	-46.70	-50.06		144.65***	363.74***	300.64***
		(8.39)	(20.17)	(19.59)		(83.27)	(229.02)	(225.70)		(6.60)	(19.01)	(21.56)		(11.76)	(45.02)	(43.92)		(21.10)	(61.58)	(56.30)
PMF		4.09	74.76***	38.26		-117.65***	-178.37	-187.66		-31.54***	-110.22***	-103.07***		-63.38***	-58.71	-54.51		621.59***	119.40	-106.64
		(13.72)	(27.27)	(28.90)		(55.37)	(122.46)	(122.54)		(5.41)	(12.13)	(13.13)		(17.26)	(36.55)	(37.44)		(77.62)	(218.11)	(217.50)
PMSR		-40.51***	-59.66***	-48.86***		-119.10***	-336.26***	-306.19***		-16.32***	20.81***	18.37***		20.23**	13.09	29.64		116.20***	-182.95***	-13.13
		(7.46)	(17.18)	(16.99)		(20.28)	(66.24)	(62.96)		(1.28)	(4.45)	(4.93)		(8.82)	(19.58)	(19.40)		(26.02)	(60.30)	(50.66)
$(PMS)^2$			0.24***	0.17**			-0.64	-0.41			24.00***	22.97***			-0.06	-0.09			2.31	1.72
			(0.07)	(0.07)			(2.32)	(2.28)			(2.98)	(3.17)			(0.08)	(0.07)			(1.75)	(1.52)
$(PMW)^2$			-0.07	0.01			-13.33***	-14.80***			3.68**	3.16*			0.13	0.14			-2.56***	-2.27***
			(0.14)	(0.15)			(4.20)	(4.13)			(1.68)	(1.89)			(0.20)	(0.20)			(0.80)	(0.73)
$(PMF)^2$			-2.57***	-2.26***			1.17	0.79			6.53***	6.06***			-0.11	-0.19			39.31*	60.92***
			(0.39)	(0.39)			(1.98)	(1.91)			(0.69)	(0.72)			(0.35)	(0.34)			(23.58)	(23.53)
$(PMSR)^2$			0.13**	0.05			0.73***	0.58***			-0.39***	-0.36***			0.02	-0.04			5.93***	2.19*
			(0.05)	(0.05)			(0.17)	(0.16)			(0.05)	(0.06)			(0.07)	(0.07)			(1.51)	(1.24)
$(TMS)^2$			43.56***	47.11***			102.88***	120.08***			-25.07**	-20.28			-59.06***	-56.33			-51.82**	-57.60**
			(10.40)	(10.60)			(35.45)	(35.17)			(12.06)	(12.98)			(13.78)	(13.70)			(24.50)	(26.18)
$(TMW)^2$			62.69***	59.66***			4.23	-11.85			-76.33***	-82.35***			28.22*	40.84			327.37***	270.65***
			(13.56)	(13.16)			(47.21)	(41.73)			(12.94)	(13.61)			(16.60)	(14.72)			(51.64)	(50.91)
$(TMF)^2$			-42.62**	-30.74*			-201.13**	-187.55**			50.23***	41.60***			-70.60***	-72.73			-259.57***	-204.21***
			(19.02)	(17.72)			(84.81)	(79.57)			(10.57)	(12.15)			(18.60)	(18.88)			(56.68)	(56.21)
$(TMSR)^2$			5.76	-9.92			515.97***	427.27***			18.63*	19.02*			10.87	12.88			206.45***	122.05**
			(13.28)	(12.63)			(134.34)	(119.84)			(9.82)	(11.03)			(25.03)	(25.07)			(57.58)	(57.95)
F(prob)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Panel corrected standard errors are given in parentheses. ***, **, and * indicating significance level at 1 percent, 5 percent and 10 percent respectively. TMS, TMW, TMF, and TMSR denote 20 years moving average temperature in Spring, Winter, Fall and Summer quarters respectively. Similar notation holds for Precipitation. The bottom most row provides probability of F-statistic. All models include time trend variable capturing technological improvement.

Table 2

Table 3

GMM Estimates Dependent Variable: Agriculture Production Index (QI)

Variables	Pakistan	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan
$QI_{i(t-1)}$	0.62****	0.57***	0.86***	0.75***	0.92***
	(0.14)	(0.16)	(0.05)	(0.05)	(0.04)
CA	-0.16	2.53**	0.01	-1.06***	-4.14***
	(0.30)	(1.14)	(0.11)	(0.40)	(1.17)
FER	0.03***	0.01*	-0.002	0.002***	-0.03*
	(0.01)	(0.00)	(0.00)	(0.00)	(0.02)
TWS	—	-0.04*	0.004	—	0.05***
		(0.02)	(0.00)		(0.02)
TRS	—	0.16	—	0.14***	-0.21*
		(0.10)		(0.03)	(0.12)
TMS	-1765.43***	-2665.08*	-541.31	170.17**	642.07**
	(427.84)	(1615.58)	(683.05)	(83.71)	(314.44)
TMW	-233.42	2125.69*	117.97	86.43	-346.45**
	(225.97)	(1216.87)	(271.36)	(56.58)	(172.87)
TMF	1722.46***	1795.37	630.72***	338.52***	1443.49***
	(617.22)	(2186.85)	(234.55)	(114.08)	(520.96)
TMSR	-689.67*	-	929.65**	-67.10	1859.42**
	(366.09)	12997.66**	(455.61)	(214.14)	(931.16)
		(6215.41)			
PMS	-2.64	23.36	-69.09**	10.15**	-34.34
	(20.87)	(140.63)	(23.92)	(4.76)	(20.94)
PMW	29.05	321.18*	17.12	0.69	59.60***
	(21.49)	(168.66)	(18.37)	(7.01)	(16.98)
PMF	-23.71	-10.63	-9.41	-20.67***	-38.15
	(15.24)	(74.43)	(8.45)	(7.05)	(41.34)
PMSR	-13.41	-128.45**	10.68***	3.61	29.26**
	(10.69)	(62.53)	(3.18)	(3.23)	(13.90)
$(PMS)^2$	0.07	-0.19	6.68***	-0.02	0.32
	(0.08)	(1.58)	(2.29)	(0.01)	(0.35)
$(PMW)^2$	-0.11	-6.38**	-1.40	-0.01	-0.57***
	(0.13)	(3.14)	(1.50)	(0.03)	(0.21)
$(PMF)^2$	-0.53**	-0.36	0.78**	0.05	2.42
	(0.26)	(1.26)	(0.35)	(0.06)	(3.79)
$(PMSR)^2$	0.03	0.30*	-0.13***	0.001	-0.41
	(0.04)	(0.16)	(0.04)	(0.01)	(0.26)
$(TMS)^2$	23.99***	34.74	9.98	-9.11***	-17.07**
	(9.18)	(23.32)	(11.10)	(2.70)	(6.84)
$(TMW)^2$	39.87***	-12.98	-1.34	9.12**	28.71**
	(13.83)	(23.81)	(7.15)	(4.00)	(11.53)
$(TMF)^2$	-42.12***	-40.09	-12.39***	-17.23***	-27.26**
	(14.94)	(45.67)	(4.29)	(4.74)	(12.31)
$(TMSR)^2$	12.79**	167.93**	-15.71**	7.09	-31.96**
	(5.89)	(82.58)	(6.40)	(4.82)	(16.14)
Prob (J-Stats.)	**0.81**	**0.43**	**0.84**	**0.53**	**0.19**

Note: Panel corrected standard errors are given in parentheses. ***, **, and * indicating significance level at 1 percent, 5 percent and 10 percent respectively. TMS, TMW, TMF, and TMSR denote 20 years moving average temperature in spring, winter, fall and summer quarters respectively. Similar notation holds for Precipitation. The bottom column provides probability of J-stat with the null of instruments are valid . All models include trend variable capturing technological improvement.

positive and statistically significant impact on agriculture production of the country (except in Sindh). Surprisingly, however, a robust negative impact of the tube-wells is documented possibly this may be due to the fact that majority of tube-wells are pumping poor quality water and adding to soil salinity (in Punjab about 25 percent of the tube-wells pump water marginally fit for irrigation and over 50 percent tube-wells water is unfit for irrigation).[42] Further, the persistent energy crises and rising energy prices in Pakistan may have resulted in lower utilisation of pumping capacity despite the increase in number of tube-wells. This study finds strong evidence for linear relationship between agriculture production and mechanisation of the sector. Increased number of tractors adds to the agriculture performance positively and the relation is robust and statistically significant. Negative sign on tractors for Balochistan may be, along with other explanations, an indicative of higher renting cost as well as lower mechanisation in the province.[43] Statistically significant positive impact of technological improvement, captured through trend variable, is observed throughout the analysis.[44] No significant interactive effect of temperature and precipitation was recorded hence dropped from the final estimations.

3.1. Instrumental Variable Estimations

Under presumed panel bias of FE method in dynamic models, the results for the specifications carrying lagged production ($QI_{i(t\ 1)}$) were estimated by applying GMM. The hausman test of the endogeniety confirms the presence of endogeniety also. Speaking on results from GMM, irrespective of the controls, previous year s production lagged I enters statistically significant and exerts a positive impact on current year s production and the trend is consistent across regions. For brevity and avoiding repetition, Table 3 reports the results for final model for Pakistan and four provinces respectively. Previous year s produce $QI_{i(t\ 1)}$) enters positively and statistically significant in all the models. No significant change in behaviour of climatic variables is observed and FE and GMM report consistent patterns of climate documenting negative impact.

Cultivated area carries a negative sign and remains significant statistically and the relation is robust to alternative specifications and estimation methodologies. Fertilisers enter consistently positive and statistically significant. Sargan J-stat accepts the null of exogeniety of instruments.

[42]Ahmed, *et al*. (1998).

[43]May be tractors used in agriculture or operational are different from total number of tractors in the districts of Balochistan.

[44]The results are not reported but are available on request.

4. ROBUSTNESS OF THE RESULTS

Having run the preliminary estimations to get the general patterns of climate impact on agriculture, robustness of the estimates is further confirmed by running estimations in log-log form and for provinces separately. Estimations are also undertaken using QI as well as Total revenue per hectare (TR) (measured as revenue per hectare).[45] Using TR as dependent variable gives us a semi-Ricardian specification. This enables us on one hand to check the robustness of our estimates and perform a reliable comparison of impact of climate change using both production function and semi-Ricardian approaches[46] on the other. For further consolidation, both specifications using QI and TR as dependent variable are estimated by applying Generalised Method of Moments (GMM). Perceived impact of lagged production, which generates endogeniety, is captured in MM estimations by introducing last year s I TR) as independent variable. The independence of precipitation and temperature is tested by incorporating climate interaction terms.[47] Given the limitations of data, technological improvements are captured through inclusion of time trend as independent variable. The estimations are controlled for deviations of climate variables from their mean(s) decomposing the climate change impact into short run response to shocks and long run impact. The results are reported in Table 4 and Table 5 for Fixed Effect Model and GMM estimation respectively with log agriculture production index [ln(QI)] as dependent variable.

Alternative set of explanatory variables are introduced moving from model M1 to model M5 for full sample (all districts of Pakistan). Physical inputs, used in log form, behave similarly as in Table 2. Fertiliser registered statistically significant robust positive effect on QI while CA affects QI negatively (except insignificant positive effect in Balochistan) and the relation is significant and robust across the alternative specifications. Table 4 improves on Table 2 in modelling the impact of climate change on agriculture. Model M3 in full sample (Pakistan) controlled for the impact of the deviation of mean values of temperature and precipitation in various quarters from the respective long-run means of climate variables. The full sample estimates show that an increase in mean temperature during Fall (TMF) and Spring (TMS) harms the agriculture sector while that in summer (TMSR) and winter (TMW) contributes positively to the agriculture production. Any increase in precipitation norm in all seasons affects the agriculture production positively except that in summer quarter. The deviation of temperature from the norm for Fall (TSDF) and Spring (TSDS) contributes positively while that in Summer (TSDSR) and Winter (TSDW) negatively to the agriculture production in Pakistan. Deviations of precipitation

[45]One should note that choice of inputs in robustness check was constrained by the availability of variables comparable across provinces.

[46]Non-availability of data on production costs precludes calculating net revenue.

[47]See Lobell and Marshall (2008).

Table 4

Fixed Effect Estimates Dependent Variable: Log Agriculture Production Index (QI)

			Pakistan			Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan
Indicator	M1	M2	M3	M4	M5	M5	M5	M5	M5
ln(FER)	0.350***	0.353***	0.349***	0.3485***	0.350***	0.736***	0.237**	0.070	0.123**
	(0.024)	(0.025)	(0.024)	(0.024)	(0.025)	(0.067)	(0.084)	(0.073)	(0.039)
ln(CA)	-0.214***	-0.255***	-0.247***	-0.2481***	-0.249***	-0.405***	-0.489***	-0.495**	0.031
	(0.060)	(0.060)	(0.060)	(0.060)	(0.060)	(0.126)	(0.108)	(0.178)	(0.106)
TMF	-0.553*	-0.706**	-0.734**	-0.7350**	-0.552	2.185**	-6.022**	2.124***	-2.588**
	(0.337)	(0.333)	(0.334)	(0.333)	(0.353)	(1.072)	(2.505)	(0.622)	(0.120)
TMS	-0.655**	-0.774**	-0.828***	-0.8447***	-1.258***	-1.467**	2.133	0.183	-3.496***
	(0.239)	(0.290)	(0.243)	(0.241)	(0.295)	(0.662)	(3.352)	(0.660)	(0.819)
TMSR	2.066***	1.938***	1.967***	1.9956***	1.923***	-7.627***	-5.361**	3.116**	0.241
	(0.423)	(0.417)	(0.420)	(0.418)	(0.435)	(1.770)	(2.688)	(1.142)	(0.143)
TMW	0.390**	0.379**	0.392**	0.3668**	0.407**	0.339	10.260***	0.987**	0.899**
	(0.153)	(0.154)	(0.1545)	(0.153)	(0.168)	(0.510)	(1.815)	(0.420)	(0.452)
PMF	0.004	0.054***	0.050***	0.0494***	0.073**	0.240**	-0.430**	-0.192**	-0.417
	(0.006)	(0.011)	(0.011)	(0.011)	(0.030)	(0.094)	(0.357)	(0.065)	(0.285)
PMS	0.015***	0.030***	0.030***	0.0296***	-0.028	-0.013	-2.037	-0.077**	-0.134*
	(0.004)	(0.008)	(0.008)	(0.008)	(0.019)	(0.056)	(0.770)	(0.034)	(0.078)
PMSR	-0.014***	-0.017***	-0.016***	-0.0163***	-0.017	-0.261***	-0.092	0.059	0.056
	(0.002)	(0.004)	(0.004)	(0.004)	(0.023)	(0.047)	(0.089)	(0.070)	(0.107)
PMW	0.011**	0.016*	0.016*	0.0166*	0.014	0.174**	-0.385	0.0002	-0.008
	(0.006)	(0.009)	(0.009)	(0.009)	(0.016)	(0.071)	(0.295)	(0.042)	(0.045)
$(TMF)^2$	0.007	0.011	0.011	0.0112	0.008	-0.049**	0.107**	-0.108***	0.089**
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.021)	(0.043)	(0.020)	(0.031)
$(TMS)^2$	0.002	0.005	0.006	0.0066	0.014**	0.022**	-0.039	-0.057***	0.072***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.011)	(0.054)	(0.013)	(0.020)
$(TMSR)^2$	-0.037***	-0.035***	-0.035***	-0.035***	-0.035***	0.096***	0.070*	-0.038*	-0.008
	(0.006)	(0.006)	(0.006)	(0.006)	(0.007)	(0.024)	(0.040)	(0.021)	(0.023)
$(TMW)^2$	0.025***	0.022***	0.022***	0.0226***	0.022***	0.016	-0.265***	0.033	-0.023
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.015)	(0.049)	(0.021)	(0.024)
$(PMF)^2$	—	-0.001***	-0.001***	-0.001***	-0.001***	-0.002***	0.013***	0.001	0.004
		(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0004)	(0.003)	(0.0004)	(0.012)
$(PMS)^2$	—	0.00003	0.00004	0.00003	0.0001**	0.000	0.042***	0.0001*	0.001
		(0.00004)	(0.00004)	(0.00004)	(0.00004)	(0.0003)	(0.011)	(0.00008)	(0.001)

Continued—

Table 4—(*Continued*)

(PMSR)^{2}	—	0.00002 (0.00002)	0.00002 (0.00002)	0.00002 (0.00002)	0.00002 (0.00002)	0.000*** (0.00003)	-0.001** (0.008)	0.000004 (0.00009)	-0.0002 (0.001)
(PMW)^{2}	—	-0.0002** (0.00007)	-0.0002** (0.00007)	-0.0002** (0.00007)	-0.0001 (0.0001)	-0.003*** (0.0007)	-0.006 (0.026)	-0.00002 (0.0002)	0.000 (0.0004)
TSDF	—	—	0.0235* (0.013)	0.0235* (0.013)	0.025* (0.013)	0.057*** (0.015)	-0.015 (0.026)	-0.040 (0.040)	-0.009 (0.033)
TSDS	—	—	0.0318** (0.010)	0.0301** (0.010)	0.030** (0.010)	0.026*** (0.012)	-0.031 (0.024)	0.040* (0.022)	-0.047** (0.0199)
TSDSR	—	—	-0.0201* (0.011)	-0.0193* (0.010)	-0.019* (0.010)	-0.028** (0.012)	-0.004 (0.025)	-0.002 (0.028)	-0.032 (0.024)
TSDW	—	—	-0.0383** (0.014)	-0.0372** (0.014)	-0.038** (0.014)	-0.015 (0.021)	-0.053* (0.029)	-0.069* (0.036)	0.051** (0.025)
PSDF	—	—	0.0007 (0.001)	—	—	—	—	—	—
PSDS	—	—	0.0001 (0.001)	—	—	—	—	—	—
PSDSR	—	—	-0.0001 (0.0004)	—	—	—	—	—	—
PSDW	—	—	0.0011 (0.001)	—	—	—	—	—	—
TMS*PMS	—	—	—	—	0.002*** (0.0006)	0.003* (0.001)	0.052** (0.025)	0.003** (0.001)	0.007** (0.003)
TMF*PMF	—	—	—	—	-0.001 (0.001)	-0.006* (0.003)	0.008 (0.013)	0.005 (0.003)	0.018 (0.014)
TMSR*PMSR	—	—	—	—	-0.00002 (0.0007)	0.006*** (0.001)	0.004* (0.002)	-0.001 (0.002)	-0.001 (0.004)
TMW*PMW	—	—	—	—	0.0003 (0.001)	-0.001 (0.004)	0.030* (0.016)	-0.001 (0.002)	0.001 (0.002)
Constant	-9.28*	-4.97	-4.67	-4.69	0.31	140.29***	65.487	-33.953**	53.272**
F-Prob	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
N	**1890**	**1890**	**1890**	**1890**	**1890**	**780**	**390**	**390**	**330**

Note: Panel corrected standard errors are given in parentheses. ***, **, and * indicating significance level at 1 percent, 5 percent and 10 percent respectively. TMS, TMW, TMF, and TMSR denote 20 years moving average temperature in Spring, Winter, Fall and Summer quarters respectively. Similar notation holds for Precipitation. The bottom column provides probability of J-stat with the null of instruments are valid . All models include trend variable capturing technological improvement.

Table 4

Table 4

Table 5

GMM Estimates Dependent Variable: Log Agriculture Production Index (QI)

Indicator	Pakistan	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan
$\ln(QI_{i(t-1)})$	0.5599***	0.741632***	0.428**	0.796***	0.567***
	(0.156)	(0.013)	(0.212)	(0.099)	(0.077)
ln(CA)	-0.2273*	-0.15413***	-0.309**	0.702	-0.007
	(0.119)	(0.014)	(0.120)	(0.450)	(0.049)
ln(FER)	0.8193*	0.151691***	0.113	2.973*	0.029*
	(0.494)	(0.006)	(0.072)	(1.570)	(0.0176)
TMS	-0.3309	-0.6917***	1.020	3.577*	-0.699**
	(0.271)	(0.062)	(1.970)	(2.072)	(0.350)
TMW	-0.0054	0.019904	1.515	-1.417	-0.321
	(0.167)	(0.027)	(1.095)	(0.900)	(0.228)
TMF	-0.6810	0.163856***	-1.663	-0.694	0.867
	(0.637)	(0.034)	(1.393)	(0.842)	(0.593)
TMSR	2.0142*	-0.88631***	-2.328	9.344**	-0.912
	(1.175)	(0.057)	(1.993)	(4.600)	(0.910)
PMS	0.0334*	-0.01258***	-0.323**	0.003	0.044
	(0.019)	(0.003)	(0.116)	(0.027)	(0.028)
PMW	0.0355*	0.05017***	0.106**	-0.035	0.023
	(0.020)	(0.004)	(0.054)	(0.052)	(0.017)
PMF	-0.0450*	0.0078***	-0.139**	-0.051	-0.132**
	(0.024)	(0.002)	(0.057)	(0.041)	(0.063)
PMSR	-0.0182*	-0.00124	0.058**	0.123*	-0.002
	(0.009)	(0.001)	(0.023)	(0.071)	(0.017)
$(TMS)^2$	0.0083	0.010754***	-0.014	-0.093*	0.012
	(0.006)	(0.001)	(0.033)	(0.052)	(0.008)
$(TMW)^2$	0.0073	0.008989***	-0.040	0.023	0.030**
	(0.006)	(0.001)	(0.030)	(0.030)	(0.013)
$(TMF)^2$	0.0011	-0.00821***	0.031	-0.017	-0.013
	(0.009)	(0.001)	(0.026)	(0.027)	(0.016)
$(TMSR)^2$	-0.0268*	0.012641***	0.030	-0.161**	0.012
	(0.015)	(0.001))	(0.028)	(0.079)	(0.015)
$(PMS)^2$	-0.0001	0.000256***	0.027**	-0.00001	-0.0004
	(0.00008)	(0.00003)	(0.010)	(0.0001)	(0.0005)
$(PMW)^2$	-0.0001	-0.00073***	-0.006	0.0002	-0.0003
	(0.00008)	(0.00006)	(0.004)	(0.0003)	(0.0002)
$(PMF)^2$	0.0003	-0.00018***	0.009**	-0.0001	0.012**
	(0.0003)	(0.00003)	(0.003)	(0.0005)	(0.006)
$(PMSR)^2$	0.0001*	0.0000044	-0.001**	-0.0004*	0.0001
	(0.00003)	(0.000004)	(0.0003)	(0.0003)	(0.0003)
TSDS	-0.0058	0.008586***	0.011	0.046*	-0.003
	(0.011)	(0.001)	(0.013)	(0.027)	(0.012)
TSDW	0.0040	0.000569	-0.021	0.022	0.001
	(0.014)	(0.001)	(0.014)	(0.043)	(0.015)
TSDF	0.0215	0.0129***	-0.021	-0.022	-0.028
	(0.015)	(0.001)	(0.013)	(0.055)	(0.020)
TSDSR	-0.0168*	-0.01494***	0.012	-0.139	0.007
	(0.010)	(0.001)	(0.013)	(0.094)	(0.013)
PSDS	0.0013*	0.000693***	0.003	-0.001	0.002
	(0.001)	(0.00007)	(0.001)	(0.002)	(0.001)
PSDW	-0.0009	0.004211***	-0.0004	0.002	0.003***
	(0.001)	(0.0001)	(0.002)	(0.003)	(0.001)
PSDF	0.0008	-0.00021	0.0001	0.001	-0.005**
	(0.001)	(0.0001)	(0.001)	(0.002)	(0.002)
PSDSR	-0.0001	-0.00019***	0.0001	0.000	-0.0002
	(0.0003)	(0.00003)	(0.0002)	(0.002)	(0.001)
Constant	-24.1467*	25.6513***	38.380	-160.025**	15.158
J-Statistic (P)	0.6348	0.5187	0.3957	0.4071	0.2731
N	1764	728	364	364	308

Note: Panel corrected standard errors are given in parentheses. ***, **, and * indicating significance level at 1 percent, 5 percent and 10 percent respectively. TMS, TMW, TMF, and TMSR denote 20 years moving average temperature in spring, winter, fall and summer quarters respectively. Similar notation holds for Precipitation. The bottom column provides probability of J-stat with the null of instruments are valid . All models include trend variable capturing technological improvement.

from its long-run norms during different seasons show no significant impact. These entire climate variables enter statistically significant and retain signs in all the models (M1 to M5). Squared terms of temperature in Summer ($TMSR^2$) and winter (TMW^2) and precipitation in winter (PMW^2) enter significantly indicating non-linear nexus with agriculture production. The exclusion of deviation of precipitation terms induces no changes in estimates supporting the insignificance of the terms in determining the agriculture production (M4). To conclude the estimations for full sample (Pakistan), the interaction terms of climate variables are introduced in Model 5 (M5). Only in spring, temperature and precipitation (TMS*PMS) make a significant joint impact at the country level.

The regional heterogeneity of agriculture in Pakistan is considered by undertaking the analysis for all four provinces separately and results are reported in last four columns of Table 4.[48] Fertiliser (FER) and cultivated area (CA) retain the nature of impact across the provinces and only a slight variation is observed with FER entering insignificant for KP while increase in CA played an insignificant role in Balochistan (BL). Plausibly a poor mix or/and lower levels of use with smaller variations across districts and over the time might be the plausible explanation for insignificant impact of fertiliser. Similarly, negligible marginal increase in cultivated area for BL may render the increment insignificant. Importantly, however, a significant variation, both in terms of direction of relation and significance level, is observed in behaviour of climate variables across the provinces as well as when compared with full sample suggesting different impact of climate variations for different regions supporting the suitability of regional analysis of climate change impact.[49] The rise in temperature in Fall (TMF), robustly negative and significant in full sample (Pakistan), submits mixed behaviour and contributes positively in Punjab and KP while the impact is negative for Sindh and Balochistan and these impacts are more severe as compared to that in full sample. The highest negative impact of rise in Fall temperature (TMF) is observed for Sindh with a coefficient as high as 6.022***. Similar increase in impact magnitude of temperature variations are documented for spring, summer and winter. Spring temperatures (TMS) exert negative impact when significant statistically with highest negative impact for Balochistan. Significant statistically, rise in summer temperature (TMSR) harms agriculture quite intensively in all provinces with agriculture in Punjab harmed the most (coefficient = 7.627***). Winter temperatures (TMW) increase exerts significant positive impact on agricultural production in all provinces except in Punjab. An extraordinary positive impact of TMW (10.260***) is recorded for Sindh. Similar variations are documented in impact

[48]To avoid repetition, only results of final model (M5) are reported.

[49]This may also indicate the aggregation problem and bears special relevance for country level as well multi country panel studies.

of precipitation across the provinces. A rise in precipitation in Fall (PMF) generates a dividend for Punjab while remain insignificant in Balochistan which may represent negligible rain in Balochistan. Summer rains (PMSR) exert a significant negative impact on agriculture of Punjab only which may be a reflection of the fact that increased rains in summer may affect cotton crop adversely while the impact is positive for winter rains (PMW) which again may suggest the dominating impact of wheat production in Punjab as it is the early growth season of wheat. Winter rains are also beneficial for wheat production under rain-fed conditions in Punjab where rain-fed wheat accounts for about 10 percent of the provincial wheat production.

Different nature of non-linear relations between climatic variables and agricultural production is observed across provinces for example quadratic term of temperature for Fall (TMF^2), insignificant at aggregate level (Pakistan), turns significant for all provinces highlighting the varying spatial impacts of climate variables. All the squared terms of temperature and precipitation exhibit similar spatial variations. Deviations of temperature in Fall (TSDF) and Summer (TSDSR) from the mean are significant only for Punjab indicating significant change in fall and summer temperatures in Punjab.[50] Interactive impact of spring temperatures and precipitation retains the pattern (positive and significant impact) across the provinces while the significant joint impact of climatic variables (TMSR*PMSR) in summer is documented for Punjab and Sindh.

Table 5 improves on Table 3 and reports estimates using log QI as dependent variable. Additionally, the GMM regression(s) reported in Table 3 are controlled for deviations of climate variables from their long-run means. Qualitatively, similar results are observed with slight variations in behaviours of climate variables. Lagged production ($\ln QI_{i(t-1)}$) positively affects agriculture production of current year and the relation is strictly robust and statistically significant across the provinces and alternative specifications. All the climate variables in one specification or the other significantly affect the agriculture production. The strongest impact of climate is observed for Punjab wherein almost all the variables enter significant statistically. Increase in temperature in Summer (TMSR) and higher precipitation in Spring (PMS) have adverse impact on agriculture of the province. Except the summer precipitation, all squared terms of temperature and precipitation confirm the significant non-linearity in the impact of climatic variable. Similarly, weather shocks (deviations of the values of climatic variables from the respective long-run means) have significant impact for Punjab whereas such shocks impact agriculture non-significantly in Sindh and KP. Temperatures and precipitation in different seasons are found affecting agriculture in all the provinces. Sargan J-stat confirms the exogeniety and validity of all the instruments used.

[50]This may also reflect prolonged heat waves in Punjab.

4.1. Estimations with Revenue per Hectare

To draw comparisons, we estimated the impact of climate change on agriculture of the country using total revenue per hectare as dependent variable. The results are reported in Table 6 and Table 7 for FE and GMM estimates respectively. Table 6 and 7 differ from table 4 and 5 in the aspect that dependent variable is revenue per hectare (TR) and not the Quantity index (QI).

As is evident from the Table 6, no significant change is observed and all the variables retain the behaviour as depicted in Table 4. Similarly GMM estimates, reported in Table 7, offer qualitatively similar results as reported in Table 5.[51] GMM estimates using log of revenue per hectare, however, show a significant change for Balochistan where most of the climate variables turn significant as compared to the same specification reported in Table 4 using agriculture production Index (QI) as dependent variable which may suggest a different agriculture market for the province as compared to the rest of the provinces.

5. CONCLUSION

In Pakistan, extended diversity of agro-ecologies turns climatic conditions an important predictor of performance of country s agriculture sector. The full sample as well as regional level analysis confirms the robust significant impact of climate change on agriculture. Fertilisers exert a positive and statistically significant impact on agriculture production of the country. Irrespective of the controls, previous year s production/revenue enters statistically significant and exerts a positive impact on current year s production and the impact is consistent across regions and alternative specifications implying that the use of agriculture inputs is primarily determined by previous year s production on-farm income) of the farmer indicating absence of credit market for farmers. Increase in long-run temperature normals have significant effect on agriculture that varies in direction as well as magnitude across seasons and regions. Increasing precipitation in all season affects the agriculture produce positively except that in spring (PMSR).

The deviation of temperature for Fall (TSDF) and Spring (TSDS) contribute positively (especially in Punjab and KP) while that in Summer (TSDSR) and Winter (TSDW) impact agriculture production negatively. Significant impact of deviation of temperature from mean is documented while that of precipitation, in general, show no significant impact suggesting no major fluctuation in the patterns when measured in the long run. A significant non-linear impact of climatic variables is also observed. A significant variation, both in terms of direction of relation and significance level, is observed in behaviour of climate variables across the provinces when compared with full sample

[51]The results are not re-explained for brevity.

Table 6

Fixed Effect Estimates Dependent Variable: Log Revenue (TR) per Hectare (1980-81 Prices)

			Pakistan			Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan
Indicator	M1	M2	M3	M4	M5	M5	M5	M5	M5
ln(FER)	0.173***	0.182***	0.1779***	0.270	0.170***	0.571***	0.040	0.034***	-0.026
	(0.012)	(0.012)	(0.012)	(0.233)	(0.012)	(0.018)	(0.037)	(0.022)	(0.027)
ln(CA)	-0.778***	-0.803***	-0.8032***	-0.460***	-0.800***	-0.704***	-1.047***	-0.865*	-0.806***
	(0.030)	(0.030)	(0.028)	(0.128)	(0.030)	(0.040)	(0.050)	(0.052)	(0.074)
TMF	-0.509**	-0.553***	-0.6096***	-0.478	-0.396**	1.470***	3.314**	0.317**	-4.201***
	(0.160)	(0.158)	(0.158)	(0.360)	(0.165)	(0.388)	(1.103)	(0.182)	(0.840)
TMS	-0.580***	-0.655***	-0.6930***	-0.238**	-0.962***	1.086***	-1.126	-0.594**	0.125
	(0.114)	(0.113)	(0.198)	(0.110)	(0.139)	(0.221)	(1.476)	(0.019)	(0.572)
TMSR	1.193***	1.147***	1.2042***	0.984	1.482***	-2.639***	-2.361**	0.794**	2.380**
	(0.201)	(0.198)	(0.073)	(0.604)	(0.204)	(0.585)	(1.183)	(0.336)	(0.998)
TMW	0.268***	0.296***	0.2928***	-0.003	0.449***	-1.178***	-0.104	0.425***	0.716**
	(0.073)	(0.073)	(0.005)	(0.073)	(0.079)	(0.203)	(0.799)	(0.122)	(0.316)
PMF	0.013***	0.025***	0.0226***	-0.009	-0.048***	0.009	-0.063	-0.054***	-0.379*
	(0.003)	(0.005)	(0.004)	(0.013)	(0.014)	(0.046)	(0.157)	(0.019)	(0.199)
PMS	-0.007***	0.013***	0.0133***	0.010	0.017*	0.022	-0.080	-0.041***	0.250***
	(0.002)	(0.004)	(0.002)	(0.009)	(0.009)	(0.022)	(0.339)	(0.010)	(0.054)
PMSR	-0.004***	-0.012***	-0.0117***	-0.009	-0.025**	-0.026**	-0.224***	0.028**	0.305***
	(0.001)	(0.002)	(0.004)	(0.006)	(0.011)	(0.012)	(0.039)	(0.020)	(0.075)
PMW	0.010***	0.002	0.0018	0.011	0.011	-0.036	0.087	0.029**	-0.056*
	(0.003)	(0.004)	(0.004)	(0.008)	(0.008)	(0.029)	(0.129)	(0.012)	(0.031)
$(TMF)^2$	0.011***	0.014***	0.0150***	0.008	0.010**	-0.025***	-0.058**	-0.009	0.119***
	0.003	(0.003)	(0.003)	(0.006)	(0.003)	(0.007)	(0.019)	(0.006)	(0.021)
$(TMS)^2$	0.004*	0.007***	0.0075***	0.004	0.012***	-0.016***	0.021	-0.002	-0.019
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.024)	(0.004)	(0.014)
$(TMSR)^2$	-0.018***	-0.019***	-0.0194***	-0.013	-0.024***	0.032***	0.026	-0.011*	-0.029*
	(0.003)	(0.003)	(0.003)	(0.008)	(0.003)	(0.008)	(0.017)	(0.006)	(0.016)
$(TMW)^2$	-0.001	-0.005*	-0.0052*	-0.001	-0.011***	0.031***	0.013	-0.018**	-0.023
	(0.003)	(0.003)	(0.003)	(0.0.005)	(0.003)	(0.006)	(0.022)	(0.006)	(0.017)
$(PMF)^2$	—	-0.0001	-0.0001	0.0001	-0.00002	0.0004*	-0.002	0.001***	0.007
		(0.00009)	(0.00009)	(0.0002)	(0.0001)	(0.0002)	(0.001)	(0.0001)	(0.008)
$(PMS)^2$	—	-0.00007***	-0.0001***	-0.0001	-0.00006**	0.00001	0.027***	0.00002	0.001*
		(0.00002)	(0.00002)	(0.00005)	(0.00002)	(0.0001)	(0.005)	(0.00002)	(0.001)

Continued—

Table 6—(*Continued*)

$(PMSR)^2$	—	0.00004***	0.00004***	0.00003	0.00004***	0.00003**	0.0002	0.00001	0.001*
		(0.00001)	(0.00001)	(0.00002)	(0.00009)	(0.00001)	(0.0001)	(0.00003)	(0.0004)
$(PMW)^2$	—	0.00002	0.00003	0.00002	0.00004	-0.002***	0.015***	-0.0001*	0.00003
		(0.00003)	(0.00003)	(0.00003)	(0.00005)	(0.0003)	(0.003)	(0.00006)	(0.0003)
PSDF	—	—	-0.001**	—	—	—	—	—	—
			(0.0004)						
PSDS	—	—	-0.0004	—	—	—	—	—	—
			(0.0004)						
PSDSR	—	—	-0.00002	—	—	—	—	—	—
			(0.0002)						
PSDW	—	—	0.00002	—	—	—	—	—	—
			(0.0004)						
TSDF	—	—	0.006	0.004	0.009	0.0102	0.000	0.001	-0.035
			(0.006)	(0.006)	(0.006)	(0.009)	(0.011)	(0.012)	(0.029)
TSDS	—	—	0.017***	-0.003	0.019***	0.0006	0.011	0.006	-0.010
			(0.005)	(0.004)	(0.005)	(0.007)	(0.011)	(0.006)	(0.014)
TSDSR	—	—	-0.015**	-0.007	-0.016***	-0.0092	0.009	-0.010	-0.041**
			(0.005)	(0.005)	(0.005)	(0.007)	(0.011)	(0.008)	(0.017)
TSDW	—	—	-0.012*	0.002	-0.011	-0.018*	-0.00902	0.006	0.018
			(0.007)	(0.010)	(0.007)	(0.010)	(0.013)	(0.010)	(0.018)
TMS*PMS	—	—	—	—	-0.0001	-0.00046	-0.005	0.002***	-0.013***
					(0.0003)	(0.0006)	(0.011)	(0.0003)	(0.002)
TMF*PMF	—	—	—	—	0.003***	0.00005	0.004	-0.0005	0.020**
					(0.0005)	(0.002)	(0.006)	(0.001)	(0.010)
TMSR*PMSR	—	—	—	—	0.0004	0.00046	0.006***	-0.001**	-0.011***
					(0.0003)	(0.0003)	(0.001)	(0.0006)	(0.002)
TMW*PMW	—	—	—	—	-0.001**	0.006	-0.013*	0.002**	0.006***
					(0.0005)	(0.002)	(0.007)	(0.001)	(0.002))
Constant	6.456**	8.087***	8.129***	-4.683	4.365	29.89***	29.959	8.474**	3.270
F-Prob	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
N	**1890**	**1890**	**1890**	**1764**	**1890**	**780**	**390**	**390**	**330**

Note: Panel corrected standard errors are given in parentheses. ***, **, and * indicating significance level at 1%, 5% and 10% respectively. TMS, TMW, TMF, and TMSR denote 20 years moving average temperature in Spring, Winter, Fall and Summer quarters respectively. Similar notation holds for Precipitation. The bottom column provides probability of J-stat with the null of "instruments are valid". All models include trend variable capturing technological improvement.

Table 6

Table 6

Table 7

GMM Estimates Dependent Variable: Log Revenue (TR) per Hectare (1980-81 Prices)

Indicator	Pakistan	Punjab	Sindh	Khyber Pakhtunkhwa	Balochistan
ln(TR(-1))	0.763***	0.67563***	0.557***	0.543***	0.5537***
	(0.023)	(0.010)	(0.039)	(0.033)	(0.061)
ln(CA)	-0.362***	-0.45075***	-0.619***	-0.581***	-0.5583***
	(0.030)	(0.010)	(0.040)	(0.034)	(0.066)
ln(FER)	0.055***	0.07914***	0.078***	0.002	0.0313**
	(0.010)	(0.004)	(0.017)	(0.008)	(0.013)
TMS	-0.164**	-0.06691*	1.779**	-0.285***	-0.6678**
	(0.076)	(0.040)	(0.593)	(0.080)	(0.253)
TMW	-0.024	-0.07244**	-0.169	0.2417***	0.5359***
	(0.051)	(0.035)	(0.347)	(0.060)	(0.144)
TMF	-0.208**	-0.23234***	0.696*	0.0097	-1.5793***
	(0.096)	(0.034)	(0.400)	(0.086)	(0.401)
TMSR	0.485***	0.02188	-2.034***	0.1145	1.6057***
	(0.131)	(0.070)	(0.485)	(0.148)	(0.445)
PMS	0.00299	-0.02202***	-0.077***	-0.0040	0.0258
	(0.002)	(0.001)	(0.023)	(0.003)	(0.018)
PMW	0.00457	0.02740***	-0.037*	0.0213***	-0.0251**
	(0.003)	(0.001)	(0.021)	(0.004)	(0.009)
PMF	0.00221	0.02865***	0.005	-0.0392***	-0.0461
	(0.003)	(0.001)	(0.009)	(0.004)	(0.048)
PMSR	-0.00492***	-0.00509***	0.013**	-0.0090***	-0.0157
	(0.001)	(0.0004)	(0.004)	(0.002)	(0.010)
$(TMS)^2$	0.00195	0.00070	-0.029**	0.0006	0.0060
	(0.001)	(0.001)	(0.010)	(0.001)	(0.006)
$(TMW)^2$	0.00201	0.00316**	0.009	-0.0163***	-0.0231**
	(0.002)	(0.001)	(0.009)	(0.003)	(0.008)
$(TMF)^2$	0.00417**	0.00302***	-0.015**	-0.0003	0.0495***
	(0.002)	(0.001)	(0.007)	(0.002)	(0.011)
$(TMSR)^2$	-0.00683***	0.00056	0.030***	0.0015	-0.0273***
	(0.002)	(0.001)	(0.007)	(0.003)	(0.008)
$(PMS)^2$	-0.00001	0.00020***	0.005**	-0.00001	-0.0002
	(0.00005)	(0.00001)	(0.002)	(0.00001)	(0.0003)
$(PMW)^2$	0.00002	-0.00012***	0.003*	-0.00003	0.0003**
	(0.00003)	(0.00003)	(0.002)	(0.00002)	(0.0001)
$(PMF)^2$	-0.00008	-0.00042***	-0.0004	0.0003***	0.0060
	(0.00005)	(0.00002)	(0.001)	(0.00005)	(0.005)
$(PMSR)^2$	0.00002***	0.00002***	-0.0001**	0.00002**	0.0001
	(0.000005)	(0.000002)	(0.00004)	(0.00001)	(0.0002)
TSDS	0.00027	0.00401***	-0.003	0.0107***	-0.0099
	(0.003)	(0.0004)	(0.004)	(0.003)	(0.007)
TSDW	-0.00159	-0.00096	-0.011*	-0.0086*	0.0072
	(0.004)	(0.001)	(0.006)	(0.005)	(0.009)
TSDF	0.00026	0.00784***	0.003	0.0113**	-0.0113
	(0.004))	(0.001)	(0.005)	(0.005)	(0.011)
TSDSR	-0.00417	-0.00681***	-0.003	-0.0057*	-0.0027
	(0.003)	(0.0005)	(0.005)	(0.003)	(0.007)
PSDS	0.00033	0.00065***	0.002**	-0.0002	-0.0004
	(0.0002))	(0.00004)	(0.001)	(0.0002)	(0.0007)
PSDW	0.00036	-0.00003	-0.001	-0.0003	-0.0001
	(0.0003))	(0.0001)	(0.001)	(0.0002)	(0.0005)
PSDF	0.00006	0.00012**	0.0004	0.0001	-0.0031**
	(0.0003))	(0.00005)	(0.0005)	(0.0002)	(0.001)
PSDSR	-0.00002	-0.00013***	-0.0001	-0.0005**	0.0007
	(0.0001))	(0.00001)	(0.0001)	(0.0002)	(0.0005)
CONSTANT	0.240	8.610***	5.828	8.041***	2.7107
J-Statistic (P)	0.59292	0.37398	0.1973	0.1583	0.1095
N	1764	728	364	364	308

Note: Panel corrected standard errors are given in parentheses. ***, **, and * indicating significance level at 1 percent, 5 percent and 10 percent respectively. TMS, TMW, TMF, and TMSR denote 20 years moving average temperature in spring, winter, fall and summer quarters respectively. Similar notation holds for Precipitation. The bottom column provides probability of J-stat with the null of instruments are valid . All models include trend variable capturing technological improvement.

suggesting different impact of climate variations for different regions supporting the suitability of disaggregate analysis of climate change impact.

Different nature of non-linear relations is observed against different provinces suggesting the varying spatial impacts of climate variables. Amid increasing water scarcity, the sensitivity of the agriculture sector of Pakistan to the changes in climate is a revealing fact. Arguably, fighting the climate successfully, through mitigation are adoption strategies, shall be a key to the better performance of the sector. The results of this study are suggestive of a strong impact of climate change on the agriculture of Pakistan and that the impact is stronger in water scarce regions relying on rain fall for cropping. Warming is to impose higher costs to the warmer areas. Further an additional cost is to be added in the rain-fed areas. Evidence supporting the mechanisation of the agriculture sector is documented in the present study. Previous year s output, neglected generally in studies on the issue, is found to be highly significant predictor of output in the current year. Modern agriculture practice, taking climate change into account must be adopted to reduce the adverse impacts of climate.

It is worth noting that results of this study should be interpreted carefully. As is common for developing countries, and especially related to agriculture, data limit us from an in-depth exploration of the issue[52]. First and foremost the data on labour inputs used in agriculture productions are not available. Secondly, non-availability of data on R&D in agriculture precludes the estimation of true impact of technological improvement on the agriculture productivity. Thirdly, an explicit incorporation of farmers perceptions and adaptations is not possible given the data limitations which may over or underestimate the true impact. Fourthly, data are not available on the costs incurred in production leaving us unable to calculate net revenues forcing use of total revenues as dependent variable. Fifthly, and finally, we were unable to gauge the impact of extreme weathers (generally measured in Minimum and maximum daily temperature or degree days) as daily data on climate variables are not available for a reasonably long time period. The estimates are not controlled for soil quality and crop switching which may overestimate the impact.

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

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

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

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