Research Article

Farmers' Adaptation Strategies to Combat Climate Change Impacts on Wheat Crop in Pakistan

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Abstract | This paper assesses the effectiveness of adaptation in enhancing the wheat yield in Pakistan, and incentives that promote adaptation to climate change. We perform a counterfactual analysis and Multinomial Endogenous Switching (MES) regression model to analyze and compare the impact of different adaptation strategies in isolation or in combination on yield. The primary data of 'Climate Change Impact Survey 2012-13' used for this purpose. Crop-specific strategies of change in the time of sowing, use of inorganic fertilizer, change in irrigation, and varietal change. Change in irrigation practice gave rise to the highest yield suggesting that this might be the necessary requirement to sustain wheat growth in Pakistan in future. Farmers are expected to receive significant positive benefits from the adaptation of the combination of strategies. Farmer's adaptive capacity, farm size, access to credit and sources of information on climate change are significant drivers of adaptation to climate change.

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Introduction

It is revealing fact that climate change has emerged as one of the core issues of the current time. It is affecting a significant portion of the population worldwide by disturbing food production, natural ecosystem, health and water supply, in major dimensions (Hassan et al., 2005). According to the fourth assessment report of Inter-Governmental Panel on Climate Change (WGII, 2007), intensity and frequency of weather are changing; there will be warmer and fewer cold days and nights along with extreme climate events with frequent heat waves and heavy precipitation. In order to reduce this intensity and frequency of changing climate condition, the world needs to concentrate on climate change mitigation and adaptation strategies. However, efforts to mitigate the adverse effects could not bring its fruits without effectual adaptation to changing climatic conditions.

Pakistan is one of the countries, most vulnerable to and affected by climate triggered calamities. It is rank as the seventh most affected country from climate change (Kreft et al., 2017).

Pakistan has experienced extreme climatic events in the recent past. Floods of 2003, 2005, 2008, and 2010-15 and worst droughts of the history for the period of 1998-2001 (Basit et al., 2012). Majority of the population in Pakistan depends on agriculture for their living. An erratic and irregular pattern of rainfall, extreme and sudden variations in temperature could increases rural farm household's susceptibility to the climate change.

Links Researchers

Adaptation has the potential to reduce the yield losses and take benefits of favorable climatic conditions (Adams et al., 1999). While, it depends upon the capacity of the system, region, or community to adapt (Maddison, 2007; Gbetibouo, 2009).

Measuring the effect of adaptation on the yield may seem, a simple exercise, but in fact, it is not a trivial task. To achieve this goal, we make use of treatment effect framework. Model provides a valuable input for policies required to promote successful adaptation strategies.

Studies on the role of adaptation in enhancing crop yield is limit to only two studies in Pakistan. Analysis do not analyze the strategies in isolation or in combinations and their role at each stage of production. Temperature and water requirements of each growth stage are different, hence necessitates a separate analysis of adaptation strategies for each stage (Schlenker et al., 2005).

These limitations have been address by Iqbal et al. (2015) in their study addressing impacts of adaptation strategies on net revenue. However, they only used 5-year meteorological data, to capture the fluctuations in the weather patterns over long term. That is another serious limitation as Climate Change is a long-term phenomenon.

The present study is a step forward in the analysis of adaptation on the yield. We used 20-years averages of temperature and precipitation and rich farm household data. Data collected from three provinces (Punjab, KPK and Sindh) of Pakistan. Multinomial Endogenous Switching regression (MES) framework (Powers, 2007) applied to address the endogeneity resulting from self-selection bias in farmer's decision to adapt. We have also contributed by incorporating the index of adaptive capacity as a determinant of adaptation.

Material and Methods

Data for the study

Data for the climate variables Temperature and rainfall obtained from Pakistan Metrological Department (PMD). While data on other socio-economic characteristics and climate related issues collected from Farm Households' Climate Change Impact Survey. Pakistan Institute of Development Economics (PIDE) conducted this survey in collaboration with the International Development Research Center (IDRC), for three provinces of Pakistan: Punjab, Sindh, and KPK. In total, 16 districts were selected to represent different cropping systems in Pakistan. Sample districts were purposively selected to feature different agro-ecological zones of the country, which included: rice-wheat, cotton-wheat, mixed, barani and partial barani from Punjab; rice-wheat, cotton-wheat and mixed from Sindh; wheat-mix and maize-wheat from KPK.

From each sampled district, 12 villages and 11-24 farm households from each village selected. It led to the selection of 198-222 farm households in each district. Out of 16 surveyed districts, eight belonged to Punjab and four each from Sindh and KPK.

Conceptual framework

Influence of adaptation on the yield studied in the two-stage process. First drivers of adaptation examined in the selection equation. Second impacts of adaptation on yield studied in Ricardian framework. Adaptation is an endogenous variable determined from both observable and un-observable factors in the outcome equation.

Farmer's adaptation decision influenced by the expected benefits- higher yield in present study. To achieve this goal farmer, adapt strategies in isolation or in combination. Adaptation strategies are endogenous variable, hence considering them as an explicit variable, such as in Ordinary Least Square (OLS) approach will yield bias estimates.

Unobserved characteristics such as farmer's preferences, their motivation and managerial skills are heterogeneous. They have an effect on farmer's decision to be in the sample and correlate with the unobservable factors that affect the outcome. Hence, create inconsistent and biased inferences (Di Falco, 2011; Abay et al., 2016). To remove this problem, we applied Multinomial Endogenous Switching regression model (Equation 1, 2a, 2b and 2n). Model has an advantage of controlling unobserved heterogeneity across farm households, compared to propensity score matching and Inverse-probability-weighted regression adjusted (IPWRA) techniques that only control influence of observable.

Let A^* be the latent variable that capture the expected benefits from adaptation or combination of adaptation strategies (expected yield is positive) and Y_i is variable of interest crop yield then,

$$A_i * = bZ_i + v_i > 0 \quad \ldots..(1)$$

$$Y_{1i} *= f_{i1}(A_i = 1) = \beta X_{i1} + u_{i1} \quad .....(2a)$$
$$Y_{2i} *= f_{i2}(A_i = 2) = \gamma X_{i2} + u_{i2} \quad .....(2b)$$
$$Y_{ni} = f_{in}(A_i = n) = \gamma X_{in} + u_{in} \quad .....(2n)$$

Where;

$$A_i = 1 \; if \; A_{i1} * > \max_{k \neq 1}(A^*_{ik})$$
$$A_i = 2 \; if \; A_{i2} * > \max_{k \neq 2}(A^*_{ik})$$
$$A_n = 1 \; if \; A_{in} * > \max_{k \neq n}(A^*_{ik})$$

A farm household is facing n regimes, where each regime except the first, is presenting a strategy in isolation or their combinations. While the first regime is presenting the reference category of non-adaptation. Vector Z_i and X_i are vectors of variables that influence the decision to adapt and farmer's yield. Error terms of adaptation Equation (1) and of output (Equation 2a, 2b and 2n) are correlated with each other due to selection bias in unobservable.

Explanatory variables considered in the adaptation equation are farm households' adaptive capacity, education, household size, farm size, farm experience, access to credit, and access to extension service, information on climate change from various sources including radio, newspaper, TV, family members, neighbors and department of agriculture.

Explanatory variables of the production function are climate variables and factors of production. Climate variables include: temperature, precipitation, and short-run climate-related shocks. Climatic shock is deviations of current climatic variables from their respective climatic normal. Further, we also incorporated cropping systems dummies and regional dummies.

Adaptation strategies grouped into four different categories: change in the time of sowing, inorganic fertilizer, change in irrigation, and varietal change. Early and late sowing is grouped as "change in time of sowing"; use of fertilizer is known as "inorganic fertilizer"; change in irrigation either by increasing or decreasing irrigation is combined under the label of "change in irrigation" and choices of adapting short cycle, longer cycle, flood tolerant or drought-tolerant varieties as "varietal change". Various groups of adaptations and their combinations; constructed mutually exclusively, are described in (Table 1).

Multinomial Endogenous Switching (MES) regression model (Equation 3a, 3b and 3n) for mutually exclusive crop specific adaptation strategies, yields consistent coefficients of the output equations by adding selection bias-correction terms (Bourguignon et al., 2007).

$$y_{1i} = \beta X_{1i} + \sigma_1 \left[rho_1 m_{i1} + \sum rho_j m_{ij} \frac{P_{ij}}{(P_{ij}-1)} \right] + \epsilon_{1i} \; if \; A_i = 1 \quad ....(3a)$$
$$y_{2i} = \beta X_{2i} + \sigma_2 \left[rho_2 m_{i2} + \sum rho_j m_{ij} \frac{P_{ij}}{(P_{ij}-1)} \right] + \epsilon_{2i} \; if \; A_i = 2 \quad .....(3b)$$
$$y_{ni} = \beta X_{ni} + \sigma_n \left[rho_n m_{in} + \sum rho_j m_{ij} \frac{P_{ij}}{(P_{ij}-1)} \right] + \epsilon_{ni} \; if \; A_i = n \quad ....(3n)$$

Where; P_{ij} is the probability of choosing strategy *j* by household *I;*

$$P_{ij} = \frac{e^{b_J z_i}}{1 + \sum e^{b_J z_i}} \quad ....(4)$$
$$J = 1, ..., j$$

Where;

rho$_i$ is the correlation between error terms of adaptation and output equations and m_{ij} is selection bias correction terms for each adaptation strategy.

Expected yield of farm households who adapted the strategy j=1…n, is

$$E(y_{2i}|A_i = 2) = \beta_2 X_i + \sigma_2 \left[rho_2 m_{i2} + \sum rho_j m_{ij} \frac{P_{ij}}{(P_{ij}-1)} \right] \quad .....(5a)$$
$$E(y_{3i}|A_i = 3) = \beta_3 X_i + \sigma_3 \left[rho_3 m_{i3} + \sum rho_j m_{ij} \frac{P_{ij}}{(P_{ij}-1)} \right] \quad .....(5b)$$
$$E(y_{ni}|A_i = n = \beta_n X_i + \sigma_n \left[rho_n m_{in} + \sum rho_j m_{ij} \frac{P_{ij}}{(P_{ij}-1)} \right] \quad .....(5n)$$

Counterfactual case of adapters is the expected yield conditioned on non-adaptation (Equation 6a, 6b and 6n). Treatment effect on treated calculated by subtracting Equation 5a from 6a and so on 5n from 6n.

$$E(y_{1i}|A_i = 2) = \beta_1 X_i + \sigma_1 \left[rho_1 m_{i2} + rho_2 m_{i1} \frac{P_{i1}}{(P_{i1}-1)} + \sum rho_j m_{ij} \frac{P_{ij}}{(P_{ij}-1)} \right] \quad .....(6a)$$
$$E(y_{1i}|A_i = 3) = \beta_1 X_i + \sigma_1 \left[rho_1 m_{i3} + rho_2 m_{i1} \frac{P_{i1}}{(P_{i1}-1)} + rho_3 m_{i2} \frac{P_{i2}}{(P_{i2}-1)} + \sum rho_j m_{ij} \frac{P_{ij}}{(P_{ij}-1)} \right] \quad ....(6b)$$
$$E(y_{1i}|A_i = n) = \beta_1 X_i + \sigma_1 \left[rho_1 m_{in} + \sum rho_j m_{i,j-1} \frac{P_{i,j-1}}{(P_{i,j-1}-1)} \right] \quad .....(6n)$$

Results and Discussion

Descriptive statistics

Average per hectare yields of wheat in the study area is 518 Kg. Majority of the farm household heads received primary to middle-class education and in the middle age, have farming experience of 22 to 25 years (Table 2).

Table 1: *Crop specific adaptation strategies adapted in combination or in isolation by farmers in Pakistan.*

Strategy	Description
C_0: No adaptation	1 if the farm household did not adapt any strategy, 0 otherwise
C_1: Change in time of sowing only	1 if the farm household changed the timings of sowing by sowing early or late as an adaptation strategy, 0 otherwise
C_2: Input intensification only	1 if the farm household intensified use of seed rate and fertilizer as adaptation strategy, 0 otherwise
C_3: Change in time of irrigation only	1 if the farm households increased or decreased irrigation as adaptation strategy, 0 otherwise
C_4: Varietal Change only	1 if farm households use drought tolerant, flood tolerant, short cycle or longer cycle variety as adaptation strategy; 0 otherwise
C_{12}: Change in time of sowing and Input intensification	1 if the farm household adapted by changing the timings of sowing and by intensifying inputs, 0 otherwise
C_{13}: Change in time of sowing and irrigation change	1 if the farm household adapted by changing the timings of sowing and by changing irrigation, 0 otherwise
C_{14}: Change in time of sowing and varietal change	1 if the farm household adapted by changing the timings of sowing and by adapting varietal change, 0 otherwise
C_{23}: Input intensification and Irrigation change	1 if the farm household adapted by intensifying inputs of sowing and by changing irrigation, 0 otherwise
C_{24}: Input intensification and varietal change	1 if the farm household adapted by intensifying inputs and by adapting varietal change, 0 otherwise
C_{34}: Irrigation change and Varietal change	1 if the farm household adapted by changing irrigation and by adapting varietal changing, 0 otherwise
C_{123}: Change in time of sowing, input intensification, and irrigation change	1 if the farm household adapted by changing the timings of sowing, by intensifying inputs and by changing irrigation, 0 otherwise
C_{124}: Change in time of sowing, input intensification, and varietal change	1 if the farm household adapted by changing the timings of sowing, by intensifying inputs and by varietal change, 0 otherwise
C_{134}: Change in time of sowing, irrigation change, and varietal change	1 if the farm household adapted by changing the timings of sowing, by changing irrigation and by varietal change, 0 otherwise
C_{234}: Input intensification, irrigation change, and varietal change	1 if the farm household adapted by intensifying inputs, by changing irrigation and by varietal change, 0 otherwise
C_{1234}: All four strategies	1 if the farm household adapted all strategies, 0 otherwise

Average family size is 8 members per family that is a huge burden on the poor households. However, it could be a large labor endowment for farm households.

Majority (65 per cent) has access to irrigation water (Table 2). Institutional infrastructure is generally poor in the rural areas of Pakistan. Half of the farmers do not have access to agricultural credit and extension services. (Table 2). Only 14 per cent of the household receive information on climate change from the agriculture department. Media and traditional knowledge are major factors in informing farmers of changing climate.

Descriptive stats of the adaptation strategies are presented in Table 3. A great majority of the wheat growers are using more fertilizer (80 percent) and improved seeds (82 per cent). Majority (70 per cent) is also practicing change in time of sowing. While more inclines to the earlier sowing (41 per cent) than late (29 per cent). Among improved seeds drought tolerant and short cycle varieties are the most common among wheat farmers. Wheat farmers are also adapting practice of more irrigation practice (56 percent) in response to the changing climate.

Exclusion restriction

To identify the model, it is important to use valid instruments for the identification of adaptation equation. These instruments should be directly correlated with the selection variable of interest and not with the unobserved factors affecting wheat yield (Di Falco and Veronesi, 2013). We used household adaptive capacity, socio-economic characteristics and sources of information on climate change as potential instruments.

Table 2: *Socioeconomic Characteristics of Farm households.*

Variable Name	Total Sample	Farm household's adapted	Farm household's did not adapted
Farm and farm households specific characteristics			
	Mean		
Education of household head	6	6	5
Farm experience of household head	25	25	24
Household size	8	8	8
Farm size (acre)	10	15	8
	Percentage		
Access to Credit	50	50	45
Access to Irrigation	65	66	58
Access to extension service	48	53	27
Sources of Information on Climate Change			
Radio	31	30	52
TV	69	70	45
Newspaper	22	21	32
Neighbor	65	65	65
Department of Agriculture	14	15	7
Traditional Knowledge	52	54	21
Sample Size	3430	3203	227

Exogenous variables considered for exclusion restriction found to be jointly significant determinants of adaptation (Model 1, χ2= 47.53; p=0.0000) at 1 per cent level of significance. Test of their joint significance (Model 2, F-stat. =1.32; p=0.21) shows their insignificance as drivers of output for non-adapters (Table 4).

Table 3: *Frequency distribution of crop related adaptation strategies (percentage of farmers).*

Strategies	Wheat farmers
1. Early Sowing	41
2. Late sowing	29
3. Use more fertilizer	80
4. Use irrigation more	56
5. Use irrigation less	28
6. Drought tolerant variety	28
7. Flood tolerant variety	12
8. Shorter Cycle variety	28
9. Longer Cycle variety	14
Total Observations	3076

Table 4: *Test of the validity of selection instruments.*

Variable	Model 1 (Probit)	Model 2 (OLS)
	Adaptation (1/0)	Output of farm households who did not adapt
Education	0.00 (0.01)	1.53 (8.71)
Household Size	0.01 (0.01)	-12.38 (9.98)
Farm Size	0.00 (0.00)	4.68 (3.43)
Farm Experience	0.00 (0.01)	4.08 (2.93)
Access to credit	-0.11 (0.08)	-107.31 (70.86)
Extension Services	-0.27***(0.11)	-1.96 (115.81)
Irrigation	0.11 (0.08)	66.16 (72.47)
Radio	-0.12 (0.08)	32.32 (72.64)
Newspaper	-0.31*** (0.09)	115.59 (81.33)
TV	0.09 (0.08)	48.58 (74.33)
Neighbor	0.11 (0.08)	90.64 (75.12)
Family	0.01 (0.08)	-114.40 (72.38)
Traditional Knowledge	0.29*** (0.08)	66.24 (85.62)
Department of Agriculture	-0.04 (0.11)	29.85 (93.85)
Adaptive Capacity	0.05*** (0.01)	6.82 (8.91)
Constant	1.25*** (0.17)	117.17 (175.39)
Wald test	χ2= 47.53***	F-stat. =1.32

Table 5: *Treatment effect of adaptation on the treated.*

Strategy	Frequency	Treatment Effect on Treated	Percent
C2	377	3.61***	13
		(0.30)	
C3	100	6.66***	24
		(0.78)	
C12	192	4.84***	17
		(0.13)	
C23	453	3.35***	12
		-0.36	
C24	177	3.93***	14
		-0.32	
C123	535	3.53***	12
		(0.49)	
C124	238	2.38***	8
		(0.33)	
C234	247	1.54***	5
		(0.94)	
C1234	571	3.63***	14
		(0.21)	

Note: *a): Results of only those cases are reported where there is significant influence of the treatment on treated; b): *** show significance at the 1 percent level of significance; c): Bootstrapped standard errors in parentheses.*

Table 6: *Estimates of wheat Yield by Multinomial Endogenous Switching Regression model, Pakistan.*

Variables	C_0	C_2	C_3	C_{12}	C_{23}	C_{24}	C_{123}	C_{124}	C_{234}	C_{1234}
S1 temp	-41.37**	0.89	59.61	3.7	-0.15	8.45	4.57	10.3	-24.93**	-0.39
	(21.11)	(11.46)	(241.67)	(26.42)	(9.24)	(25.34)	(9.21)	(9.04)	(10.50)	(6.19)
S1 temp sqr	0.99**	-0.13	-1.74	-0.07	-0.01	-0.12	-0.07	-0.15	0.52**	0.06
	(0.48)	(0.29)	(8.87)	(0.75)	(0.30)	(0.84)	(0.28)	(0.21)	(0.26)	(0.15)
S2 temp	54.28**	-7.04	-78.73	-12.49	-7.66	-2.94	-8.26	-0.9	28.86	-4.23
	(30.17)	(11.96)	(302.07)	(25.69)	(9.97)	(26.92)	(9.48)	(8.95)	(14.00)	(7.55)
S2 temp sqr	- 1.43**	0.46	2.5	0.3	0.35	-0.12	0.27	-0.07	-0.59	0.05
	(0.75)	(0.32)	(11.98)	(0.80)	(0.36)	(1.01)	(0.32)	(0.28)	(0.42)	(0.21)
S3 temp	-37.04	19.76**	9.34	19.64	11.35*	18.33	12.52	6.4	-15.73	11.31
	(35.83)	(9.09)	(322.22)	(16.33)	(6.79)	(26.30)	(7.94)	(10.69)	(15.74)	(6.96)
S3 temp sqr	0.61	-0.42**	-0.12	-0.33	-0.24*	0.36	-0.29*	-0.15	0.24	-0.21*
	(0.59)	(0.19)	(5.77)	(0.29)	(0.13)	(0.47)	(0.16)	(0.19)	(0.28)	(0.13)
S1 Precip	-2.53**	-1.87**	-0.24	-1.49	-0.30*	2.35	-0.52	-0.56	0.06	-1.34
	(1.39)	(0.83)	(4.99)	(2.21)	(0.39)	(1.77)	(0.48)	(0.69)	(0.79)	(0.41)
S1 Precip sqr	0.00	0.01	0.23	0.00	0.003*	0.00	0.00	0.00	0.00	0.00
	(0.01)	0.00	(0.25)	(0.02)	0.00	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
S2 Precip	-1.26	1.63**	-8.78	0.45	0.62*	-0.55	0.43	0.43	0.02	0.7
	(1.88)	(0.80)	(11.00)	(2.40)	(0.36)	(1.26)	(0.60)	(0.71)	(1.42)	(0.48)
S2 Precip sqr	0.01	-0.01	-0.08	0.02	0.00	0.03	0.01	0.01	0.01	-0.01
	(0.02)	0.00	(0.26)	(0.03)	0.00	(0.01)	(0.01)	(0.01)	(0.01)	0.00
S3 Precip	-0.91	1.52	31.25	4.23	0.88	1.41	-0.29	1.73	-0.05	1.1
	(1.90)	(2.13)	(21.09)	(4.25)	(0.75)	(2.30)	(1.18)	(1.40)	(1.43)	(0.70)
S3 Precip sqr	-0.05	0.00	-0.06	0	0	0	0	0	0	0
	(0.01)	(0.00)	(0.05)	(0.02)	0.00	(0.01)	0.00	0.00	(0.01)	0.00

Note: *a): * Significance at the 10 percent level; ** show significance at the 5 percent level and *** significance at the 1 percent level; b): Bootstrapped standard errors in parentheses; 'S' stands for stage of production; c): S is for stage of Production; R-W is Rice-Wheat; C-W is Cotton-Wheat; B is Barani and PB is Partial Barani.*

Adapting by changing irrigation practice is the most successful strategy for wheat growers; expected to increase the wheat yield by 24 per cent. Increase in application of inorganic fertilizer is another successful strategy for wheat growers. It is expected to increase the yield by 13 per cent. However, its combination with change in the time of sowing will further increase the yield by 4 per cent (Table 5). These findings are in accordance with those of (Iqbal et al., 2015) for Pakistan, where delay in the sowing time is expected to increase the yield. (Table 5).

Farmers are expected to receive significant increase in yield from majority of the combination. These results are in accordance with the studies by (John et al., 2017; Di Falco and Veronesi 2013); emphasizing the importance of adapting in combination.

Estimates of the significance of climatic and non-climatic factors on wheat yield

Table 6, Continue reports the result of MES regression model for output equations. Portfolio of strategies are important in combating the adverse impacts of climate change. In this section we discussed in details the role of each portfolio for each stage of production.

At the first stage of production, there is a significant U-shaped relationship between wheat yield and climate variables. An excessive increase in temperature without adaptation could increase the possibility of seedling mortality and a decrease in the number of plants at the germination and tillering stage. However, portfolio adaptation successfully reverses this negative impact.

At the vegetative stage relationship with mean temperature is *inverted* U-shaped for non-adapters. It is approving the success of adaptation in enhancing resilience of adapters. However, our results do not support adaption at third stage of production.

Negative impact of heat stress reported at the grain formation and maturity stage, as evident by an *inverted* U-shaped relationship. An increase in

Table 6: *Continue.*

Variables	C_0	C_2	C_3	C_{12}	C_{23}	C_{24}	C_{123}	C_{124}	C_{234}	C_{1234}
S1 Precip Dev	-2.12	-0.81	5.38	-1.38	0.26	2.32	0.21	0.15	0.26	-1
	(1.34)	(0.77)	(7.87)	(2.02)	(0.38)	(1.54)	(0.36)	(0.64)	(0.76)	(0.38)
S2 Precip Dev	0.02	0.50*	-8.33	0.84	-0.23	-0.73	0.01	-0.11	-0.44	-0.51
	(1.36)	(0.49)	(12.07)	(1.76)	(0.35)	(0.72)	(0.37)	(0.42)	(1.25)	(0.35)
S3 Precip Dev	-1.82	1.75	26.48	4.31	1.1	1.58	-0.31	1.52	-0.08	1.72
	(2.59)	(2.25)	(18.04)	(4.12)	(0.87)	(2.52)	(1.29)	(1.49)	(1.69)	(0.85)
S1 Temp Dev	3.18	-3.48	3.24	4.14	-2.2	2.86	0.05	3.36*	1.11	1.70**
	(2.40)	(2.45)	(21.52)	(3.62)	(1.36)	(3.71)	(1.49)	(1.96)	(1.60)	(0.88)
S2 Temp Dev	-6.06	0.61	17.05	-12.32	-4.77	-3.62	-6.04	-9.9	-1.4	-5.02
	(5.01)	(4.53)	(31.62)	(5.92)	(2.43)	(7.80)	(1.91)	(4.06)	(3.25)	(1.85)
S3 Temp Dev	2.3	0.35	-1.67	5.98**	0.93	-0.69	-1.33	0.5	1.87	-2.28
	(2.49)	(2.02)	(36.73)	(3.12)	(1.62)	(4.83)	(1.94)	(1.89)	(2.07)	(1.32)
R-W Zone	-4.35	4.62	6.6	8.78	1.39	2.52	2.07	2.27	-3.76	1.53
	(9.42)	(5.00)	(68.62)	(7.62)	(2.08)	(10.74)	(4.37)	(4.58)	(10.55)	(3.01)
C-W Zone	7.97	4.77	29.47	18.27***	1.13	5.98	2	5.81	-0.25	4.83
	(7.13)	(5.50)	(65.54)	(6.98)	(2.74)	(7.55)	(4.81)	(4.31)	(10.55)	(3.32)
B and PB	5.37	0.82	9.03	11.00**	3.25**	5.91**	-1.48	1.82	0.57	0.68
	(6.30)	(3.31)	(77.33)	(4.78)	(1.52)	(2.84)	(3.62)	(4.04)	(10.33)	(2.57)
Mixed-Zone	3.63	1.31	18.22	16.76***	2.87	7.18	0.44	3.34	-3.1	3.67
	(6.86)	(4.16)	(74.07)	(5.75)	(2.04)	(5.27)	(4.47)	(4.50)	(10.31)	(3.05)
Tractor	-0.58	-0.31	-0.61	-0.85	-0.37	-0.33	0.09	-0.22	-0.28	0.14
	(0.70)	(0.37)	(2.48)	(0.84)	(0.39)	(0.70)	(0.41)	(0.60)	(0.53)	(0.35)
Seed	-0.57	0.08	-0.26	-0.14	0.09	-0.04	-0.01	-0.02	0.02	-0.02
	(0.09)	(0.07)	(0.32)	(0.11)	(0.07)	(0.11)	(0.06)	(0.08)	(0.10)	(0.06)
Labor	0.32	0.25	-1.51	0.51	0.60***	0.11	-0.17	0.28	0.52	-0.23
	(0.35)	(0.24)	(1.21)	(0.54)	(0.22)	(0.42)	(0.26)	(0.38)	(0.44)	(0.21)
Fertilizer	-0.65	0.35	3.06	1.34	0.75*	3.22***	0.69	-0.34	0.24	0.87**
	(0.84)	(0.59)	(2.20)	(1.16)	(0.45)	(0.78)	(0.51)	(0.62)	(0.78)	(0.49)
Constant	507.94	188.84	1.84	203.23	-12.48	300.23	-83.17	-58.14	241.69	72.08
	(507.12)	(15.47)	(387.05)	(221.61)	(87.16)	(309.98)	(86.48)	(118.3)	(162.6)3)	(74.9)1)

temperature above its maximum required limit at third stage of production accelerates the process of crop development, and forcing early maturity (Bowden et al., 2008).

Portfolio adaptation having combination of irrigation change, protects wheat from extreme rainfall at first stage that could limits the functioning and survival of seeds and roots by reducing soil's oxygen concentration. In Pakistan, most of the wheat is grown in irrigated areas and in rotation with rice and cotton. Farmer has to wait for the land to dry before sowing the crop. Hence, adaptation by changing the irrigation practices could be prolific in combating the adverse impacts of excessive rainfall.

Incidence of normal rainfall along with increased adaptation proved beneficial for crop growth at vegetative stage. In Pakistan at the time of vegetation, crop normally faces the shortage of water in canal irrigated areas of Pakistan, which could disturb the process of photosynthesis. Hence, adaptation and normal rainfall are desired elements to counter water stress.

Adaptation also counter the short run climatic shocks on wheat growth, and significantly positive impact on yield observed for the agro-ecological zones of cotton-wheat, mixed, barani and partial barani.

Determinants of adaptation

Higher adaptive capacity of farmers increases the likelihood of adaptation to climate change (Table 7, Continue). Adaptive capacity is constructed on the basis of Sustainable Livelihood framework.

Table 7: *Marginal effects of MNL model of farm level adaptation to climate change, Pakistan.*

Variables	C_1	C_2	C_3	C_4	C_{12}	C_{13}	C_{14}
Adaptive capacity	-0.00	-0.00	.00	-0.00	-0.00***	0.00	0.00
Education	-0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00
Household Size	0.00	0.00	0.00	-0.00	0.00	-0.00	0.00
Farm Size	0.00	-0.002	0.00	0.00	-0.00	0.00	0.00
Farm Experience	-0.00	0.00	-0.00	0.0003**	-0.03**	0.00	-0.00
Credit	0.00	0.03***	0.00	0.02***	-0.01	0.00	-0.00
Extension	-0.00	-0.03**	-0.00	0.00	-0.01*	-0.00	-0.00*
TV	0.00	-0.02**	-0.02***	-0.00	0.01	-0.01**	-0.00
Radio	0.00	0.01*	-0.02***	0.00	0.00	0.00	-0.00
Newspaper	0.00	-0.03	-0.00	0.00	0.01	0.05	0.00
Family Members	-0.00	0.02**	0.02***	0.01**	0.00	0.00	-0.00
Neighbor	0.00	-0.01	0.01	0.001	-0.01*	-0.00	0.00
Department of Agriculture	-0.04	0.01	0.01	-0.01	-0.00	0.00	0.00
Traditional Knowledge	-0.00	0.06***	-0.03***	0.00	0.02***	-0.00	-0.00

Table 7: *Continue.*

Variables	C_{23}	C_{24}	C_{34}	C_{123}	C_{124}	C_{134}	C_{234}	C_{1234}
Adaptive capacity	0.003**	0.00	-0.00	0.01***	0.00	0.00	0.00	-0.01***
Education	-0.00	0.002**	0.00	-0.00	0.00	0.00	0.00	0.00
Household Size	0.00	-0.00	0.00	-0.01	0.00	0.00	0.001*	0.00**
Farm Size	0.00	-0.00	0.0002***	-0.00	0.00	0.00	0.001**	0.00***
Farm Experience	0.00	0.002***	0.00	-0.002***	0.00	5.95	-0.00	0.00
Credit	-0.02*	0.004	0.01**	-0.03**	0.01	0.00	0.02**	-0.02
Extension	-0.01	-0.03***	-0.00	-0.11***	0.01*	0.00	0.00	0.10
TV	0.04***	-0.04	0.01**	0.02	0.01	0.00	0.05***	0.03
Radio	-0.02	-0.01	-0.01	-0.03*	0.03***	0.00	0.02	-0.04**
Newspaper	0.02	-0.03	-0.02	0.03	0.01	0.00	-0.02	0.08
Family Members	0.03*	0.02	0.01	-0.03**	-0.03***	0.00	0.02*	-0.08***
Neighbor	0.02	0.04***	0.01	0.02	-0.004	0.00	0.01	-0.06***
Department of Agriculture	0.09	-0.02	0.00	0.05	-0.04	0.00	-0.01	-0.05
Traditional Knowledge	0.01	0.03***	-0.02***	0.07***	0.02***	0.00	-0.04***	0.07***

Where, accumulating different assets increased farmer's capacity to respond to climate change. Our results are consistent with Kurosaki (2006) and Hassan and Nhemachena (2008) which have established that assetsin the possession of farm households enhance their ability to adapt to climate change. A farm household having more diversified sources of income, valuable assets, and possession of land and livestock is considered to be financially more strong and economically stable. Which is one component of adaptive capacity in present study. Having financial and economic stability enhances the ability of farmer to adapt new crop varieties and more inorganic fertilizer.

Higher education also increases farmers' likelihood of adaptation (Table 7, Continue). Our results are consistent with the finding of Teklewold et al. (2013), Deressa et al. (2009) and Maddison (2007), which demonstrated that education improves farmer's information on new and improved technologies.

As expected large farm size increases the likelihood of adaptation (Table 7, Continue). The farmer with large landholdings has better access to cheap credit, have economies of scale in the selection, ordering and transportation of inputs that are required to make adjustments under changing climate (O'Brien et al., 2000).

Likelihood to adopt new crop varieties also increased with farming experience (Table 7, Continue). Experienced farmers are commonly better informed of the changing climatic conditions, and they are better evaluator of different adaptation strategies in the face of climate change (Gbetibouo, 2009; Uddin et al., 2014).

Our results also show a key role of access to credit in governing adaptation decisions of farm households (Table 7, Continue). Many studies (Di Falco et al., 2011, Gorst et al., 2015; Abid et al., 2015) have confirmed the importance of financial assistance in acquiring advanced technologies.

Access of extension services do not play a significant positive role for most of the cases (Table 7, Continue). It points on the ineffectiveness of extension centers in providing adequate information to the farmers on new technologies and farming practices. We have also observed heterogeneity in the effects of sources of information on adaptation decision across sources and strategies adapted (Table 7, Continue).

Conclusions and Recommendations

The evidence coming from the study strongly postulates that climate change adaptation has significant potential to compensate for the adverse impacts of climate change. First important finding made during the analysis is that portfolio adaptation is rewarding in enhancing crop yield, however, irrigation is the most rewarding strategy to increase the yield of wheat. Our second major finding is that the potential of adaptation differs among crop growth stages, due to differences in the impacts of climate change at each stages of production. While our third finding is that higher adaptive capacity to climate change, education, farm size, farm experience, access to credit and sources of information on climate change are important drivers of farmer's adaptation decision.

Future research should focus on investigating the potential of adaptations by targeting particularly those farming communities which have been hit most by the adversaries of climate extremes like floods and droughts. Research and development efforts should be focused on new crop varieties and hybrids that have the ability to withstand climatic extremes and demand fewer resources (land, water, etc.).

Author's Contribution

Aisha Siddiqua: Conceived the idea, overall management of the article, initiated and finalized the paper.
Munir Ahmad: Supervised the work, Provided technical input at every step.
Nusrat Habib: Data entry, literature review and References.

Supplementary Material

There is supplementary material associated with this article. Access the material online at: http://dx.doi.org/10.17582/journal.pjar/2019/32.2.218.228

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