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Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan

Akhter Ali [a,*], Olaf Erenstein [b]

[a] International Maize and Wheat Improvement Center (CIMMYT) NARC, Park Road, Islamabad, Pakistan
[b] Socioeconomic Program, International Maize and Wheat Improvement Center (CIMMYT), Texcoco, Mexico

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ABSTRACT

Climate change is set to be particularly disruptive in poor agricultural communities. We assess the factors influencing farmers' choice of climate change adaptation practices and associated impacts on household food security and poverty in Pakistan using comprehensive data from 950 farmers from its major provinces. A probit model was used to investigate the factors influencing the use of climate-change adaptation practices; the censored least absolute deviation (CLAD) was used to analyze the determinants of the number of adaptation practices used; and a propensity score matching (PSM) approach was employed to evaluate the impact of adaptation practices on food security and poverty levels. Adjustment in sowing time (22% households), use of drought tolerant varieties (15%) and shifting to new crops (25%) were the three major adaptation practices used by farmers in the study area. Results show that younger farmers and farmers with higher levels of education are more likely to use these adaptation practices, as do farmers that are wealthier, farm more land and have joint families. The number of adaptation practices used was found to be positively associated with education, male household heads, land size, household size, extension services, access to credit and wealth. Farmers adopting more adaptation practices had higher food security levels (8–13%) than those who did not, and experienced lower levels of poverty (3–6%). Climate change adaptation practices at farm level can thereby have significant development outcomes in addition to reducing exposure to weather risks.

1. Introduction

Climate change is increasing recognized as a global phenomenon with potentially far-reaching implications (Stern, 2006; IPCC, 2007b; IPCC, 2014) and associated with more frequent extreme weather events (Stern, 2006; IPCC, 2007b; Karl et al., 2009). Poor people living in agricultural communities in developing countries are expected to be the most affected by these climatic changes (Maskrey et al., 2007). Developing countries are most vulnerable to climate change though they are only contributing 10% to the annual global carbon dioxide emissions (Maskrey et al., 2007). South Asian countries are particularly affected because of the vast populations still dependent on predominantly agriculture-based rural economies and the vast number of poor people. This poses serious challenges to their social, economic and ecological systems (Zhuang, 2009;

* Corresponding author at: International Maize and Wheat Improvement Center (CIMMYT), NARC, Park Road, Islamabad, Pakistan.
E-mail address: akhter.ali@cgiar.org (A. Ali).

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Mirza, 2011). The World Bank's South Asia Climate Change Strategy reported similar concerns that the poorest people in the region will suffer the most from climate change because of unfavorable geography, limited assets, and a greater dependence on climate-sensitive sources of income (World Bank, 2009). The frequent occurrences of extreme weather events in the region in recent years (e.g. flash floods in Pakistan and India) are perceived to be directly associated with climate change and likely to keep the poor in a perpetual poverty trap (Mendelsohn and Dinar, 1999).

Climate change manifests itself through increasing variation in the weather, including temperature, precipitation, and wind. Scientific research confirms climate change is occurring and expected to aggravate in coming decades (Stern, 2006; IPCC, 2007b; IPCC, 2014). Since 1950, the number of warm days and nights has increased, and it is projected that the length, frequency, and intensity of heat waves will increase on most of the land (Field et al., 2012). As a result of climate change the pattern, timing and intensity of the precipitation has also altered. The number of heavy precipitation events has increased but with strong regional variations (Field et al., 2012). Rise in temperature and changes in precipitation are changing water availability and other stresses for crops with effects on crop yield, income, and poverty. Globally abnormal disasters have increased from 125 per year in 1980 to 400–500 in 2008 (Maon et al., 2009). Despite the fact that Pakistan has been a low producer of carbon dioxide gasses (0.2 million metric tons), it is considered one of the worst affected by global warming and Pakistan's response to solving the problem has remained uninspired (Smadja et al., 2015). Due to adverse climatic conditions Pakistan experiences high economic costs in terms of damage to property and infrastructure, losses in agricultural productivity, rehabilitation and rebuilding costs of those areas distressed by environmental disasters (Husain, 2015).

The impact of climate change on food security and poverty depends on multiple interacting drivers especially the timing of extreme events which are expected to become more frequent (IPCC, 2007a). The largest number of food insecure persons are found in South Asia, which has roughly 300 million undernourished (FAO et al., 2012). In addition to the common measure of calorie availability, food security can be broadened to include nutritional aspects based on the diversity of diet.

Many of the impacts of climate change are likely to occur in and are channeled through the climate-sensitive sectors such as agriculture (Mendelsohn, 2001). Climate change and variability presents a major challenge to agricultural production and rural livelihoods and it affects approximately 2.5 billion people who derive their livelihood in part or in full from agricultural production systems. To reduce the adverse impact of climate change on agriculture, adaptation is considered a vital component of any policy response to climate change (Brooks and Adger, 2005; Deressa et al., 2009; Gbetibouom, 2009). Studies show that without adaptation strategies, climate change is generally detrimental to agriculture, but can partly be offset by various adaptation measures at the farm level (Downing, 1991; Easterling III et al., 1993, Rosenzweig and Parry, 1994; Smith and Lenhart, 1996; Mendelsohn and Dinar, 1999; Reilly and Schimmelpfennig, 1999; Smit and Skinner, 2002). The degree to which the agricultural sector is affected by climate change depends on the adaptive capacity of the farming communities (Gbetibouo, 2009).

Climate change adaptation strategies for agriculture include: (a) micro-level options, such as crop diversification and altering the timing of operations (Deressa et al., 2009); (b) market responses, such as income diversification and credit schemes (Hussain and Mudasser, 2007); (c) institutional changes, mainly government responses, such as subsidies/taxes and improvement in agricultural markets (Mendelsohn, 2001); and (d) technological developments, such as the development and promotion of new crop varieties and advances in water management techniques, etc. (Smith and Lenhart, 1996; Mendelsohn, 2001; Smit and Skinner, 2002; Kurukulasuriya and Rosenthal, 2003; Hussain and Mudasser, 2007; Deressa et al., 2009). However, some of the adaptation methods are highly localized and cannot be directly adopted and implemented in other regions or agriculture settings.

2. Agriculture and climate challenges in Pakistan

Agriculture remains the backbone of Pakistan's economy, contributing to about 20% of the total GDP and employing 43% of the workforce. More than two-thirds of Pakistan's population lives in rural areas, and their livelihood continues to revolve around agriculture and allied activities. There have been some structural changes over time, but the contribution of agro-based products continues to maintain its relative importance, giving impetus to the overall economic development and growth of the economy (Government of Pakistan, 2003). Cotton, wheat, rice, sugarcane, maize, fruit and vegetables account for more than 75% of the value of total crop output (Government of Pakistan, 2012–13).

In this context, agriculture is important for ensuring food security and reducing poverty. However, increasing weather variability and climate change have threatened the agricultural sector and thereby, have become major barriers to achieving food security and alleviating poverty in Pakistan. The increase in temperature can affect agriculture through its impact on cropping seasons, the increase in evapotranspiration, the increase in irrigation requirements and the increasing heat stress on crops. The use of short duration crop varieties and adjustment in sowing time may reduce the adverse impact of the aforementioned climatic risks. Semi-arid and arid drylands in resource-poor regions of Pakistan, including Sindh and Baluchistan, are more vulnerable to climate change, especially to reduced rainfall, increased evapotranspiration and drought.

Several studies in Pakistan revealed that cereals and other crops are vulnerable to heat stress and temperature rises. For example, a 1 °C rise in temperature would result in wheat yield declines of 5–7% (Aggarwal and Sivakumar, 2011). Another study (Sultana and Ali, 2006) found that wheat production would decline by 6–9% in arid, semi-arid and sub-humid regions of Pakistan while it can increase in the humid zone. Similarly, an increase in temperature by 1.5 °C and 3 °C could *decrease* wheat yield by 7% and 21% respectively in the Swat district of Pakistan (with average altitudes of 960 masl) whereas this could *increase* wheat yield by 14% and 23% respectively in Chitral district (with average altitudes of 1500 masl) (Hussain and Mudasser, 2007). Studies show that rice yield also declines with the rise in temperature. In semi-arid regions of Pakistan, the rice yield could decline by 15% from 2012 to 2039, 25% from 2040 to 2069 and 36% from 2070 to 2099 if the rise in temperature continues (Ahmad et al., 2013). Along with the increase in temperature, decreasing rainfall affects crop production. If rainfall decreases by 6%, net irrigation water requirements in Pakistan could increase by almost 29%. This will negatively affect over 1.3 million farm households in Pakistan and most of the crop production including cereals, fruits, and vegetables (MoE-GIRP, 2003).

In order to adapt to climate change risks in agriculture, farmers use several adaptation strategies. Adaptation measures such as an adjustment in sowing time, use of stress-tolerant crop varieties and shifting to new crops (e.g. more stress tolerant, or with shorter or longer crop cycles), could significantly reduce vulnerability to climate change (Smit and Skinner, 2002). Adaptation practices can involve changes in planting dates, fertilizer used, irrigation, plant breed or other aspects of crop management and the cultivation process (Challinor et al., 2014) and have crop specific implications (Porter et al., 2014). These adaptation practices typically reduce risk and are more likely to minimize the severity of the impact of climate change. Thus, farm households using adaptation practices are more likely to be food secure compared to those not adopting.

Pakistan has experienced extreme weather events like untimely and heavy rainfall and flash floods in hilly regions causing enormous damage to the crops and properties of farmers. It is anticipated that these conditions will increase as a function of climate change. Keeping in mind the importance of agriculture to the economy and rural livelihoods, the significance of climate change adaptation strategies is crucial. Although, the adaptation practices are potentially important, not all the farmers use such practices. Therefore, this paper assesses the use and determinants of climate-change adaptation practices by farmers in Pakistan and their impact on household food security and poverty. The contribution of this paper is threefold: first, it uses a multivariate probit to assess the determinants of choice of adaptation practices simultaneously (specifically, adjustment in sowing time, use of drought-tolerant varieties and shifting to new crops); second, it investigates the determinants of the number of practices used; and third, it assesses the impact of these practices on food security and poverty. The remainder of this paper is organized as follows: Section 3 discusses the conceptual framework in terms of farmers' adaptation to climate change; Section 4 outlines the data and variables used in the models; Section 5 presents the empirical results and discussions; finally, Section 6 concludes.

3. Conceptual framework

In Pakistan, different farmers try different strategies to adapt to climatic challenges. A multivariate probit estimation was first used to investigate the choice determinants of climate change adaptation practices distinguishing between the adjustment in sowing time, use of drought-tolerant varieties and a shift to new crops. A censored least absolute deviation was then used to understand the determinants of the number of climate-change adaptation practices used. A propensity score matching approach was employed to analyze the impact of adaptation practices on food security and poverty.

We consider a risk-averse farm F_i that opts for a number of strategies (S_j). It is assumed that households that have opted for adaptation strategies have higher utility levels compared to those that have not:

$$U[F(S_1)] > U[F(S_0)] \quad (1)$$

It is further assumed that farm households adopting two strategies have higher utility levels compared to households having adopted only one strategy and so on.

$$U[F(S_1, S_2)] > U[F(S_0, S1)] \quad (2)$$

The number of adaptation strategies adopted by the farmers was estimated by employing the censored least absolute deviation (CLAD) model. The CLAD estimator is a generalization of the least absolute deviation (LAD) estimator, Unlike the standard estimators of the censored regression model such as tobit or other maximum likelihood approaches, the CLAD estimator is robust to heteroscedasticity and is consistent and asymptotically normal for a wide class of error distribution. As the CLAD estimator imposes the weakest stochastic restrictions on the error terms, it results in the most precise estimates of the policy effects.

The impact of the adaptation strategies on household welfare in Pakistan was estimated by employing propensity score matching (PSM). The expected treatment effect for the treated population is of primary significance and given as

$$\tau|_{I=1} = E(\tau|I = 1) = E(R_1|I = 1) - E(R_0|I = 1) \quad (3)$$

where τ is the average treatment effect for the treated (ATT), R_1 denotes the value of the outcome for adopters of the new technology and R_0 is the value of the same variable for non-adopters. As noted above, the major problem is that we do not observe $E(R_0|I = 1)$.Although the difference $[\tau^e = E(R_1|I = 1) - E(R_0|I = 0]$ can be estimated, it is potentially a biased estimator.

In the absence of experimental data, the PSM can be employed to account for this sample selection bias (Dehejia and Wahba, 2002). The PSM is defined as the conditional probability that a farmer adopts the new technology, given pre-adoption characteristics (Rosenbaum and Rubin, 1983). To create the condition of a randomized experiment, the PSM employs the unconfoundedness assumption, also known as conditional independence assumption, which implies that once

Z is controlled for, technology adoption is random and uncorrelated with the outcome variables. The PSM can be expressed as:

$$p(Z) = \Pr\{I = 1|Z\} = E\{I|Z\} \quad (4)$$

where I = (Abara and Singh, 1993) is the indicator for adoption and Z is the vector of pre-adoption characteristics. The conditional distribution of Z, given p(Z) is similar in both groups of adopters and non-adopters.

After estimating the propensity scores, the average treatment effect for the treated (ATT) can then be estimated as:

$$\tau = E\{R_1 - R_0|I = 1\} = E\{E\{R_1 - R_0|I = 1, p(Z)\}\} = E\{E\{R_1|I = 1, p(Z)\} - E\{R_0|I = 0, p(Z)\}|I = 0\} \quad (5)$$

Several techniques have been developed to match participants with non-participants of similar propensity scores. Propensity score matching rests on two strong assumptions, i.e. the conditional independence assumption and the common support condition. In the case of PSM, the most important variable of interest is the average treatment effect for the treated (ATT). ATT is the difference in the outcome of the farmers having used adaptation practices and similar farmers not having adopted. For estimation, two different matching algorithms i.e. nearest neighbor matching (NNM) and kernel-based matching (KBM) are employed in the current paper. After matching, the matching quality has to be accessed, and the standard errors and treatment effects have to be estimated. A number of balancing tests have been employed to access the matching quality, such as reduction in the median absolute bias before and after matching, the value of R^2 before and after matching and the p-value of joint significance of covariates before and after matching (Becker and Ichino, 2002; Caliendo and Kopeinig, 2008).

We use PSM to estimate the impacts of the number of adaptation practices used on food security and poverty. For food security, the amount of food required to lead a healthy life was used as a measure/threshold point, and household below this line were considered food insecure. It is a dummy variable which is 'one' if the food consumption is above the threshold level of food necessary to live a healthy life and 'zero' otherwise. For poverty estimation, the headcount index of poverty was estimated; households below the poverty line were considered poor. A dummy variable for poverty was used which is equal to 'one' if poor, 'zero' otherwise. The impact is estimated on the number of practices adopted by the farmers. For instance, if one farmer adopts one strategy, how great is the impact on that household's food security and poverty level? Similarly, if the household adopts two practices and so on, the impact is noted.

4. Data and variable description

4.1. Data

The study uses a primary dataset collected in 2014 using multi-stage sampling from 950 farmers in the four main provinces of Pakistan (Punjab, Khyber Pakhtunkhwa, Sindh, and Balochistan), which constitute 98% of the total land area of Pakistan. In the second stage, several districts were selected from each of the four provinces and in the third and the fourth stages, *tehsils* (sub-districts, 119 total) and villages (275 total) were randomly selected (Table 1). From each village 3–5 households were randomly selected, resulting in 350 farmers from the Punjab, 250 each from the Khyber Pakhtunkhwa (KPK) and Sindh provinces and 100 farmers from Balochistan. In Punjab and Sindh, the agricultural lands are mostly irrigated by canals while in KPK and Balochistan only a small proportion of the agricultural land is irrigated by canals. Using a structured questionnaire, data on a number of socioeconomic, farm and household characteristics were collected. In addition, data relating to the farmers' experience of climate changes, various adaptation practices adopted and their impact on crop yields, household food security and income levels were collected.

Table 1
Sampling framework.

Province	Punjab	Khyber Pakhtunkhwa	Sindh	Balochistan
Districts sampled	Sheikhupura, Hafizabad, Gujranwala, Sialkot, Narowal, Sargodha, Chiniot, Faisalabad, Toba Tek Singh, Chakwal, Jhelum, Rawalpindi, Mianwali, Multan, D.G. Khan, Lodhran, Bahawalpur, R.Y. Khan, Vehari, Bahawalnagar	D.I. Khan, Nowshera, Mardan, Kohat, Swabi, Peshawar, Charsada, Karak, Bunir, Bannu, Lakki Marwat	Nawabshah, Hyderabad, Dadu, Khairpur, Mirpur Khas, Tando Allah Yar, Sanghr, Nausharo Feroze, Matiari, Ghotki, Sukkur, Shikarpur, Thatta	Jhal Magsi, Nasirabad, Jaffarabad, Sibi, Killa Saifullah, Zhob, Loralai, Pishin
Number of blocks/*tehsils* sampled	61	26	24	8
Number of villages sampled	105	79	73	18
Number of households sampled	350	250	250	100

4.2. Variable description

Table 2 presents the descriptive statistics for the variables used in this study. The majority of the households (96%) are male-headed with an average household size of 10. Joint families are common in South Asia, and the data revealed that 68% of the rural households were joint families. The mean age of the farmers was 43 years and mean years of schooling was about nine years, indicating that farmers in the study area were middle-aged are fairly educated. On an average, the farming household had about 14 years of experience in agriculture, which is quite substantial. A small number of the surveyed households had migrated to the present location (8%), and 92% of the households were found to be local. The average size of land holding was about 2.65 ha; 74% farmers in the survey owned land, and the remaining 26% were pure tenants;. Approximately 65% of the farmers have good quality soil, and the rest have poor quality soil. Two third of the farmers (67%) have fragmented land, and an overwhelming majority (85%) have plain land. Land leveling was practiced by 23% of the farmers and only 8% of the farmers cultivated legumes for increasing the soil fertility. Access to blacktop roads was limited to about 48% of the rural households.

Few households have tractors (9%), irrigation tube wells (7%) or cars (19%). The average livestock ownership is about 7.3 per household. Only 6% of the farmers have access to a credit facility, and about 26% of the farmers have access to extension services. Mean income and expenditures of the household were Pakistani Rupees 42,165 and Pakistani Rupees 36,906 respectively.

Most (87%) of the respondents reported observing changes in climatic conditions, which suggests that climate change has been experienced by most of the surveyed rural society. Similarly, majority noted a change in rainfall (timing and amount), monsoon onset and temperature during last ten years. Probably being a farming household, the weather events that affect agriculture are well noted by these households. Farmers typically adjusted the sowing time of their crops (22%) to the changing conditions, while 15% of the farmers adopted heat/stress tolerant varieties. A quarter shifted to new crops due to changing weather conditions. Two-thirds of the farmers recycle their seed, and the rest use the seed from other sources, mostly from fellow farmers and dealers.

5. Empirical results and discussion

5.1. Determinants of specific farmers' climate change adaptation practices

Table 3 presents the results of the multivariate probit estimation of the determinants of farmers' adaptation practices to climate change distinguishing between the adjustment in sowing time, use of drought-tolerant varieties, and a shift to new

Table 2
Data and description of variables.

Variable	Description	Mean	Std Dev.
Age	Age of the household head in years	43	11.6
Male headed	Dummy, 1 if household head is male and 0 otherwise	0.96	0.75
Household size	Number of family members in the household	10.13	5.12
Joint Family	Dummy, 1 if living in joint family, 0 otherwise	0.68	0.34
Household head	Dummy, 1 if farmer is head of the family, 0 otherwise	0.89	0.39
Farming experience	Farming experience in years	14.44	7.83
Local resident	Dummy, 1 if farmer is local, 0 otherwise (migrant)	0.92	0.41
Education	Number of years of schooling of the household head	8.71	5.42
Land size	Farm land holding, ha	2.65	1.42
Landowner	Dummy, 1 if farmer is owner of land, 0 otherwise	0.74	0.55
Land fragmentation	Dummy, 1 if the land is fragmented, 0 otherwise	0.67	0.35
Good soil	Dummy, 1 if the soil is of good quality, 0 otherwise	0.65	0.48
Plain land	Dummy, 1 if the field slope is plain, 0 otherwise	0.85	0.51
Land leveling	Dummy, 1 if farmer practiced land leveling, 0 otherwise	0.23	0.43
Legumes	Dummy, 1 if farmer grows legumes, 0 otherwise	0.08	0.15
Tractor	Dummy, 1 if farmer owns a tractor, 0 otherwise	0.09	0.13
Tube well	Dummy, 1 if farmer owns a tube well, 0 otherwise	0.07	0.27
Car	Dummy, 1 if farmer owns a car, 0 otherwise	0.19	0.24
Livestock	Number of livestock owned by the farmer	7.35	5.03
Income	Household income from all sources, Pak Rs. per month	42,165	12,560
Expenditure	Household expenditure, Pak Rs per capita	36,906	25,783
Credit	Dummy, 1 if household accessed credit, 0 otherwise	0.06	0.28
Extension	Dummy, 1 if farmer has contact with extension services, 0 otherwise	0.26	0.15
Tar road	Dummy, 1 if household has access to black top/surfaced road, 0 otherwise	0.48	0.57
Membership	Dummy, 1 if farmer is member of any organization, 0 otherwise	0.16	0.12
Climate change	Dummy, 1 if the farmer has experienced climate change, 0 otherwise	0.87	0.32
Temperature increase	Dummy, 1 if farmer reported temperature increase, 0 otherwise	0.91	0.17
Rainfall change	Dummy, 1 if farmer reported changed rainfall patterns, 0 otherwise	0.85	0.26
Monsoon onset	Dummy, 1 if farmers have experienced change in the onset of monsoon, 0 otherwise	0.79	0.25
Sowing time change	Dummy, 1 if farmer adjusted the sowing time, 0 otherwise	0.22	0.17
Tolerant Varieties	Dummy, 1 if farmer adopted stress-tolerant varieties, 0 otherwise	0.15	0.11
New Crops	Dummy, 1 if farmers shifted to new crops, 0 otherwise	0.25	0.13
Recycled seed	Dummy, 1 if home saved seed is used, 0 otherwise	0.66	0.32

crops. Based on the review of the literature and microeconomic theory, a set of independent variables are included in the model.

5.1.1. Demographic

Age of the household head turned out to be negatively associated with the adoption of the three adaptation practices, which suggests that younger farmers are more likely to adopt compared to their older counterparts possibly for being innovative and keen to try new technology and methods to improve agriculture. Older farmers could also be not aware of recent innovations in agriculture and/or are reluctant to try new methods.

Joint families and family size are both positively associated with adaptation practices, possibly reflecting labor supply. The association between household size and adaptation strategies has been similarly found in other studies (Croppenstedt et al., 2003; Deressa et al., 2009; Abid et al., 2015). Other studies have made an association between larger households and the ability to supply surplus labor to non-farm activities (Lanjouw and Lanjouw, 2001; Reardon et al., 2001; Rahut and Micevska Scharf, 2012; Gautam and Andersen, 2016) and the income generated could be invested in climate risk coping strategies. The gender of the household head proved insignificant – which compares with the mixed results reported in other studies: in some male headed households were more likely to adopt climate risk coping strategies (Deressa et al., 2009) while in others female-headed households (Nhemachena and Nhem, 2007).

5.1.2. Human capital

Years of education of the household head was positively associated with all three adaptation methods. Educated farmers are likely to be more aware of climate change and agricultural innovations and may be more interested in adopting technology and methods to cope with climate risk. Investing in education is critical for overall development and may thus also provide a policy instrument for increasing the use of climate risk coping strategies and reducing the vulnerability of farm

Table 3
Climate-coping strategies adopted by farmers (multivariate probit estimates).

Variable	Adjustment in sowing time	Drought-tolerant varieties	Shift to new crops
Demographics			
Age (yr)	−0.03**(−2.06)	−0.02*(1.73)	−0.04*(1.69)
Male-headed (Dummy)	−0.02(−0.65)	0.01(1.42)	0.03(1.53)
Household size (#)	0.01*(1.81)	0.02(1.93)	0.01*(1.74)
Joint family (D)	0.02***(2.64)	0.01**(2.01)	0.03***(2.57)
Human capital			
Education (yr)	0.02***(3.17)	0.04***(2.56)	0.01**(2.03)
Land			
Land size (ha)	0.01***(3.76)	0.02**(2.26)	0.01***(3.51)
Land owner (D)	−0.02*(−1.88)	−0.03***(−2.91)	−0.02**(−2.56)
Land fragmentation (D)	−0.04***(−2.56)	−0.01(1.55)	−0.02(1.42)
Good soil (D)	0.02***(2.43)	0.01*(1.70)	0.02**(2.55)
Plain land (D)	0.02*(1.76)	0.03**(2.30)	0.01*(1.84)
Land leveling (D)	−0.02**(2.14)	0.02***(2.78)	0.03***(2.54)
Non-land assets and income			
Tractor (D)	−0.01(−0.45)	−0.02(−0.70)	−0.03(−0.48)
Tube well (D)	0.03*(1.85)	0.02***(1.97)	0.01*(1.92)
Car (D)	0.02**(2.04)	0.01*(1.82)	0.02***(2.65)
Livestock (#)	0.01***(3.05)	0.02**(2.27)	0.01***(2.74)
Income (Pak Rs.)	0.03***(2.76)	0.01**(2.14)	0.02***(3.01)
Access to services			
Credit (D)	−0.04(−1.38)	−0.02(−0.75)	−0.01(−1.55)
Extension (D)	0.01*(1.69)	0.02*(1.71)	0.02**(2.17)
Tar road (D)	0.02**(2.23)	0.01***(2.74)	0.01***(2.61)
Membership (D)	0.02**(2.15)	0.01*(1.80)	0.03***(2.54)
Province			
Sindh (D)	0.03**(2.14)	0.03*(1.94)	0.03***(2.53)
KPK (D)	−0.01***(−2.73)	−0.01(−1.24)	−0.01*(1.74)
Balochistan (D)	−0.02**(−2.17)	−0.01**(−2.14)	−0.02***(−2.63)
Constant	0.02**(2.03)	0.01(1.36)	0.01*(1.74)
Cross equation correlation	ρ_{12}	ρ_{13}	ρ_{23}
	0.14***(2.75)	0.12***(2.46)	0.11***(3.10)
LR Chi Square	173.82		
Prob > Chi Square	0.000		
Number of observations	950		

Note: In parenthesis t-values are reported. D: dummy (yes = 1) ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

households. Other studies have similarly found a positive correlation between education and adoption of climate risk management (Thomas et al., 2007; Hassan and Nhemachena, 2008; Deressa et al., 2009; Bryan et al., 2013; Abid et al., 2015).

5.1.3. Land

Land is a major agricultural productive asset and wealth indicator. Land holding size is strongly associated with all three adaptation methods – in line with the generally reported positive association between farm size and technology adoption (Abid et al., 2015; Tiwari et al., 2009; Bryan et al., 2013). Farmers with large landholdings are likely to have more capacity to try out and invest in climate risk coping strategies. In Pakistan the majority of farms are small-scale with 90% of the farms being two hectares or less (Bryan et al., 2013); although land distribution is highly skewed, and one-third of the farmers are pure tenant farmers having no land ownership (Government of Pakistan, 2014–2015). Perhaps somewhat surprisingly, after controlling for land size (and other wealth indicators, see below), ownership of land turned out to be negative for all three adaptation methods. Other studies have shown mixed results for the relationship between tenancy status and climate change adaptation: some found a positive association between land ownership and adaptation (Fosu-Mensah et al., 2012; Iheke and Agodike, 2016), others reported a negative correlation (Nabikolo et al., 2012; Abid et al., 2015, 2016; Iqbal et al., 2015; Javed et al., 2015), the latter variously associated with the need for tenants to pay land rents and have more agriculturally reliant livelihoods.

Farmers with fragmented land are likely to (only) adjust sowing time – possibly for not involving major investments and hence easy to pursue especially when fields are fragmented. Good soil quality and plain land are both positively related to all three adaptation methods. Better agricultural land is typically more productive so potentially increasing the marginal return to the investment and incentives to adapt to climate risk. Farmers who have practiced land leveling activities are less likely to adjust sowing time, but more likely to use stress-tolerant varieties or shift to new crops. Land leveling is more likely in irrigated fields which reduces the need to adjust sowing time and enhances diversification prospects and technological innovation.

5.1.4. Non-land assets and income

In addition to land, there are various other proxies for farmers' wealth, including livestock and car ownership. Both of these non-land assets were positively related to the three adaptation methods. Similarly, household income is positive. Wealthy households are likely to have the ability to invest in new agricultural technology and the capacity to take the associated risk of adopting innovations. The wealthy households tend to adopt climate adaptation strategies because of their ability to invest capital in new technology and methods to adapt to the climate risk. Irrigation facilities are expected to play a critical role in adaptation to climate change. Tube well ownership, although relatively uncommon (7%), is indeed positively associated with all three adaptation methods (although at 5%-10% level of significance), possibly also reflecting the household's ability to invest and the importance of agriculture (Abid et al., 2015, 2016). Perhaps somewhat surprisingly, tractor ownership had no significant effect – but this likely reflects the limited ownership of tractors, the reliance of the majority of famers on tractor rental services (a practice common throughout South Asia) and that we already control for various other wealth indicators.

5.1.5. Access to services

Extension services, access to tar roads and association membership are all positively associated with all three adaptation methods, likely denoting the role of access to information and other resources which empower the farm household to adopt such climate-risk coping strategies (Abid et al., 2015, 2016). Our findings align with other studies, including those that show the positive effects of institutional membership (Adesina et al., 2000) and extension services (Deressa et al., 2009), with extension services enhancing the availability of information of the climate risk and adaptation options (Maddison, 2007; Nhemachena and Nhem, 2007). Perhaps again somewhat surprisingly, credit had no significant effect – but this likely reflects the limited additional investments needs associated with each of the three adaptation methods and that we already control for various wealth indicators which were closely associated.

5.1.6. Location

Location typically plays an important role in climate change adaptation (Vincent, 2007; Tiwari et al., 2008; Hinkel, 2011; Below et al., 2012). The current study included provincial dummies to control for the location effect on adaptation strategies. With Punjab being the base for the model, these indicate significant regional effects. Interestingly, Sindh has a positive effect on the adoption of each practice. This is likely associated with the location of Sindh to the South of Punjab being generally hotter and drier. In contrast, the more agro-ecologically diverse and generally less developed Balochistan and KPK have a generally negative effect on the adoption.

The cross-equation correlations are positive and highly significant at the 1% level of significance, indicating that these adaptation practices need to be estimated jointly. The LR Chi-square is also highly significant at the 1% level of significance, indicating the robustness of the variables included in the model.

5.2. Determinants of the aggregate number of adaptation methods used

Table 4 presents the determinants of the aggregate number of adaptation methods used using the censored least absolute deviation (CLAD) estimation.

5.2.1. Demographic

The age coefficient is again negative indicating that young farmers adopt more adaptation methods than the older farmers, possibly because young farmers are more aware of climate change and adaptation practices. The family size coefficient is positive indicating that the farmers with larger families adopt more adaptation practices. Male-headed households adopt more adaptation methods compared to the female-headed household. Locally originating households (i.e. non-migrants) are positively associated with the number of practices adopted (though significant only at 10%), possibly owing to the local knowledge and access to local networks.

5.2.2. Human capital

'Years of schooling' is again positive indicating that the higher the education level, the more practices the farmer will adopt. More educated farmers are likely more aware of climate change, adaptation practices and the benefits of the adaptation practices.

5.2.3. Land assets

Various land indicators are associated with the number of adaptation practices used. Households with more land implement more practices, possibly because they have a higher ability to adopt. Landowners practice more adaptation strategies compared to tenants. Farmers practicing land leveling adopt fewer practices (albeit significant at 10%) and associated with the mixed effect of land leveling on the individual practices. Other land quality indicators (fragmentation; soil quality; plain land) are however not associated with the number of adaptation practices used.

Table 4
Number of strategies adopted by the farmers (CLAD estimates).

Variable	Coefficient	t-values
Age (yr)	−0.01***	2.84
Male headed (Dummy)	0.02***	2.55
Household size (#)	0.02***	2.93
Joint family (Dummy)	0.01	1.05
Local (Dummy)	0.02*	1.91
Human Capital		
Education (yrs)	0.03***	3.17
Land		
Land size (ha)	0.03***	2.73
Land owner (Dummy)	0.01***	2.74
Fragmented land (Dummy)	0.03	1.28
Good soil (Dummy)	0.02	0.55
Plain land (Dummy)	0.03	0.59
Land leveling (Dummy)	−0.01*	−1.67
Non-land assets and income		
Tractor (Dummy)	−0.02	−1.25
Tube well (Dummy)	0.03	1.52
Car (Dummy)	0.01***	2.60
Livestock (#)	0.01***	2.43
Income (Pak Rupees)	0.03**	2.16
Access to services		
Credit (Dummy)	0.02***	2.62
Extension (Dummy)	0.01***	2.55
Tar road (Dummy)	−0.02	−0.33
Membership (Dummy)	0.04***	3.81
Province		
Sindh (Dummy)	0.02**	2.12
KPK (Dummy)	−0.04*	−1.76
Balochistan (Dummy)	0.02	1.38
Constant	0.02***	2.59
Initial sample size 950		
Final sample size 641		
Value of R-square 0.372		

Note: In parenthesis t-values are reported. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

Table 5
Impact of climate change on household food security and poverty levels (PSM estimates).

Matching algorithm	# of strategies	Outcome	ATT	t-values	Critical level of hidden bias	Number of treated	Number of control
NNM	1	Food Security	0.07*	1.66	1.20–1.25	410	432
NNM		Poverty	−0.02*	−1.72	1.50–1.55	419	362
KBM		Food Security	0.08**	2.31	1.10–1.15	510	418
KBM		Poverty	−0.03***	−3.02	1.25–1.30	486	473
NNM	2	Food Security	0.09**	2.15	1.80–1.85	364	403
NNM		Poverty	−0.03*	−1.67	1.30–1.35	375	417
KBM		Food Security	0.08***	2.54	1.40–1.45	501	463
KBM		Poverty	−0.05***	−2.72	1.30–1.35	477	352
NNM	3	Food Security	0.12**	2.31	1.25–1.30	415	372
NNM		Poverty	−0.06**	−1.96	1.05–1.10	436	459
KBM		Food Security	0.14***	2.58	1.20–1.25	474	381
KBM		Poverty	−0.08***	−3.16	1.30–1.35	462	721

Note: ATT stands for the average treatment affect for the treated. NNM stands for the nearest neighbor matching and KBM stands for the kernel-based matching. The results are significant at ***, **, * 1%, 5% and 10% levels respectively.

5.2.4. Non-land assets and income

Car ownership, livestock ownership and income all are positively associated with the number of adaptation practices used. Ownership of other non-land but agricultural assets (tractors, tube wells) is not to common nor associated with the number of adaptation practices used.

5.2.5. Access to services

Access to infrastructure and services are critical for accessing materials and knowledge and expected to play a major role in adoption of technology including the adaptation options by the smallholder farmers. Access to credit, extension services and organizational membership all are positively associated with the number of adaptation practices used, which aligns with other studies on technology adoption, adaptation and development.

5.2.6. Location

The provincial dummy's again indicate significant regional effects. With Punjab being the base for the model, Sindh has a positive effect on the number of practices used whereas KPK has a negative effect and Baluchistan proved non-significant.

5.3. Impact of adaptation methods on household food security and poverty

Table 5 presents the impacts of the number of adaptation methods used on household food security and poverty levels based on propensity score matching. Farmers who adopt one adaptation strategy have higher food security levels (7–8%) and

Table 6
Indicators of covariate balancing (before and after matching).

Matching algorithm	# of strategies	Outcome	Median absolute bias – before matching	Median absolute bias – after matching	% bias reduction	Value of R^2- before matching	Value of R^2 – after match-ing	Joint significance of covariates before matching	Joint significance of covariates after matching
NNM	1	Food Security	17.40	4.28	75.4	0.416	0.001	0.001	0.364
NNM		Poverty	19.16	5.13	73.2	0.372	0.002	0.000	0.347
KBM		Food Security	20.43	6.17	69.7	0.268	0.001	0.002	0.392
KBM		Poverty	21.50	5.29	75.3	0.519	0.003	0.001	0.260
NNM	2	Food Security	18.24	4.33	76.2	0.350	0.001	0.003	0.413
NNM		Poverty	19.17	5.04	73.7	0.284	0.004	0.000	0.527
KBM		Food Security	24.50	6.32	74.2	0.365	0.005	0.001	0.632
KBM		Poverty	22.81	5.21	77.1	0.269	0.001	0.002	0.513
NNM	3	Food Security	19.25	4.78	75.1	0.308	0.001	0.003	0.417
NNM		Poverty	15.36	5.24	65.8	0.221	0.002	0.001	0.513
KBM		Food Security	23.57	6.23	73.5	0.206	0.003	0.001	0.275
KBM		Poverty	22.43	4.17	74.1	0.316	0.003	0.002	0.194

Note: NNM stands for the nearest neighbor matching and KBM stands for the kernel-based matching.

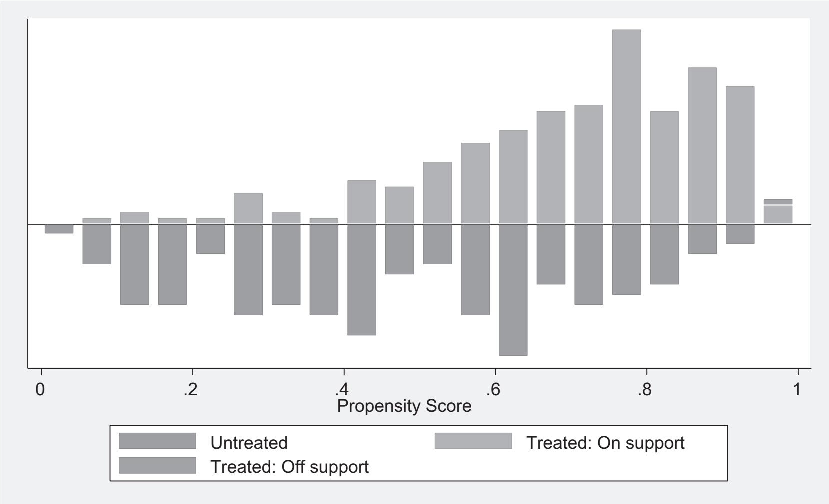

Fig. 1. Propensity score matching estimates.

lower poverty levels (2–3%) compared to those that have not adopted, both in nearest neighbor matching (NNM) and kernel-based matching (KBM).

Similarly, in both NNM and KBM, if the household adopts two adaptation practices the food security levels are higher (8–9%) and the poverty levels lower (3–5%) compared to farmers who have not adopted any adaptation strategy. If the household use three adaptation practices the food security levels are even higher (12–14%) and the poverty levels are even lower (6–8%) in NNM and KBM. These results have important policy implications. First, it highlights that adaptation practices help to enhance the food security of rural households and help to reduce rural poverty. Second, it highlights that households should be encouraged to adopt a number of adaptation practices so as to increase food security and reduce poverty. Households not using adaptation practices are more food insecure and poorer. The critical level of hidden bias is also reported in Table 5. The critical level of hidden bias indicates the level up to which the adopters and non-adopters differ in their odds of adoption.

Table 6 presents the balancing tests for the PSM. Before matching, the bias is quite high (15–24) and after matching reduced to 4–6. The percentage bias reduction is 69–76%. The R^2 is quite high before matching and is quite low after matching indicating that after matching they are quite similar are to each other. The p-value of joint significance of covariates indicates that before matching there are systematic differences between the adopters and non-adopters, and after matching the adopters and non-adopters are quite similar to each other. The indicators of covariates balancing are presented in Fig. 1 and indicate the imposition of the common support condition and the balancing of covariates before and after matching.

6. Conclusion

We examined the factors influencing the choice of climate-change adaptation practices and associated impacts on household food security and poverty in Pakistan. Farmers in Pakistan are using a variety of adaptation practices to counter the adverse impacts of climate change. Our survey of 950 farmers across four major provinces of Pakistan (Punjab, Khyber Pakhtunkhwa (KPK), Sindh and Balochistan) in 2014 found 22% of the households to have made sowing time adjustments, 15% have adopted drought tolerant varieties, and 25% have made shifted to new crops. Various factors are influencing the choice of climate-change coping strategies in Pakistan. A multivariate probit estimation was used to investigate the determinants of choice of climate-change adaptation strategies, and a censored least absolute deviation (CLAD) was used to understand the determinants of the number of climate-change coping strategies. The propensity score matching approach was employed to analyze the impact of coping strategies on food security and poverty levels.

Given the positive relation between climate-change adaptation strategy and food security, and the negative association between climate-change adaptation strategies and poverty levels indicated by the propensity score matching, there is scope for policy to further promote the adoption of climate-change adaptation strategies. The results of the multivariate probit estimation on the determinants of farmers' adaptation methods to climate change revealed some interesting facts, which are unique in the context of Pakistan and also have significant policy implications. Firstly the results highlight the importance of awareness and knowledge about the local context, climate change, adaptation strategies and its benefits. Secondly, the result points to the importance of wealth on the ability of the farm households to invest in climate risk coping strategies. Hence, policy should focus on two aspects: (i) increasing the awareness of climate change and climate risk coping strategies and its benefits; and (ii) increasing the affordability of climate risk coping capacity by augmenting the farm household assets and lowering the cost of adaptation. Policy on increasing the awareness should focus on increasing access to education and agricultural extension services. Policy on enhancing the accessibility of the climate risk coping strategies should focus on increasing the endowments for instance through access to services and alternative livelihoods, and providing support to especially the poorer households.

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