Impact of Farm Households' Adaptations to Climate Change on Food Security: Evidence from Different Agro-ecologies of Pakistan

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ABSTRACT

The study used data from 3298 food crop growers in Pakistan. Potential Outcome Treatment Effects Model was applied to evaluate the impact of adaptations on household food security. A household Food Security Index (FSI) was constructed applying PCA. Adaptation strategies employed by the farmers in response to climate change were categorised into four groups namely: changes in sowing time (C1); input intensification (C2); water and soil conservation (C3); and changes in varieties (C4). Out of 15 mutually exclusive combinations constructed for evaluation, only 7 combinations were considered for estimating the treatment effects models because of limited number of observations in other cases. Results of only two of the 7 are discussed in the paper, as the other 5 had very small number of adapters and the impact measures shown either insignificant results or had opposite signs. The first (C1234) combined all the four while the second (C234) combined the last three strategies. The results suggest that the households which adapted to climate changes were statistically significantly more food secure as compared to those who did not adapt. The results further show that education of the male and female heads, livestock ownership, the structure of house—both bricked and having electricity facility, crops diversification, and non-farm income are among the factors which raise the food security of farm households and their impacts are statistically significant. The variables which are significantly negatively associated with the food security levels include age of the head of household, food expenditure management, households having less than 12.5 acres of land—defined as marginal (cultivate <6.25 acres) and small (cultivate >6.25 to ≤12.5 acres). Farmers of cotton-wheat, rice-wheat, and rain-fed cropping systems are found to be more food secure as compared to the farmers working in the mixed cropping systems where farm holdings are relatively small and high use of tube-well water adding to salinity of soils. It is crucial to invest in the development of agricultural technological packages addressing issues of climate change relevant to different ecologies and farming systems; improve research-extension-farmer linkages; enhance farmers' access to new technologies; improve rural infrastructure; development of weather information system linking meteorological department, extension and farmers; and establishment of targeted food safety nets as well as farm subsidy programs for marginal farm households.

Keywords: Adaptation to Climate Change, Food Security and Treatment Effects Model

1. INTRODUCTION

> *"The impacts of global climate change on food systems are expected to be widespread, complex, geographically and temporally variable, and profoundly influenced by socio-economic conditions"* [Vermeulen, *et al*. (2012) p. 195].

The research evidence shows that climate change has direct and devastating impacts on agriculture sector since it heavily relies on climatic variations [Parry, *et al*. (1999)]. The intensity of the impact depends on the current levels of temperature and/or precipitation patterns and the biological tolerance limits for crops, per capita income, the proportion of economic activities linked to agriculture and the existing land use pattern [Benhin (2006)]. The impact of even a single climate- or weather-related event could ruin the long-term gains in the economic development (FAO, 2008). Cereal crops production are already under heat stress in South Asia [Kelkar and Bhadwal (2007)]. Therefore, the crops yields could decline up to even 30 percent by the end of this century [IPCC (2007)]. Production of these crops is an important component of food security[1] in the region. One of the major challenges this region would be facing in the coming decades is assuring food security to rapidly increasing population—and Pakistan is no exception. With the current rate of growth, the population of Pakistan is expected to get doubled by 2050—making it the 4th largest nation by 2050 from the current status of 6th most populous state of the world [Ahmad and Farooq (2010)].

Pakistan, like other developing countries, is highly vulnerable to climate change because of its growing dependence on agriculture for food and fiber needs. Additionally, the agriculture sector of Pakistan is dominated by the small resource-poor farmers having very little ability to adapt. Climate change is expected to reduce the growing season length for major cereals in all major agro-ecological zones of Pakistan [Iqbal, *et al*. (2009a; and 2009b)]. As a result, the yields could decline by 6–11 percent of wheat and 15–18 percent of basmati rice by 2080, which are the main cereals being produced in the country. A more recent

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[1]The World Food Summit in 1996 defined the term as "food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life". This definition embodies five aspects: availability, access, stability, nutritional status and preferences of food. All of these components are influenced by physical, economic, political and other conditions within communities and even within households, and are often destabilised by climatic shocks and natural disasters such as the conflicts [UK Parliament (2006)].

study estimated that every 1^0C increase in temperature only during the November and December—the sowing months would result in reduced yield of wheat by 7.4 percent [Ahmad, *et al*. (2014)]. Another study also indicates a significant negative impact of rise in temperature on both basmati and coarse rice [Ahmad, *et al*. (2014a)].

The history shows that despite all efforts made by the government of Pakistan through investing in R&D and policy interventions to enhance food supply in the country to meet the burgeoning demand, it remained net importer of food commodities in most of years during the last couple of decades. Since the climate change has emerged as a new threat to the ecosystem in general and agriculture sector in particular, the food security situation is expected to get worsen in the presence of rapidly growing population in future. To avoid any potential major disruption in food supply and to check the widening food supply-demand gap, coordinated efforts are needed in the country on long term basis to develop a vibrant research system to get over the potential future threats of climate change. Besides developing high-tech technologies to raise the agricultural productivity and reduce post-harvest losses throughout the commodity value chain, efforts are essential to limit the population growth as well.

To effectively deal with the potential threats to food system in future, it is critical to analyse its linkages with the changing climate. It has however been argued that the quantification of the impacts of climate change on food security is a very challenging task because of complexity of the relationship between climatic, economic, social and political factors with the food security [IPCC (2013); Ziervogel, *et al.* (2006)]. The empirical studies analysing the subject that directly relates climate change to food security are therefore rarely found in the literature. Since agriculture is a major source of income for most of the rural population, adaptation of this sector to the changing climate is essential to protect the livelihoods of the poor and to ensure food security [Elizabeth, *et al.* (2009); Bradshaw, *et al*. (2004); Wang, *et al*. (2009)].

The adverse impacts of climate change on agriculture can be dealt with two ways—mitigation and adaptation strategies. Mitigation refers to interventions or policies to reduce or to enhance the sinks for greenhouse gases, and is a long-term solution to tackle climate change and limiting its negative impacts in the future [Chambwera and Stage (2010)]. Considerable efforts and resources are required as well as cooperation from those countries which are the source of cause and are resourceful—the developed world. The developing countries like Pakistan, however, face difficulties as they are short of resources and lack appropriate infrastructure to efficiently and effectively employ mitigating strategies. It has been argued that despite immediate employment of mitigation strategies, the earth's warming up will continue for decades to come since these strategies do not have abilities to reverse impacts of the past, current and/or of unavoidable emissions in future [IPCC (2007); Chambwera and Stage (2010)]. Therefore, the looming threats can only be tackled through adaptation, which is a shorter term action to cope with the potential adverse impacts of changing climate on agricultural production and to reduce the risk of various key vulnerabilities on human and natural systems as well as on food security [OECD (2009); Mendelsohn and Dinar (1999); Schneider, *et al*. (2007); Gebrehiwot and van der Veen (2013); Chambwera and Stage (2010)]. The adaptation is therefore one of the fundamental policy options to moderate the impacts of climate change [Adger, *et al*. (2003); Kurukulasuriya and Mendelsohn (2008)]. The non-adjustment of agricultural systems and practices will hit hard the farming community particularly in developing countries—affecting farm productivity as well as income, food and livelihoods security [Kandlinkar and Risbey (2000); and Hassan and Nhemachena (2008)].

Adaptation is essentially an adjustment in human and/or natural systems to deal with the impacts of actual or expected changes in climate [IPCC (2001); Adger, *et al*. (2003); FAO (2008)]. The common adaptations in agriculture include shifting planting date, changing crop varieties, switching crops, expanding area, changing irrigation, diversifying income and crops, mixed crop livestock farming systems, and migrating etc. [Burke and Lobell (2010); Bradshaw, *et al*. (2004); Kurukulasuriya and Mendelsohn (2006); Nhemachena and Hassan (2007)]. The findings of some of the empirical studies suggest that household characteristics, household resource endowments, access to information and finances influence the probability of adaptation strategies [Maddison (2007); Nhemachena and Hassan (2008)].

There is no dearth of literature that links the performance of agriculture with the climate change using variant methodologies. However, there is paucity of empirical work that documents the link between farm households' food security and adaptation strategies to climate change. Majority of the studies like Maddison (2007), Nhemachena and Hassan (2007), Hassan and Nhemachena (2008), Yesuf, *et al.* (2008), Seo and Mendelsohn (2008), Gbetibouo (2009), Deressa, *et al.* (2009), Debalke (2011), Nabkolo, *et al*. (2012), Legesse, *et al.* (2013), Kurukulasuriya and Mendelsohn (2008), Di Falco (2014) dealt with adaptations and their effects on agriculture and food productivity in Africa. Some work, like Esham and Garforth (2013) has however been done on Asia. Two studies are found analysing the relationship between adaptations and food security: Di Falco, *et al*. (2011) examined the effects of adaptations to climate change on wheat productivity and its implications for food security in Ethiopia; and Demeke, *et al*. (2011) analysed the impact of rainfall shocks on food security and vulnerability of rural households in Ethiopia. None of these studies looked at how the adaptations to climate change directly influence the rural households' food security—which is not simply food supply/production. A recent study by Pangapanga, *et al*. (2012) has however tried to examine the impacts of droughts and floods adaptations on household crop production and food security in Malawi.

This study assumes that a household is considered to be food insecure if food grains *'availability'* per person per year is less than 300kgs. As such the study ignores the other components of food security as well as the endogeneity of the adaptations of agriculture to climate change.

The present study fills this gap by syndicating Demeke, *et al*. (2011) and Di Falco, *et al*. (2011) approaches and apply Treatment Effects approach to evaluate the impact of adaptations on household food security. This approach involves estimating three equations simultaneously: a selection/treatment equation involving a dichotomous adaptation variable as a dependent, and two outcome equations where a household Food Security Index (FSI) is considered as dependent variable. Following Demeke, *et al*. (2011), (FSI) is generated, comprising various factors such as size of landholdings, production of food grains, food grains received as assistance, improved food storage capacity, per capita food consumption, farm as well as household assets and access to toilet facility, by applying Principle Component Analysis (PCA). The farm-level adaptation strategies identified include adjusting sowing time, inputs intensification, water and soil conservation and adopting longer and/or shorter duration varieties (Details in Section 4.1) .

The remaining paper is organised as follows. Section 2 provides the details of the data, methodological framework and empirical model. Section 3 presents the empirical model and estimation strategy followed by Section 4 that describes the construction of variables used in the study. The results and discussion is given in Section 5. The last section concludes the paper.

2. DATA AND METHODOLOGICAL FRAMEWORK

2.1. Data

We used the data from 'Climate Change Impact Survey [CCIS (2013)]' conducted by the Pakistan Institute of Development Economics (PIDE), Islamabad, sponsored by the International Development Research Centre (IDRC). This survey was conducted for the cropping year 2012-13. Survey schedules were developed to record the household and village level information. For this three well-designed questionnaires—one each for male[2] and female[3] respondents of the

[2]The questionnaire for males encompasses information regarding household profile and farm characteristics; cropping patterns; crop production practices; and climate change related questions covering farmers' perceptions about climate change ant its impact on crop production, and adaptations and copping strategies adopted by them to mitigate the adverse effects of climate change.

[3]The survey schedule for females covers information regarding family size and composition; education and employment status of family members; extent of participation of each (working-age) member in farm and non-farm activities and income earned; information on housing and sanitation; ownership of durables; quantity of various items consumed and expenditures involved; livestock ownership and milk production; and climate related questions including their perception about climate change and its impact on human lives and copping strategies adopted.

same household, and one village-questionnaire was used to obtain village profile[4]. Before the implementation of the survey, intensive training was imparted to enumerators and supervisors. The questionnaires were revised in the light of discussions, comments and suggestions made during training sessions as well as keeping in view the feedback received after pretesting.

The Universe for this study comprises agricultural households from rural areas of Punjab, Sindh and KP provinces. The agriculture practices and cropping patterns differ within provincial boundaries depending on variations in agro climatic conditions in different parts of each province. Each province has distinct agro climatic zones[5] and each of these zones is more or less homogeneous in terms of agricultural practices, mix of crops grown, and in other agricultural respects. The agro climatic zones within a province have been treated as strata for subsequent selection of districts/villages/ households for the survey.

The sample size of any survey depends upon the size of population being studied, variability of characteristics in the population being measured, desired precision level in the estimates and the financial resources available to conduct the survey. Most of the household characteristics to be measured and information to be collected in this Survey have already been covered in a number of other household surveys carried out in the past[6]. Based on the past experience, a sample size of 3432 farm households has been determined in such a way that the district/agro climatic zone/provincial level estimates could be developed.

In all 16 districts—8 from Punjab and 4 from each of Sindh and KP provinces were selected in such a way that all agro climatic zones in each province are duly represented in the sample. From each sampled district, 12 villages were selected randomly and from each selected village, 18 farm households were interviewed; thus giving a total sample of over 200 farm households in each district — a sample size capable of producing reliable estimates even at district level[7]. The sample selected represents various categories of farms—by size and tenancy, cropping patterns, and variations in agro climatic conditions/issues. In order to save the financial and time costs, instead of selecting sample farm

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[4]Contains information like geographical area of the village and cultivated land, composition of farms by size and tenancy, population, village infrastructure, over time change in village level cropping patterns, input prices and village standard regarding usage rates of selected input/services, land values and rents by status of land fertility, and common diseases in the area etc.

[5]Punjab includes Rice-Wheat, Cotton-Wheat, Mixed, Barani (rain-fed), and Partial Barani; Sindh includes Rice-Wheat, Cotton-Wheat, and Mixed; and KP incudes Wheat-Mix, and Maize-Wheat.

[6]Including Pakistan Social and Living Standard Measurement (PSLM) Survey and Pakistan Panel Rural Household Surveys etc. The Panel Household survey-rural part produced reliable estimates with a sample size less of than 3000 households.

[7] In district level surveys such as PSLM and Multiple Indicator Cluster Survey (MICS) respectively conducted by Pakistan Bureau of Statistics (PBS) and provincial governments, a minimum sample of 200 households has been adopted. These surveys covered urban as well as rural populations within a district whereas this study covers only rural agricultural households.

household in selected districts by listing down all the farm households in the districts and then selecting 200 farm households through random procedure, twelve villages were selected randomly in each of the sampled district and then 18 farm households were selected from each village.

In total, 3298 farm households, out of sample size of 3432, were selected for the analysis of this study. These households were found growing any or all of major food crops—wheat, rice, and maize. The village level climate related variables—temperature and precipitation were generated through ECHAM5 GCM using Grid Analysis and Display System (GrADS) software using village level observations of latitude and longitude recorded by the survey team through GPS.

2.2. Conceptual Framework

History of the concept of food security goes back to the Universal Declaration of Human Rights in 1948 when the right to food was acknowledged as an essential component of human wellbeing. It was the world food crisis of 1972–1974 when the issue of food (in) security attracted colossal attention of the researchers and policy makers. The concept continued to develop and refined overtime and the scholars advanced numerous definitions and voluminous indicators of food security to bring more clarity in the subject [Ahmad and Farooq (2010)]. The most accepted definition of food security is that it is a situation "when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life" [FAO (1996)]. This definition imbeds five fundamental aspects including availability, access, stability, nutritional status and preferences of food. These components are influenced by physical, economic, political and other conditions under which the communities live in. The conditions even vary within households, and are often destabilised by climate shocks and other natural disasters and conflicts.

The first aspect, 'availability', refers to sufficient quantities of quality/nutritious food available to every individual/household in a given country through any means—production, imports, or food aid etc. The second component 'access' involves both physical access—where food is available, and economic access—entitlement to food [Sen (1982)]. The former involves efficient market infrastructure to have access of people at low cost. The entitlement can be ensured either by own production or having food buying capacity or having access/right to other sources of getting desired food [Timmer (2000); Staaz, *et al*. (2009)]. Only the availability of sufficient food at country/local level does not guarantee that all people are food secure—since low incomes, lack of roads and infrastructure could limit access to desired quantities of quality food [Ahmad and Farooq (2010)]. Therefore, both availability and access parts of food security are inseparably inter-linked [Pinstrup-Andersen (2009)].

The third component is 'stability' that concerns with reliable supply of nutritious food at the national/household/individuals levels. Besides availability of food, stability requires better management of domestic production, food markets integration, and rational use of buffer stocks and trade [FAO (2002)]. The definition of food security also alludes to a fourth element which is safe and nutritious food that is required for an active and healthy life. Therefore, the human body has to effectively utilise the available nutrients in the food consumed [Staaz, *et al*. (2009)]. This aspect is influenced directly by food preparation and health conditions of an individual—influenced by sanitation, clean drinking water and proper food storage, processing and basic nutrition. The last element of the food security is the 'preferences' for food that relates to the social and religious norms. People with equal access to food but having different food preferences based on religion, society norms, taste etc. could reveal totally a different nature of food security. Therefore, the foods are to be socially and culturally acceptable and consistent with religious and ethical values [Pinstrup-Andersen (2009)]. The fifth components of food security has not been taken up in the analysis because of the data limitations.

Food security is a complex matter and is not directly observable [Demeke, *et al*. (2011)]. However, its multiple dimensions can be captured using various indicators. Given the data set, we will be able to capture first four elements—availability, access stability and utilisation. Following Qureshi (2007) and Demeke, *et al*. (2011), we identified various indicators of food security including size of operational landholding, production of major food crops—wheat, rice, and maize, food crops diversification—vegetables, pulses and fruits, food grains received as assistance, food storage facility, per capita food consumption, farm as well as household assets, and access to toilets. The size of operational land holding, production of major food crops on the farm, per capita consumption of food and farm household assets represent two important elements that are availability and access to food. Having food storage facility indicates stability in the supply of food at the household level—also shows the capacity of the household to cope with any unanticipated food crisis like situation [Demeke, *et al*. (2011); Haddad, *et al*. (1994)]. Farm diversification towards fruits, vegetables and pulses is suggestive of dietary diversity which also reflects nutritional quality of the food consumed by the households [Demeke, *et al*. (2011)]. The type of toilet facility implies the level of hygiene and sanitary situation of the household which is associated with health status of its members. Using these food security indicators, we construct an aggregate Food Security Index (FSI) using a Principal Component Analysis (PCA)—the detailed methodology is given in the next section.

The next question is that what influences farm level household food security. The previous empirical literature indicates that the likelihood of food security is influenced by household level conditions (H) including education, health, harvest, household assets, expenses, regional conditions (D)—infrastructure, markets, enabling institutions, and climate, and adaptation strategies to moderate the impacts of climate change (A). Keeping in view the determinants, the empirical food security model can be written:

$$FSI=f(H, D, M) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Where FSI is food security index, H represents vector of household characteristics, D denotes the vector of regional variables—dummy variables (bivariate) will be generated to represent a particular region/cropping system/climatic zone, and M denotes the vector of adaptation strategies adapted at the farm.

As discussed earlier, the climate change poses significant threats to the agriculture sector and thus food security. The adaptation to climate change is of therefore fundamental importance in moderating these impacts. For devising appropriate adaptation policies and effective development projects, it is important to understand the role of the different factors that influence farmers' adaptation [Di Falco (2014); Gebrehiwot and van der Veen (2013)]. There are different ways to adapting to climate change in agriculture [Deressa, *et al.* (2011)]. These adaptations are affected by different factors [Nhemachena and Hassan (2007); Deressa, *et al.* (2011)]. Studies have shown that factors like education of the head of household, household size, gender of the head, livestock ownership, use of agricultural extension services, access to agricultural credit, climate indicators—temperature and precipitation, farm assets, information about technology/ adaptations, etc. affect adaptation to climate change [Deressa, *et al.* (2011); Hassan and Nhemachena (2008); Gebrehiwot and van der Veen (2013)].

2.3. Construction of Food Security Index (FSI)

Food security index is generated using nine indicators including size of operational landholding, production of major food crops—wheat, rice, and maize, food crops diversification—vegetables, pulses and fruits, food grains received as assistance, food storage facility, per capita food consumption, farm as well as household assets and access to toilet facility (see Table 1). Following Qureshi (2007), FSI is constructed by applying Principal Component Analysis (PCA). The PCA is a statistical procedure that linearly transforms the selected indicator variables of food security into smaller components that account for most of the variation in the original indicators [Dunteman (1994); Demeke, *et al.* (2011)]. Assuming there are *n* indicators/variables which are likely to be correlated (X_1, X_2 $X_3, \ldots, X_n$). The PCA technique has the ability to limit the indicators to only those which capture the maximum variation and also has the advantage of creating uncorrelated components whereby each component is a linear weighted combination of the initial variables [Demeke, *et al.* (2011)]. This can be written as:

$$PC_1 = a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + \ldots + a_{1n} X_n \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

$$PC_m = a_{m1}X_1 + a_{m2}X_2 + a_{m3}X_3 + \ldots + a_{mn} X_n$$

where a_{mn} represents the weight for the mth principal component and the nth variable (X_n). The PCA will result into a series of components with the first component explaining the largest variance in the data and each of the following components explains additional but smaller proportion of the variance in the original variables—subject to the constraint that sum of the squared weights ($a_1^2 + a_2^2 + a_3^2 + \ldots\ldots + a_p^2$) is equal to one [Demeke, *et al.* (2011)]. Once the components of the PCA are identified, the Food Security Index (FCA) can be derived for each household as follows:

$$FSI_j = \sum F_i [(X_{ji} - X_i)/S_i]$$

Where FSI_j is the Food Security Index that follows a normal distribution with a mean of 0 and a standard deviation of 1, F_i is the weight for the ith variable in the PCA model. X_{ji} is the jth household's value for the ith variable, and X_i and S_i are the mean and standard deviations of the ith variable.

Table 1

Indicators of Food Security

Indicators of Food Security	Units
Operational land	Acres
Production of major food crops i.e. wheat, rice, and maize	Mounds (40kgs)
Food crops diversification (i.e. vegetables, pulses, fruits)	Dummy variable (0/1)
Having improved food storage capacity	Dummy variable (0/1)
Attaining any food assistance during food shortage/shock	Dummy variable (0/1)
Per capita food consumption	Kgs
Farm assets (i.e. tractors, threshers, plough etc.)	Dummy variable (0/1)
Domestic assets (i.e. fridge, TV, motorcycle, etc.)	Dummy variable (0/1)
Does household has toilet facility	Dummy variable (0/1)

Source of Data: Climate Change Impact Survey [CCIS (2013)].

3. ECONOMETRIC MODEL AND ESTIMATION STRATEGY

3.1. Methodological Framework

There is no dearth of empirical literature that analyses the determinants of adaptations to climate change including Maddison (2007), Gbetibouo (2009), Deressa, *et al.* (2009), Debalke (2011), Ngigi, *et al.* (2012), Legesse, *et al.* (2013), Esham and Garforth (2013), Sanga, *et al*. (2013). Kurukulasuriya and Mendelsohn (2008); Hassan and Nhemachena (2008); Mary and Majule (2009); Deressa and Hassan (2010); Babatunde and Qaim (2010); Nhemachena, *et al*. (2014), Apata, *et al.* (2010), Afangideh, *et al.* (2012), Kansiime, *et al.* (2014), Gebrehiwot and van der Veen (2013) and Balew, *et al*. (2014). The estimation techniques used by these studies are also diverse including instrumental variable approach, conventional Heckman two step selection model, bivariate and multinomial Logit/Probit models.

Various published studies are found on analysing the impact of adaption of new technologies on food productivity and food security. However, the very recent examples include Di Falco, *et al*. (2011), Demeke, *et al.* (2011) and Shiferaw, *et al.* (2014). Di Falco, *et al*. (2011) examined the impact of adaptations on wheat productivity and its consequent implications for food security. This study applied two step endogenous regression technique and found that adaptations to climate positively and statistically significantly influenced wheat productivity that in turn would help achieve household food security. Demeke, *et al.* (2011) using farm household level panel data from rural Ethiopia examined the impact of rainfall shocks on household's food security. This study constructed a time variant Food Security Index (FSI) using various combinations of food security indicators and applying Principal Component Analysis (PCA). Based on FSI, the households were classified into relative food security groups and their determinants were assessed using fixed effects instrumental variable regression procedure. The paper highlighted the critical role of rainfall variability in households' food security among some other factors. Shiferaw, *et al.* (2014) investigated the impact of adoption of improved wheat varieties on food security in Ethiopia. The study used endogenous switching regression treatment effect model, binary and general propensity score matching approaches and found consistent results across models indicating that adaption of modern varieties increased food security. The common element in all of these studies and the present study is the farm household survey data to achieve a major objective of evaluating the impact of climate change/adaptation to climate change on farm household food security.

Evaluating just impact requires that the exposure to adaptation strategies (treatment) should be randomly assigned and the influence of observable and unobservable characteristics between the treatment and control groups is the same which would lead to differential impact attributable entirely to the treatment [Shiferaw, *et al.* (2014)]. The data used in the present study to analyse the impact of adaptation strategies to climate change (treatment) on food security relates to farm level households survey where the treatment groups are not randomly assigned. In the present study, we are interested in evaluating the impact of treatment on the outcome variable—household food security. The objective here, therefore, is to find three measurements. First, the Average Treatment Effect (ATE), Average Treatment Effect on the Treated (ATET), and Potential Outcome Means (POMs). In binary-treatment (t) case, where t=1 when an individual i gets the treatment otherwise t=0, two respective potential outcomes for an individual can be denoted as y_{i1} and y_{i0}. y_{i1} and y_{i0} are actually the realisations of the random variables—y_1 and y_0, respectively. Given these notations, the parameters of interest can be defined as follows.

(1) ATE is the average effect of treatment in the population—which is expressed as ATE = E(y_{1i} - y_{0i}); where E[.] stand for expected value, y_1 is the outcome (the level of food security index) if the strategy adopted and y_0 is the outcome for the same household in the absence of adaptation.
(2) ATET is the average treatment effects of those who actually received the treatment (t=1) and is written as $ATET = E(y_{1i} - y_{0i} \mid t=1)$.
(3) POM_t is the average potential outcome for the treatment level t and is expressed as $POM_t = E(y_t)$.

3.2. Empirical Techniques and Estimation Strategy

The technique used in the analysis of the present study forms part of the counterfactual framework developed by Rubin (1974) which was pursued to evaluate causation in both observational and experimental studies [cited in Henderson, *et al*. (2014)]. The major problem of causal inference is that how to know about the counterfactual–what would have happened had they been not treated, and what would have happened if non-treated is exposed to the treatment. The statistical method named 'treatment effects' can be used to overcome this problem. We get the doubly-robust inverse-probability-weighted regression-adjusted results (IPWRA), that combines weighting and a regression estimator [Imbens and Wooldridge (2009); cited in Henderson, *et al*. (2014)]. The IPWRA overcomes the fundamental issue of causal inference by identifying the effect of a particular treatment—adaptation strategy, by directly finding the actual value of the treatment and a counterfactual measure.

In order to implement the 'treatment effects' model using inverse-probability weighted regression adjusted (IPWRA) technique, we stipulate the potential outcome model that specifies the observed outcome variable y_i is y_{0i} when t=0, and y_{1i} when t=1. Mathematically, we can express this as $y_i = (1-t)y_{0i} + ty_{1i}$. The outcome functions—outcome model, conditional on adaptation, can be written as

$$y_0 = x\beta_0 + \varepsilon_{0i} \qquad if\ t = 0 \qquad \ldots \quad \ldots \quad \ldots \quad (1)$$

$$y_1 = x\beta_1 + \varepsilon_{1i} \qquad if\ t = 1 \qquad \ldots \quad \ldots \quad \ldots \quad (2)$$

Where y_1 and y_0 are outcome variables representing Food Security Index (FSI) for adapters and non-adapters, respectively; x represents a vector of covariates, and β represents the parameters to be estimated. The ε_1 and ε_0 are error terms that are not related to x. The potential outcome model proposed above separates each potential outcome into a predictable component, $x\beta_t$, and an unobservable ε_t.

The treatment assignment process is written as

$$t = \begin{cases} 1, if\ z\gamma + \eta > 0 \\ 0 \text{ otherwise} \end{cases} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

where γ is a vector of unknown coefficients to be estimated, and *z* represents a vector of covariates. The η is an unobservable error term that is not related to either x or *z*. The treatment assignment process is separated into a predictable component of $z_i \gamma$ and an unobservable error term η.

It is important to state here that y_i, t_i, z_i and x_i are the variables which are observed, while the data do not provide information on both y_{0i} and y_{1i} for any given *i*, while the model for *t* determines how the data on y_0 and y_1 are missing. To estimate the model given in Equations 1 and 2, we used '*teffects ipwra'* command in STATA 13. This command provides *doubly robust estimators.* These estimators have remarkable property that though the estimation involves two models, only one of the two requires to be specified correctly in order to get correct estimates from the whole system of equations. This technique requires certain assumptions, such as [Bördős, Csillag, and Scharle (n.d.)]:

(1) *Unconfoundedness* criterion, which indicates that the potential outcomes of the treated and untreated do not depend on treatment if conditioned on the covariates. It implies that unobserved shocks that affect, whether a subject is treated, do not affect the potential outcomes, and unobserved shocks that affect potential outcome has no impact on treatment. This is a reasonable assumption given our objective and the nature of study. The objective variable, i.e. Food Security Index (FSI), is constructed using nine household level indicators—food security is not simply the household food production or availability which forms only the one constituent indicator of multidimensional food security. This assumption facilitates estimation technique that combines regression adjustment (RA) and inverse probability-weighting (IPW) methods. The data only reveal information about $E(y_0|x, z, t = 0)$ and $E(y_1|x, z, t = 1)$, but we are interested in an average of $E(y_0|x, z)$ and $E(y_1|x, z)$, where *x* represents the outcome covariates and *z* the treatment-assignment covariates. This assumption allows us to estimate $E(y_0|x, z)$ and $E(y_1|x, z)$ directly from the observations for which $E(y_0|x,z,t=0)$ and $E(y_1|x,z,t=1)$, respectively.

(2) The overlap assumption states that each individual has a positive probability of receiving each treatment level—we can match treated subjects with similar non-treated subjects to have accurate estimate of the counterfactual.

(3) The independent and identically distributed, *iid*, sampling assumption—that the potential outcome and the treatment status of each individual are unrelated to the potential outcomes and treatment statuses of all other individuals in the population.

To estimate the potential outcome model presented in Equations 1 to 3, the first assumption imposes a set restrictions on the covariance matrix of the error terms—ε_0 , ε_1 and η. Assume having normal distribution:

$$\begin{pmatrix} \varepsilon_0 \\ \varepsilon_1 \\ \eta \end{pmatrix} \sim \mathrm{N}\left\{ \begin{pmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix}, \begin{pmatrix} \sigma_0^2 & \rho_{01}\sigma_0\sigma_1 & \rho_{\eta^0}\sigma_0 \\ \rho_{01}\sigma_0\sigma_1 & \sigma_1^2 & \rho_{\eta^1}\sigma_1 \\ \rho_{\eta^0}\sigma_0 & \rho_{\eta^1}\sigma_1 & 1 \end{pmatrix} \right\} \quad \ldots \quad \ldots \quad (4)$$

where σ_0 and σ_1 are standard deviations of ε_0 and ε_1, respectively, $\rho_{01}$is the correlation between ε_0 and ε_1, ρ_{η^0} is the correlation between η and ε_0 and ρ_{η^1} is the correlation between η and ε_1. In the normally distributed latent variable specification of a binary dependent variable, variance of η is normalized to 1. Since the CI assumption specifies that $\rho_{\eta^0} = \rho_{\eta^1} = 0$, the expression in 4 can be written as:

$$\begin{pmatrix} \varepsilon_0 \\ \varepsilon_1 \\ \eta \end{pmatrix} \sim \mathrm{N}\left\{ \begin{pmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix}, \begin{pmatrix} \sigma_0^2 & \rho_{01}\sigma_0\sigma_1 & 0 \\ \rho_{01}\sigma_0\sigma_1 & \sigma_1^2 & 0 \\ 0 & 0 & 1 \end{pmatrix} \right\}$$

The above covariance matrix highlights the fact that unobserved shocks influence treatment assignment expression but not the potential outcomes.

The *teffects* can yield various estimators: estimators based on outcome variables; based on treatment assignment; based on both treatment assignment and outcome variables; that match on covariates; and that match on predicted probabilities of treatment. We prefer to use combination of probability of treatment and outcome models, because of its advantage of yielding consistent estimates even if one of the two is correctly specified—the property called doubly-robust. What this approach does is that it uses the inverse probability weighted regression adjustment (IPWRA) estimators combine models for outcome and treatment status. This methodology, the inverse-probability-weighted-regression-adjustment (IPWRA) uses the inverse of the predicted probabilities obtained from the propensity score regression as weights when performing regression adjustment. The IPWRA estimators use a three-step approach to estimating treatment effects:

(a) Estimates the parameters of the treatment model and calculates the inverse-probability weights;

(b) Uses the estimated inverse-probability weights to fit weighted regression models of the outcome for each treatment level and obtains the treatment-specific predicted outcomes for each subject;

(c) Computes the means of the treatment-specific predicted outcomes that yield the estimates of the ATEs and ATETs.

4. DESCRIPTION OF VARIABLES USED IN THE STUDY

4.1. Adaptive Strategies

This study focuses on four major food crops--wheat, basmati rice, coarse rice and maize. Adaptation strategies have been categorised into four groups: 1) changes in sowing time; 2) input intensification; 3) water and soil conservation; and 4) changes in varieties. Changes in sowing time strategy covers adaptation strategies of those farmers who are cultivating the above mentioned food crops. Input intensification comprises more usage of fertiliser and seed rates. Water and soil conservation covers usage of irrigation, introduced intercropping, changed crop rotation, laser land levelling, tillage practices, liming, manuring, used water harvesting technique. The varietal change consists of planting drought tolerant varieties, planting shorter and longer cycle varieties, planting flood tolerant varieties, etc. Since the farmers prefer multiple strategies to deal with the impacts of climatic and non-climatic stresses, we used the combination of these strategies by making these combinations mutually exclusive. There are 15 combinations in total and all are mutually exclusive and the details are given in Table 2.

4.2. Determinants of Adaptations and Food Security

Socio-economic household characteristics: The literature suggests that various socio-economic household characteristics play crucial role in adapting to climate change. The first set of variables includes *age, education* and *gender* of the household head. No female head of the farming households were found in the data. However, the educational status of female responsible for household chores is considered to see its impact on food security. All heads of households are male and the education of heads of households are reported in number of years completed.

Livestock Ownership: It is considered to be an important variable that influences the adaptation capacity of the farmers in general and small farmers in particular—since it serves as ready cash. A variety of animals is therefore always owned by the farmers. Therefore, the number of animals has been converted into cow equivalents (see Table 3).

Table 2

Farm Level Adaptation Strategies to Climate Change (All Mutually Exclusive)

S. No.		Strategy	Description
Single Strategy			
1	C1	Changing sowing time	C1 = 1 if the farm household only changed the timings of sowing as adaptation strategy; 0 otherwise
2	C2	Inputs intensification—seed & fertiliser	C2 = 1 if the farm household intensified use of seed rate and fertiliser as adaptation strategy; 0 otherwise
3	C3	Water and soil conservation strategies	C3 = 1 if the farm household only adapted water and soil conservation strategies as adaptation strategy; 0 otherwise
4	C4	Changes in varieties	C4 = 1 farm household changed crop only as strategy; 0 otherwise
Combinations of Strategies			
5	C14		C14 = 1 if the farm household only adapted changing wheat varieties and delayed/early sowing as adaptation strategies; 0 otherwise
6	C 24		C24 = 1 if the farm household only adapted changed varieties and inputs use as strategies, 0 otherwise
7	C34		C34 = 1 if the farm household changed only adapted varieties and water and soil conservation as strategies; 0 otherwise
8	C12		C12 = 1 if the farm household only adapted delayed/early sowing and changed inputs use as strategies; 0 otherwise
9	C13		C13 = 1 if the farm household delayed/early sowing and water and soil conservation strategies as adaptation strategies; 0 otherwise
10	C23		C23 = 1 if the farm household only adapted changed inputs use and water and soil conservation strategies as strategies, 0 otherwise
11	C124		C124 = 1 if the farm household only adapted changing wheat varieties, delayed/early sowing and changed inputs use as strategies; 0 otherwise
12	C134		C134 = 1 if the farm household only adapted changing varieties, delayed/early sowing and water and soil conservation strategies as strategies; 0 otherwise
13	C234		C234 = 1 if the farm household only adapted changing varieties, changed inputs use and water and soil conservation strategies as adaptation strategies; 0 otherwise
14	C123		C123 = 1 if the farm household only adapted change in sowing, changed inputs use and water and soil conservation strategies as strategies; 0 otherwise
15	C1234		C1234 = 1 if the farm household adapted changing varieties, change in sowing, changed inputs use and water and soil conservation strategies as strategies; 0 otherwise

Table 3

Cow Equivalent Animal Units

Animal Type	Age and Sex Composition	Weight
Buffaloes	Buffaloes in milk	1.50
	Buffaloes (dry)	1.20
	Heifer Buffaloes	0.60
	Young stock (Buffaloes)	0.30
	Male Buffaloes	1.20
Cow	Milking Cow	1.00
	Breeding Cow	1.00
	Heifer Cow	0.40
	Young stock Cow	0.25
	Dry Cow	0.80
	Bullocks	1.20
Goat and Sheep		0.25
Camel		1.50
Horses		1.00
Donkeys		0.50

Access to Credit Market: It is another determinant considered to be impacting the adaptive capacity positively; particularly for those farm households that have poor resources to mobilise in case of any shock. Thi*s* variable is categorised in two groups—formal sources of borrowing including banks and other government or non-government organisations and non-formal sources of borrowing including friends, relatives, and village dealers, traders etc.

Agricultural extension: The major source of formal technical advice and information about the technology at the government level has been the department of agricultural extension. The literature suggest that access to information and guidance regarding adaptation strategies through the department of agricultural extension does play a significant role in adapting agriculture to climate change to moderate its impacts. This variable takes a value of 1, if a farmer received any information/guidance about agricultural practices or technologies; otherwise zero is assigned.

Household's savings: Household savings and management is another variable that is expected to influence adaptation to climate shocks positively. Household savings include seed stocks kept for next season and other personal savings etc. This again takes values of zero or 1—takes value of 1, if a household consumed up any or all types of savings, otherwise zero.

Food expenditure management: Various households resort to reducing expenditures on food as a copping strategy in case of any shock. Reduction in food expenditure could be in the form of buying less expensive foods, reduced proportions of meals by adult women, reduced proportions of meals by children, and reduced proportions of meals by elderly, etc. This is again a binary variable: takes a value of 1 when any or all of these strategies is adopted by the household, otherwise zero.

Crop diversification: Diversification towards growing a number of crops is another important coping strategy that has potential of reducing food insecurity and provides greater financial stability and flexibility. The variable is introduced as a dummy—taking value of 1 for growing more number of crops.

Operational holding: This comprises total area of the farm under cultivation net of rented out and rented in and farmers are categorised into three major group: marginal farmers—cultivate up to 6.1 acres of land; small farmers—possess land greater than 6.1 to 12.5 acres; and the large farmers operating on above 12.5 acres of land. This study uses two variables—marginal and medium farmers and large farm category is considered as a reference.

Social index: It represents a social structure which is made up of a set of social actors—individuals or organisations. The individuals/families get help/assistance of each other in various activities whenever the families/individuals face shock or any urgency. Examples of such activities include land preparation, planting crops, harvesting, sharing farm implements, borrowing seeds, green/dry fodder, food grains, look after livestock, etc. Using these indicators and applying Principal Component Analysis (PCA), we constructed a social networking index.

Household infrastructure: Two dummies are used to capture household infrastructure: 1) does the household live in a *pakka* or *kacha* house? A dummy variable is generated –where *pakka* house is assigned value of 1 and the *kacha* 0; and 2) household enjoys the facility of electricity or not—again 1/0 for yes/no observations.

Off-farm income opportunities hours: The availability of time is an important factor affecting technology adoption [Bonabana-Wabbi (2002)]. The impact could be positive or negative on the adoption. The participation heavily draws on the leisure time farmer that may hinder adoption. Having the time to earn some extra resources without affecting the farming activities, participation in non-farm activities can promote the adaptations.

Climate change variables: Farm level adaptations basically are in response to climate change. To capture the influence of long-term changes in climate and short-term weather shocks, this study uses 10 years' average temperature and precipitation normals for *kharif* (summer) and *rabi* (winter) seasons representing climate change, and respective seasonal deviations of survey year's temperature and precipitation from long-term means (10 years) to represent weather shocks.

Ecological zones: There are various ecological zones in the country representing different cropping systems. These are cotton-wheat, rice-wheat, and rain-fed areas.

5. RESULTS AND DISCUSSION

This study aims to identify the impacts of farmer's adaptations to climate change on food security. In order to achieve this objective, the study applies the *'teffects IPWRA'* command in STAT 13 and estimates the model given in Equations 1 to 3 separately for 7 adaptation strategies which are constructed mutually exclusively (see Table 2). The '*teffects IPWRA'* command/ technique provides the actual measure of the impact and its counterfactual. To investigate the effects of adaptations on food security, Potential Outcome Means (POM), Average Treatment Effect (ATE), and Average Treatment Effect for Treated (ATET) are estimated. These measures imply the impacts of adaptations on food security, and their counterfactual. The determinants of food security and the decision to adapt have also been found by applying the said procedure. The outcome variable is Food Security Index (FSI). The covariates in outcome equations include educational level of male and female decision makers, age of male household head, family size, farm size—small and large dummies, household savings, access to formal and informal credit market, access to non-farm income, food expenditure management, crop diversification, having facility of electricity and *pakka house*, cropping zones dummies—rice-wheat, cotton-wheat, and arid, while mixed cropping zone was taken as controlled. The treatment equation includes some of the variables used in outcome equations besides various other covariates—like social networking, tenancy status—owner and owner-cum-tenants, agricultural extension, electronic media, and climatic variables—'last 10 years' average' of temperature and precipitation as well as their deviations from survey year's temperature and precipitation for *Kharif* and *Rabi* seasons.

Of the 15 mutually exclusive combinations (Table 2), only 7 combinations are considered to estimate the treatment effects models because of limited number of observations in other cases. The results of 7 of these models are reported in Table 5. Further to this, we will discuss only two of the 7 since the other 5 combinations have very small number of adapters (see last two columns of Table 5). The table shows that only two combinations, C1234 and C234, have significant number of adapters, 1399 and 828 of respective strategy/combination, respectively, while the results from strategy models show either negative impacts on the outcomes or their impacts are non-significant.

The results reported in Table 4 suggest that C1234 and C234 combinations of adaptation strategies are advisable to be discussed—since the reliability of the results from other models is questionable due to limited number of observations of adapter households. The difference between these two is only of 'changing sowing timing' as adaptation strategy, while the other strategies are the same—input intensification, water and soil conservation, and varietal change. The results given in Table 4 for the C1234 strategy indicate that potential outcome means (POM) for those households which adapted this combination is higher than those

Table 4

Calculations of ATE, ATET and Potential Outcomes

	POMs			ATET			Non-
Strategy	P0M(0)	POM(1)	ATE	1 vs 0	POM(0)	Adapters	adapters
C1234	-0.01946*	0.0258*	0.0452***	0.0425**	0.00001	1,399	1,903
C234	-0.0096	0.0363**	0.0459***	0.0403**	-0.0097	828	2,474
C134	-0.0001	0.0484	.0485483	0.0682*	-0.0728	50	3,252
C124	0.0005	-0.0101***	-0.1013***	-0.0226	-0.1586***	93	3,209
C123	0.00110	-0.02300	0.0242	-0.01851	0.0548	152	3,150
C23	0.0034	-0.0808***	-0.0842***	-0.0561***	-0.0404	169	3,133
C34	0.0003	-0.0002	-0.0004	0.0056	-0.0113	153	3,149

Note: ***, ** and * indicate the level of significance of the estimates at least at 1 percent, 5 percent and 10 percent level of probabilities.

of non-adapting households. The measure of POM(1) for adapters is found to be positive (0.0258) and is highly statistically significant whereas POM(0) for non-adapters is negative (-0.01946) and is also statistically significant. These significant differences in POM suggest that the households which are adapting to climate changes are more food secure as compared to those which did not adapt. The ATE is the population average and indicates the difference of outcomes if the whole population adapts to climate and none adapts to climate changes. This measure came out to be 0.0452 having positive sign and is statistically highly significant suggests that the households which adapted to climatic changes are significantly more food secure than those which did not adapted. However, it is to be noted that the farmers are smart and resourceful to adapt to all possible adaptation measures to reduce the impact of climate change on food security. These adaptation strategies include changes in sowing time, input intensification, water and soil conservation, and varietal changes.

The average treatment effect among treated households (ATET) is also measured. This measure specifies that if the adapter households have had not adapted to the climate change then what would have been their outcome condition—the level of food security. If all of the adopter households were to become non-adapters, the average outcome would be 0.00001 which indicates that the adapting households appeared to be better off than non-adapting sample of households even if had they not adapted to climate change they still would have been relatively more food secure than the actual non-adapters in the population. If all adapting subsample households become non-adapters, the ATET (=0.0425) estimate came out to be approximately equal to the ATE (=0.0452). This result highlights the fact that the non-adapter households have significantly lower levels of food security than those which adapted to climate change, while the base point or non-adapters are experiencing the small potential outcome means, i.e. 0.00001, that is also statistically insignificant—may be due to small variation within the sample. Intuitively, it suggests that those farmers who adapted to climate change were already more food secure than that as if they were non-adapters.

The values of ATET, ATE and POMs obtained from model that uses C234 combination of strategies also shows positive and significant impacts on food security implying that the farm households who adapted combination of input intensification, water and soil conservation, and variety change are also more food secure than those who have not adapted to climate change. There is a significant differences between adapters and non-adapters where potential outcome means and ATE are positive and significant for adapters. ATET suggests if treated households became untreated or non-adapters, they would be food insecure. Hence, estimated results are suggestive that combination C234 has also been beneficial for the farm households which adapted it.

It is worth mentioning that all other combinations either have ATE and ATET measures negative or are statically non-significant. Therefore, it can safely be concluded that the farm households resort to adapting multiple strategies to moderate the impact of climate change.

The determinants of food security of adapter and non-adapter households are reported in Table 5. The potential outcome model given in Equations 1 to 3 is estimated using treatment effects technique '*teffects*' applying inverse-probability-weighted-regression-adjustment 'IPWRA' command in STATA that combines models for outcome and treatment status. The estimates thus obtained are doubly-robust. The *teffects IPWRA* command estimates endogenous treatment effect model using three equations—two outcome equations one each for adapters and non-adapters, and a treatment or selection equation. The parameter estimates are reported respectively in Tables 6 and 7.

Table 5

Parameter Estimates of the Outcome Equations

	C234		C1234	
Variables	Non-adapters	Adapter	Non-adapters	Adapter
Education of female head	0.0049*	0.0082	0.0048*	0.0066
Education of male head	0.0049***	0.0115****	0.0048***	0.0114***
Age of farmer	-0.0012*	-0.0024**	-0.0012*	-0.0026**
Marginal farmer	-0.7465***	-0.8697***	-0.7472***	-0.8693***
Small farmers	-0.5280***	-0.6369***	-0.5292***	-0.6421***
Livestock ownership	0.0255**	0.0071^^	0.0254**	0.0064^
Household savings	0.0235	0.0045	0.0237	0.0069
Family size	-0.0005	0.0069^^	-0.0008	0.0062^^
Formal credit	-0.0191	0.1770***	-0.0188	0.1947***
Informal credit	-0.0463	0.0541	-0.0465	0.0575
Electricity	0.0896***	0.1131***	0.0903***	0.0879**
Pakka house	0.1061***	0.1186***	0.1054***	0.1167***
Food expenditure management	-0.0674*	-0.0057	-0.0669*	-0.0102
Crop diversification	0.1328***	0.0679	0.1330***	0.0624
Non-farm income	0.0469**	0.0592^^	0.0436**	0.0798**
Cotton-wheat zone	0.1699***	0.1458***	0.1685***	0.1601***
Rice-wheat zone	0.0838***	0.0680**	0.0788***	0.0885***
Arid-zone	-0.0493***	-0.0654***	-0.0496***	-0.0607**
Constant	0.3339***	0.3273***	0.3379***	0.3531***

Table 6

Parameter Estimates of Treatment/Adaptation Equation

Variables/Determinants	C234 Coefficients	C1234 Coefficients
Education of male head	0.0164*	0.0164*
Formal credit	0.1981^	0.1929^
Informal credit	0.1303	0.0781
Age of male head	0.0024	0.0020
Non-farm income	0.4812***	0.4219***
Social index	-0.2163***	-0.2208***
Owner cultivator	0.2278*	0.2821**
Owner-cum-tenant	0.1980^	0.2526*
Agri. extension	0.0612	0.1186^
Electronic media	-0.5066***	-0.556***
Precipitation Normal *kharif*		0.0060***
Precipitation Normal *rabi*		0.0099***
Temp. Deviation *khareef*	0.7695***	
Temp. Deviation *rabi*	-0.4423****	
Precip. Devition *kharif*		-0.0132***
Precip. Devition *rabi*		0.0089^^
Cotton-wheat zone	-0.1673	-0.3528***
Rice-wheat zone	-1.2558***	-1.3233***
Arid zone	-0.4324***	-0.4984***
Constant	-1.2179	-1.7866***

Note: ***, **, *, ^^ and ^ indicate the level of significance at least at 1 percent, 5 percent, 10 percent, 15 percent and 20 percent.

Table 7

Parameter Estimates of Treatment/Adaptation Equation

Variables/Determinants	C234 Coefficients	C1234 Coefficients
Education of male head	0.0164*	0.0164*
Formal credit	0.1981^	0.1929^
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Age of male head	0.0024	0.0020
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Constant	-1.2179	-1.7866***

Note: ***, **, *, ^^ and ^ indicate the level of significance at least at 1 percent, 5 percent, 10 percent, 15 percent and 20 percent.

The most of parameter estimates in outcome equations for both strategies—C234 and C1234, are statistically significant and having expected signs. The results of both of these strategies are to a great extent similar in direction of the impact in outcome equations of the non-adapters and adapters. We did not find significant departure in terms of deriving the overall conclusions. The dependent variable in outcome equations is food security index and thus it's a continuous variable. Therefore, the signs and magnitude of the parameter estimates are important while interpreting the results. The results show that education of the male and female heads, livestock ownership, the structure of household—both bricked and having electricity facility, crops diversification and non-farm income are the factors which raise the food security of farm households and their impacts are statistically significant.

The female education turned out to be more pronounced and thus have important implications from policy point of view. These findings are consistent with the results of Li and Yu (2010) and Aslam and Rasool (2014). In order to reduce food security at the rural farm household level, the priority has to be given to educate the rural masses—in particular the female education is crucial in this regard. Livestock ownership is another important factor which contributes significantly positively to ensure farm household food security—more the number of animals have the household the better is its food security status. It normally acts as a liquid asset and the households can meet their needs immediately by selling animals (small ruminants in particular) and their products (especially the milk).

The farm households which are having bricked houses and have access to electricity connections are more food secure as compared to those who do not have access to such facilities. Basically, both of these variables imply that theses households are relatively better off than those who live in mud houses and without electricity. Diversification towards growing more number of crops including minor and major crops, fruits, vegetables, pulses and oilseeds crops implies greater financial flexibility and nutrient diversification. Lin (2011) argues that crop diversification improves the resilience by suppressing pest and disease outbreaks on a single crop under changing climate scenarios, and also acts as buffer against crop failures due to the frequently occurring climatic and extreme events. The provision of incentive both at markets and technological development levels for the major crops hinders promotion of this strategy and encourages mono-cropping system. Therefore, in order to improve food security in the country crop diversification needs to be encouraged through a balanced economic policy and improved inputs and output markets infrastructure.

The parameter estimates of non-farm income variable are positive and statistically significant in all equations implying a considerable potential in reducing food insecurity at the farm household level by generating off-farm employment opportunities. Pakistan's agriculture is dominated by the very small holdings having poor resources and thus are more vulnerable to climate change. Since agriculture involves a high degree of risk and is extremely vulnerable to a range of climatic and non-climatic stresses, the off-farm income is considered to be an instrument to deal with such risks [Mishra and Chang (2008); Joo and Mishra (2013)]. This result is consistent with the studies done by Mustafa (2014) and Babatunde (2010).

The variables which are significantly negatively associated with the food security levels include age of the head of household, food expenditure management, households having less than 12.5 acres of land—defined as marginal (cultivate <6.25 acres) and small (cultivate >6.25 to ≤12.5 acres). The aged farmers are considered to be more risk averse and hesitate to implement new ideas and innovations which make them less productive under the changing climate. The 'reduction of expenditure on food items as strategy to tackle the weather shocks' has significantly negatively impacted the level of household food security—especially of the non-adopter households to climate change. The results show a very alarming situation of the farm households having less than 12.5 acres of land since they are significantly more food insecure than the medium and large farmers (>12.5 acres of land). Agriculture Census of Pakistan (2010) shows that 89 percent of the farmers cultivate ≤12.5 of land and area under their cultivation is 48 percent of the total, while the remaining 52 percent of land is being cultivated by the only 11 percent of the total farm households. The marginal and small farmers are resource poor, less productive and less efficient. This indicates that financial and technological resources should be well targeted to reduce the food security in the country.

The cropping zones' parameter estimates show that farm households located in cotton-wheat, and rice-wheat systems are significantly more food secure than those of living in mixed cropping system and arid zone. This result however is against our expectations—particularly in the rice-wheat and cotton-wheat systems. These systems are more of mono-cropping systems, while the mixed system has more diversified cropping system. This could be due to the reason that wheat grain contributes about half of the calories in total consumption, and it is the only crop where government intervenes highly by not only fixing prices but also assuring market/procurement. During the last couple of years, wheat prices remained mostly above the international level. Despite surplus production, it remained unaffordable by even the rural poor. Districts included in our sample of mixed zone are normally short of wheat production.

The next question is what determines the adaptation decisions of the farm households. Since the dependent variable is binary, we applied the *logit* model to evaluate the factors determining the farm household decisions. The parameter estimates of adaptation equation are reported in Table 6. The comparison of the results obtained from both the estimated models—combinations C1234 and C234, shows that some of the signs of the parameter estimates turned out to be opposite.

Our major aim in this study is to analyse the impact of adaptations to climate change on farm household food security, however, we need to briefly discuss the factors that determine the adaptations so as to derive effective policy implications.

The factors which are more likely to contribute positively—across the models, towards farm level adaptations to climate change include education of the head of household, access to formal credit, non-farm income, owner and owner-cum-tenant cultivators, and access to government's agricultural extension department. Though some of these parameter estimates are statistically non-significant, but the signs do imply the positive influence on adaptations to climate change. The empirical literature on technology adoption shows that these factors play an important role in facilitating farm level adaptation [e.g. Feder, Just, and Zilberman (1985); Daku (2002); and Doss and Morris (2001)]. The signs of the parameter estimates are however consistent across models. The owner and owner-cum-tenant cultivators are likely to be more adaptive to climate changes as compared to sole tenants. The most probable reason could be that the tenants, who do not have the right of ownership, work under constant fear of eviction. They have no incentive to make long term investments in land improvements and technologies/adaptations, and using farm resources more optimally. The farm households who are using electronic media as information source for agricultural practices and weather related issues are less likely to adapt to changes in climate. The reason for this unexpected sign could be that the electronic media though is doing a marvellous job in disseminating the day to day weather conditions, but the farming community gets no information on long term patterns of climate changes to which the farming is supposed to respond. An important implication of this result is that since the threat of climate change is real, it requires effective actions including creating awareness among farming communities.

Regarding the influence of climate change variables on the adaptation to climate, we used average of last 10 years of temperature and precipitation (climate normals) in *Kharif* and *Rabi* seasons, and deviations of survey year's temperature and precipitation from the respective long-term means. We statistically tested the contribution/impacts of climatic variables by controlling the other non-climatic variables by running logit regressions and the test results are reported in Annex 1. The results show that the temperature normals—both in *kharif* and *rabi* seasons, have jointly no influence in both adaptation regressions—C234 and C1234. The precipitation normals—both *kharif* and *rabi,* however have significantly influenced the adaptation in C1234, while these variables had no joint impact on adaptions in C234 strategy. The temperature deviations from long term means significantly impacted adaptation C234, but have shown no influence in C1234 adaptation, while the precipitation deviations from long-term means have shown impact in contrary. It is difficult to make any solid conclusion from the response of the climatic variables to adaptations to climate changes, since the nature of data used in the study which relates to only one cropping year. However, the results of this study are suggestive of the influence of climatic related variables on the adaptations to climate change, which in turn play an important role in assuring food security.

The results of location variables show that the farming households in cotton-wheat, rice-wheat and arid zones are less likely to adapt to changes in climate as compared to mixed zones. The fixed crop rotations are being followed in rice-wheat and cotton-wheat systems having a little flexibility in following diverse adaptations. The farmers in rain-fed areas also face the same situation as of having limited crop choices and diversification. -

6. SUMMARY AND CONCLUSIONS

The study uses data regarding 3298 food crop growers out of a total sample of 3432 farm household from 16 randomly selected districts of Pakistan for the Climate Impact Survey (CCIS, 2013). This study assesses different adaptation strategies employed by Pakistani farmers in response to climate change; identify various factors that influence adaptation decisions, and determine whether these strategies help to achieve food security for rural farm households.

A household Food Security Index (FSI) comprising various factors[8] is constructed by applying Principle Component Analysis (PCA). The identified adaptation strategies have been categorised into four groups namely: changes in sowing time (C1); input intensification (C2); water and soil conservation (C3); and changes in varieties (C4). In total, 15 mutually exclusive combinations were constructed. Out of 15, only 7 combinations have been considered to estimate the treatment effects models because of limited number of observations in other cases. Results of only two of the 7 have been discussed in the paper, as the other 5 combinations have very small number of adapters and the impact measures shown either insignificant results or had opposite signs. These two combinations are C1234 and C234. The first (C1234) combined all the four while the second (C234) combined the last three strategies.

This study used Potential Outcome Treatment Effects Model to evaluate the impact of adaptations on household food security. The estimated measures include Potential Outcome Means (POM), Average Treatment Effect (ATE) and Average Treatment Effect among Treated households (ATET). The results suggest that the households which adapted to climate changes are statistically significantly more food secure as compared to those who did not adapt.

The results from both C234 and C1234 strategies are to a great extent similar in direction and significance of the impact in outcome equations of the non-adapters and adapters. The results show that education of the male and female heads, livestock ownership, the structure of house—both bricked and having

[8]factors such as size of landholdings, production of food grains, food grains received as assistance, improved food storage capacity, per capita food consumption, farm as well as household assets, and access to toilet facility.

electricity facility, crops diversification, and non-farm income are among the factors which raise the food security of farm households and their impacts are statistically significant. The variables which are significantly negatively associated with the food security levels include age of the head of household, food expenditure management, households having less than 12.5 acres of land—defined as marginal (cultivate <6.25 acres) and small (cultivate >6.25 to ≤12.5 acres). Farmers of cotton-wheat, rice-wheat, and rain-fed cropping systems are found to be more food secure as compared to the farmers working in the mixed cropping systems where farm holdings are relatively small and high use of tube-well water adding to salinity of soils.

The determinants of adaptation decisions of the farm households include education of the head of household, access to formal credit, non-farm income, owner and owner-cum-tenant cultivators, and access to government's agricultural extension services. The farm households in which electronic media is used as information source for agricultural practices and weather related issues are less likely to adapt to changes in climate. Though the electronic media is doing a marvellous job in disseminating information on day to day weather conditions, but it has failed to provide information on long term patterns of climate changes to which the farming is supposed to respond. The sign of the social networking/farm dependency index also came out to be negative and statistically significant as well. This index includes getting help in land preparation, planting crops, and harvesting along with sharing farm implements, borrowing seeds, green/dry fodder, and food grains; and looking after livestock etc. The index in its true sense is reflective of either one or more of the adverse conditions including shortage of labour, lack of certain skills, scarcity of farm capital, and limited financial resources. Therefore, it negatively affects the outcome of the adaptation decisions.

The results indicate that the temperature normals—both in *kharif* and *rabi* seasons have jointly no influence on adaptation. However, the precipitation normals, temperature and precipitation deviations are likely to influence the adaptations but the effects are not consistent across models. The location variables show that the farming households in cotton-wheat, rice-wheat and arid zones are less likely to adapt to changes in climate as compared to households in mixed zones. The fixed crop rotations are being followed in rice-wheat and cotton-wheat systems having a little flexibility in following diverse adaptations. The farmers in rain-fed areas also face the same situation of limited crop choices and diversification.

It is crucial to invest in the development of agricultural technological packages addressing issues of climate change relevant to different ecologies and farming systems; improve research-extension-farmer linkages; enhance farmers' access to new technologies; improve rural infrastructure; development of weather information system linking meteorological department, extension and farmers; and establishment of targeted food safety nets as well as farm subsidy programs for marginal farm households.

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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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