The impact of farmers' adaptation to climate change on rice yields: implications for sustainable food systems

sustainability

MDPI

Article

The Impact of Farmers' Adaptation to Climate Change on Rice Yields: Implications for Sustainable Food Systems

Nasir Abbas Khan [1], Uttam Khanal [2], Clevo Wilson [3], Ashfaq Ahmad Shah [4] and Muhammad Atiq Ur Rehman Tariq [5,6,7,*]

1 Research Center of Risk Management and Emergency Decision-Making, School of Management Science and Engineering, Nanjing University of Information Science & Technology, Nanjing 210044, China
2 Productivity Commission, Melbourne, VIC 8003, Australia
3 School of Economics and Finance, Queensland University of Technology, Brisbane, QLD 4000, Australia
4 Research Center for Environment and Society, School of Public Administration, Hohai University, Nanjing 211100, China
5 College of Engineering and Science, Victoria University, Melbourne, VIC 8001, Australia
6 Institute for Sustainable Industries & Liveable Cities, Victoria University, Melbourne, VIC 8001, Australia
7 College of Engineering, IT & Environment, Charles Darwin University, Darwin, NT 0810, Australia
* Correspondence: atiq.tariq@yahoo.com

Abstract: Remarkable agricultural productivity gains have been achieved during the last several decades as a result of green revolution (GR) technologies that have greatly increased food production and reduced hunger. However, climate change threatens to reverse the progress made so far in the fight against food insecurity. The agricultural sector in many developing countries, including the rice and wheat producers such as in Punjab (Pakistan and India), is highly vulnerable to climate change, which has serious implications for rural livelihoods and food security. Adaptation is considered a key tool to tackle climate challenges at the farm level and is, therefore, the focus of this study in terms of its impact on rice yields. A household survey was conducted in the Punjab province of Pakistan, and farmers were interviewed face-to-face. We employed a simultaneous equations model to assess the differential impacts of climate change adaptation on adapting and non-adapting farmers' rice yields. Using the cross-sectional data of 480 rice growers, an endogenous switching regression model provided a means to estimate the selection bias of farmers' attributes. The results show a significant positive impact of adaptations on rice yields. Specifically, the yield of farmers who adapted to climate change was 24% higher than the non-adapting farmers. The results further indicate that non-adapters can also benefit from the adaptation strategies if they decide to adapt. We also found a significant positive effect of farmers' climate risk perceptions, literacy level, access to irrigation, ownership of livestock, and availability of farm advisory services on their adaptation decisions. These results, therefore, suggest that policymakers should take into account farmers' local adaptation knowledge and farming practices when formulating adaptation policies.

Keywords: climate risk; adaptation; agriculture; endogenous switching; Pakistan

Citation: Khan, N.A.; Khanal, U.; Wilson, C.; Shah, A.A.; Tariq, M.A.U.R. The Impact of Farmers' Adaptation to Climate Change on Rice Yields: Implications for Sustainable Food Systems. *Sustainability* **2022**, *14*, 16035. https://doi.org/10.3390/su142316035

Academic Editor: Hossein Azadi

Received: 6 October 2022
Accepted: 21 October 2022
Published: 1 December 2022

1. Introduction

In the 1960s and 1970s, several green revolution (GR) technologies were introduced in a number of south Asian countries, including Pakistan [1,2]. As a result, significant food productivity increases were achieved, leading to substantial progress in reducing food insecurity and hunger. However, Conway [3,4] has argued that relative to conventional farming systems, crop productivity accrued from the GR-enabled modern farming systems was higher but less sustainable and more variable, especially in the early adaption stages. Conway concluded that GR was bringing challenges to ecological, economic, and social sustainability. These findings—which were highlighted over three decades ago—have pivotal implications for GR-dependent developing nations such as nations in south Asia.

In particular, the introduction of GR technologies produced a revolutionary increase in the yields of crops such as rice and wheat, which fulfill most of the demand for food in south Asia. This was brought about through changes such as distribution of modern irrigation technologies, including shallow, deep tube wells and chemical fertilizers [5].

Studies have reported that climate change intensifies the risks to food security, more specifically for vulnerable countries and populations [6,7]. This poses the question as to how sustainable the current GR-enabled farming systems are in the face of climate change and degradation of natural resources [8]. This article, therefore, explores how GR technologies and climate change adaptations (fertilizers, irrigation, farming patterns) are being practiced since the advent of the GR and to what extent are they contributing to sustaining crop productivity in countries such as Pakistan.

Climate change has become a global developmental challenge [9]. Of the various sectors, agriculture remains the hardest hit [9,10]. Although climate change is globally evident, countries in the southern hemisphere are relatively more vulnerable to its induced risks [11,12]. Erratic rainfall, extreme temperatures, floods, and droughts are the major challenges the developing world is exposed to [9,13]. South Asia is counted among the world's most vulnerable regions having the least ability to cope with climatic and induced risks [10,14,15]. This is largely due to the region's high population density and its heavy dependence on agriculture and associated sectors [6]. To take an example, there are projections that the yields of cereal crops—which meet most of the South Asian countries' food demand—may be subject to alarming declines. Several studies predict declines of 4–10% for major cereal crops by the end of this century [6,16,17]. If accurate, this would pose a serious threat to the region's food security, given the fact that food production needs to be doubled by 2100 to meet the rapidly increasing population [18].

Pakistan is one of the most vulnerable countries that has faced extreme climate events for the past 2–3 decades. Since 1960, the average temperature has increased by nearly half a degree Celsius (0.41 °C) and the rise is expected to reach up to 3 °C by the year 2100 [19]. This changing temperature and the consequential increase in the intensity of various natural hazards have significantly affected rainfall patterns and cropping calendars across various agroecological zones [20,21]. For instance, in the past two decades, Pakistan has been subject to five major floods [22–24], two extreme drought periods [25], and an increased incidence of biological hazards such as crop insects and disease [26,27]. The flood of 2010 cost the country over USD 10 billion, with extensive human and animal casualties [28,29]. It is reported that the recent flood of 2022 is even more disastrous than the historic flood of 2010 as it has affected 30 million people and washed out one third of the country, costing enormous loss of human and animal lives [22]. A recent locust attack, which devastated the country's crop sector, has been attributed to temperature and precipitation changes [27]. Such catastrophes are a serious threat to the livelihoods of farming communities and food security in a country in which agriculture accounts for over 50% of GDP and employs 43% of its labor force (indirectly 70%) [30]. Given the frequency of extreme climate events, Pakistan is now ranked among the world's five most vulnerable nations to climate change [15]. Thus, given the seriousness of the challenges that Pakistan's agriculture sector faces, it is imperative that current farming systems are adapted to climate change.

There is a wide range of literature that indicates that farm-level adaptation strategies are a useful way of tackling climate variabilities and that such strategies need to be responsive to local settings [31–33]. This research shows that by taking appropriate adaptation actions, climate challenges can be transformed into opportunities that raise crop yields [34,35]. By definition, adaptation strategies are the farming strategies that farmers can adopt in order to align their farming systems to the current or potential climate changes [9,36]. The literature shows that various types of adaptation can be categorized based on planning prospects (short-term or long-term), timing (reactive or anticipatory), form (technical, institutional, legal, behavioral, or educational) and actors involved (private or public) [37]. In addition, autonomous and planned adaptation are ways of describing adaptation types. Adaptation that is designed and led by the government or institutions is referred to as planned adaption, whereas autonomous adaptation strategies are the actions taken by the farmers (based on their local knowledge) without or with minimum interventions from the government [38]. Khanal et al. [39] argued that autonomous adaptation is a relatively better instrument, especially for smallholders in developing countries, given its capacity to respond to sudden fluctuations in climate.

There is a large body of research that lists farming communities' adaptation to climate change [20,36,40,41]. These actions mainly include changes and adjustments in the farming systems, such as soil and water management practices and shifting of crop cultivation dates. Studies show that farmers' adaptive capacity and adaptation behaviors are largely shaped by factors associated with the nature of the farming household. Such factors include the household head's age, his/her level of education, farm and non-farm assets, and access to information and advisory services [36,42]. Despite the abundant research on agricultural adaptation to climate change, there remains little in the literature that focuses on the efficacy of local-level adaptation actions. Several researchers have modeled the impact of adaptation strategies on crop yield in different countries. In Africa, Amare et al. [31] and Falco et al. [35] assessed the effectiveness of adaptation measures on farmers' crop yields and local food security. In South Asia, Khanal et al. [39] and Suresh et al. [33] have conducted similar assessments. These studies reveal a different level of efficacy in climate adaptation techniques, varying with respect to socioeconomic and agroecological features of the local farming systems.

However, there are very few Pakistani studies that address this aspect, given they largely dwell on assessing climate change vulnerability and identifying adaptation measures [14,26,43,44]. For instance, Shah et al. [14] studied farmers' vulnerability and adaptation in Khyber Pakhtunkhwa province of Pakistan and found that most farmers are well-aware of their vulnerability and have positive intentions toward climate change adaptation. Abid et al. [43] reported findings from three agroecological zones of Pakistan, stating that wheat farmers in Punjab are faced with increased variation in temperature and rainfall and are employing multiple adaptation strategies to minimize adverse impacts on crops. Khan et al. [26] assessed the vulnerability of rice farming communities in Punjab and reported a higher level of exposure and susceptibility of rice farmers in Punjab. Despite growing literature, only a handful of studies considered adaptations' impact on farm efficiency [45,46]. For instance, Abid et al. assessed that adaptation to climate change positively influences wheat farmers' farm income and crop returns. Similarly, Ali et al. [46] assessed the impact of adaptation on household food security and poverty. One of the limitations of these studies is that they employed the propensity score matching technique for evaluating adaptations' impact on crop yield, which, according to recent research, does not generate accurate results, as it is unable to account for unobservable factors, which is an issue addressed by the endogenous switching regression model [32,47]. Additionally, among the existing studies, none focused on a vulnerable region, such as the rice-growing area of Punjab province, in examining the interrelation between farmers' adaptation measures and rice yields—one of the most vulnerable crops in Punjab [21,26]. Therefore, we make a contribution to filling this research gap in terms of its focus on localized adaptation and contribute to the global literature on the effectiveness of agricultural adaptation to climate change. This study had two key objectives: (1) to assess rice farmers' adaptation strategies to climate change and associated factors, and (2) to evaluate the impact of farmers' adaptation on rice yields in the study area.

Theoretical and Conceptual Framework

This study has chosen the theoretical Model of Private Proactive Adaptation to Climate Change (MPPACC) as a heuristic for this empirical research [48]. MPPACC is well-suited for structuring farmers' narratives and analyzing farmers' CC and adaptation appraisal as well as their effects on adaptation intention and avoidance, considering socio-cognitive context factors. The model assumes that an individual evaluates a certain risk or opportunity in the first step (climate risk perception or CC appraisal) and evaluates his or her subjective capability to deal with this risk or opportunity in the second step (adaptation intention or adaptation appraisal). The MPPACC does not explicitly describe the stimulus of CC perception; therefore, this study first considered farm vulnerability to CC as the stimulus of the adaptation process.

Climate change vulnerability of farming communities is caused by temperature and rainfall variability in the study area. To elaborate, the variations in these primary climate indicators result in irregular rainfall patterns, increasing temperature, and heatwaves, consequently leading to increased occurrence of risks and uncertainties (i.e., droughts, floods, and biological hazards) that adversely affect productivity and hence the livelihoods of farming communities. The magnitude of these risks brought by climate change shapes farmers' vulnerability against such uncertainties and risks. For instance, in the current study context, rice growers are highly vulnerable if the crop has a higher level of exposure and sensitivity to the risks of high temperature, irregular rainfall, droughts, and insect/disease attacks. Studies argue that farmers' vulnerability can be reduced by improving their adaptive capacity, which modulates risk exposure and sensitivity [49,50]. Afterward, given the higher exposure and sensitivity (vulnerability) of the farming systems, farmers perceive and recognize various risks based on risk occurrence (likelihood) and severity (impacts) on their crops, known as risk perception, described as climate change appraisal in the MPPACC [48]. In the climate change adaptation framework, this stage is marked as the most critical stage that directly influences farmers' adaptation decisions. Empirical and theoretical studies [51,52] showed that climate risk perception and adaptation is an interrelated process that jointly shapes the vulnerability or resilience of a farming system. Therefore, MPPACC takes climate change perception or appraisal as a first step to adaptation, i.e., the farmers will only opt to adapt their farming to climate change if they perceive and recognize climate change and its induced risk as hazardous to their crop; otherwise, they might not adapt. After risk perception, the next step is adaptation decision or intention to adapt (adaptation appraisal in the MPPACC); farmers plan to adopt certain adaptation measures based on their expected benefits. For instance, farmers intend to adopt adaptation measures if they believe that adaptation helps to reduce the adverse climate effects and generates more farm yield; otherwise, they might not consider adaptation. According to the MPPACC, positive intention (expected benefit) is the necessary precondition for actual adaptation, while negative intention (no expected benefits) or so-called avoidance is a barrier to adaptation [53]. At this stage, various internal and external factors influence farmers' adaptation decisions. With regard to the internal factors, the current study followed the classification by Schmitzberger et al. [54] that includes farmers' socioeconomic characteristics and farm-related attributes, such as their age, education, income, and farm assets, while the external factors include institutional services such as the provision of credit services, climate information, and farm advisory services. Apart from the determinants, the adaptation capacity or extent is restrained by various limitations or constraints, leading to inadequate or no adaptation of farming communities to climate change. Lastly, adaptation defines farm vulnerability or resilience; for instance, effective adaptation in the farming system leads to sustained or increased crop productivity, improving the farm resilience to climate effects. At the same time, inadequate or non-adoption of adaptation strategies may keep the farmers vulnerable to climate change and adversely affect their farm resilience (Figure 1).

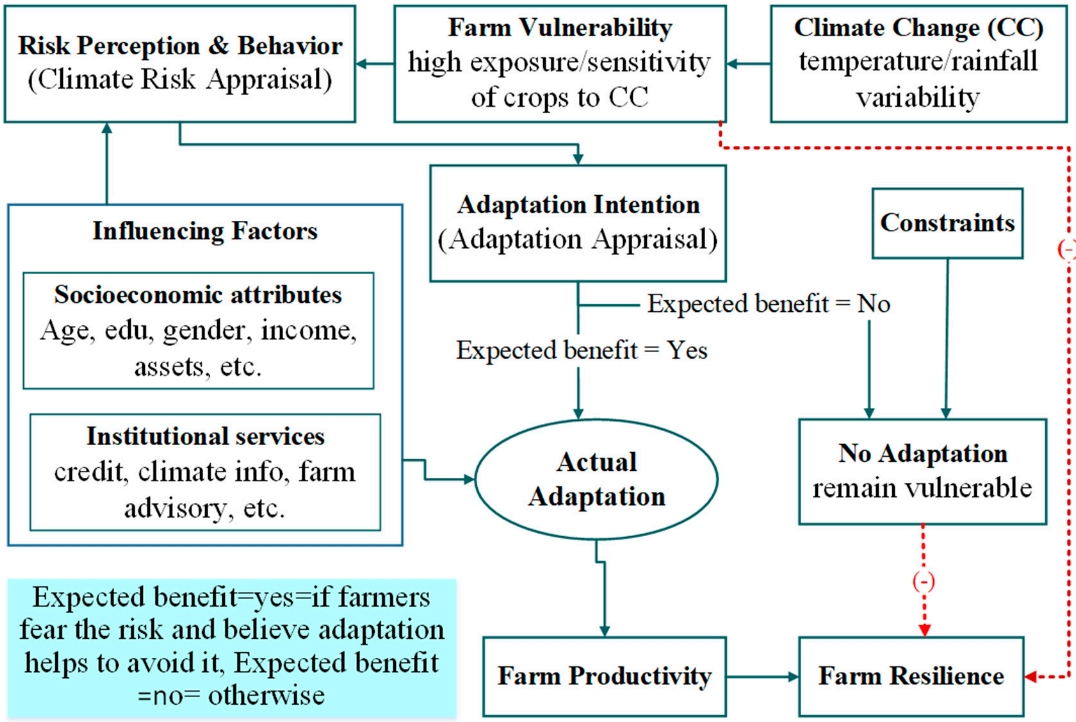

Figure 1. Theoretical model for farmers' adaptation to climate change, guided by the MPPACC [48].

2. Methods and Data

2.1. Research Site

This research was conducted in the Punjab province of Pakistan, with a focus on rice-growing areas. Punjab is Pakistan's most populous province and its leading agricultural region. Its population exceeds 110 million [30], an overwhelming proportion of which live in rural areas (80%) and are employed in the agriculture sector. Punjab contributes over 50% of the country's total agricultural GDP, producing 70% of the country's total cereal crops and 60% of the country's total rice production [26]. The province's rice growing zone is in the eastern part bordering India. Specifically, we selected four rice-producing districts of the province, which include Gujranwala, Sheikhupura, Nankana, and Kasur. Figure 2 shows the location of selected study areas.

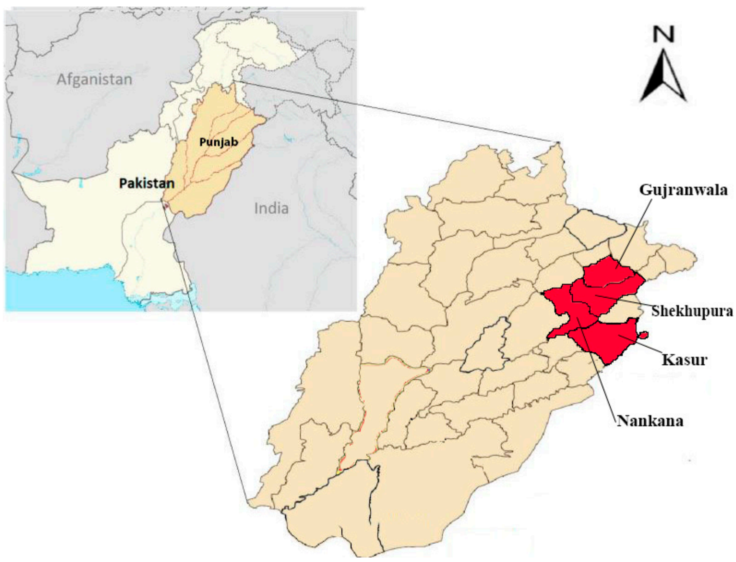

Figure 2. Location of the research sites.

Rice was selected as the focus of this research, given it has been the worst affected crop in Punjab province compared to food crops such as wheat or maize [21,55]. For instance, a study showed the vulnerability of rice crops by projecting up to a 35% yield decline by 2100 due to current and potential climate changes [21]. In general, the study area has both a hot and cold climate according to the season. The average temperature in summer ranges between 29 and 30 °C, whereas the average winter temperature is 16–18 °C [56]. Farming in the region is mainly irrigated agriculture, having two major cropping seasons, called Rabi (winter) and Kharif (summer), with major crops being wheat and rice, respectively. Given the importance of adaptation and challenges of climate change to rice crops, we selected four districts from the region to explore the relationship between farmers' adaptation to climate change and their rice yield—which is reportedly declining given climate change-led water scarcity and changing patterns of monsoon rains.

2.2. Data

In this study, we adopted a multi-stage random sampling approach in selecting farmers from the study area. Initially, given the climate change vulnerability and agricultural significance, the rice-growing zone of Punjab province was chosen as the key focus. We selected four districts from the rice-growing region by using the simple random sampling approach. The third step involved randomly selecting two tehsils (sub-districts/towns) out of each of the selected districts (subtotal 8). In the fourth stage, we selected two union councils (UC) from each tehsil, restricting this to rural union councils. Two villages from each UC were randomly selected in the fifth stage, making a subtotal of 32 villages. In the last stage—using random sampling—we interviewed 20 farmers from each village, making a total of 480 farmers. Figure 3 explains the sampling procedure employed in this study.

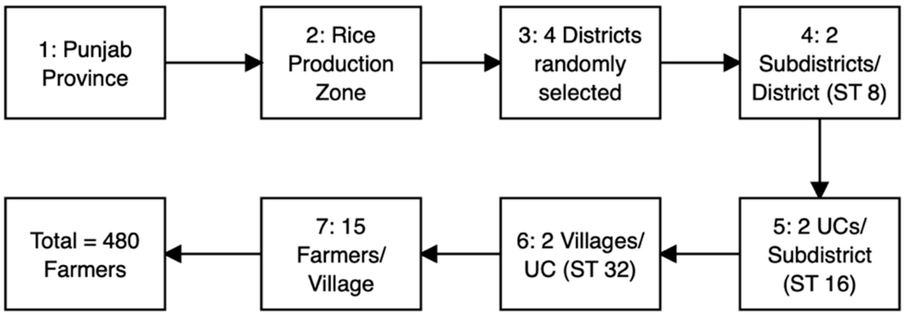

Figure 3. Flowsheet diagram of the sampling.

All of the farmers were interviewed face-to-face, given their low literacy levels. A predesigned structured questionnaire (pretested on 30 farmers outside the sample) was used to obtain information on farmers' socioeconomic, farm-related and institutional service-related attributes, their climate risk perceptions, adaptation measures, and rice yields for the 2018 cropping season. All of the farmers were informed about the purpose of the study and the use of the data.

2.3. Analytical Framework and Empirical Models

Farmers' perceived risks vary, and therefore they adopt various adaptation measures accordingly [57,58]. These measures differ widely based on farmers' personal characteristics and agroecological traits of the farming system. From our wide-ranging literature review [14,32,36,40,42,59], we selected key farmers' socioeconomic, farm-related, and institutional service-related attributes to measure their relationship with adaptation while evaluating adaptations' impact on rice yield. The details of farmers' selected attributes, along with their description, are provided in Table 1. In addition, we included farmers' risk perception in the selected variables to assess their influence on farmers' adaptation decisions, given it can clearly play a key role in farm-related decisions.

Table 1. Name, definitions, and descriptive statistics of the study variables.

Variable Name	Variable Type and Description	Mean	Standard Deviation
Rice yield	Continuous (maunds [1]/acre [2])	37.591	5.630
Adaptation	Dummy (1 = farmer adapts to climate change, 0 = No)	0.700	0.459
Farmers' age	Continuous (Years)	47.246	11.903
Farmers' education	Continuous (Years of schooling)	7.533	4.415
Landholding	Continuous (Number of Acres [1])	8.073	6.885
Land ownership	Dummy (1 = farmer owner, 0 = No)	0.886	0.317
Tube well ownership	Dummy (1 = farmer own, 0 = No)	0.640	0.480
Livestock animals	Number of livestock animals owned by the household	4.586	3.344
Farm advisory	Dummy (1 = farmer received, 0 = No)	0.420	0.494
Credit service	Dummy (1 = farmer utilized, 0 = No)	0.326	0.469
Climate risk perception	Dummy (1 = farmer perceives climate change risk, 0 = No)	0.506	0.500

[1] Maund or Mann is a commodity measuring unit in Pakistan (1 maund = 40 kg); [2] land unit used in Pakistan (1 hectare = 2.47 acre).

To do so, we used a commonly adopted method—the use of a risk matrix—where a respondent's perception of a risk's likelihood (incidence) and impact (severity) is weighted on a 1–5 point-based scale (from 1 being the lowest to 5 being the highest) [60]. Initially, we asked farmers whether they think climate change occurred and asked them to rank occurrence on the given scale (Figure 4). The same process was repeated to obtain their responses on the impacts of climate change. Afterward, we accumulated the obtained scores into the risk matrix and calculated scores varying between 1 and 10. In the third stage, we ranked farmers into two categories, namely low-risk perceivers whose scores ranged between 1 and 5 and high-risk perceivers with risk scores above 6. We assigned the value 0 to low-risk perceivers and 1 to high-risk perceivers. To evaluate farmers' adaptations' impact on rice yield, we used the endogenous switching regression model, which was assessed to be the most suitable model given the challenge of hidden endogeneity in observational studies.

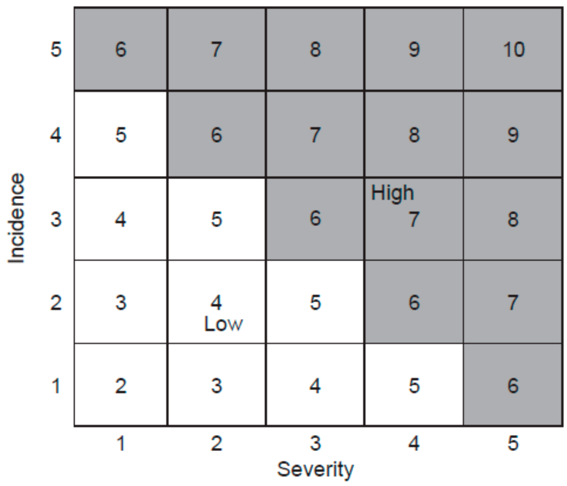

Figure 4. Risk matrix.

2.4. *Adaptation Impact on Rice Yields: An Endogenous Switching Regression Analysis*

We followed Khanal et al. [32] in modeling the climate change adaptations and the resultant effect on rice yields. We employed an endogenous switching regression model to examine the impact of adaptation on rice productivity as well as the likelihood of adopting adaptation practices. In this model, the farm households are grouped into two categories based on the adaptation status by means of a switching equation:

$$A_i^* = Z_i\alpha + \eta_i \quad (1)$$

$$A_i = \begin{cases} 1\, if A_i^* > 0 \\ 0\, if A_i^* \leq\ 0 \end{cases} \quad (2)$$

$$y_i = \begin{cases} y_{Ai} = x_{Ai}\beta_A + \varepsilon_{Ai} \text{ if } A_i = 1 \\ y_{Ni} = x_{Ni}\beta_N + \varepsilon_{Ni} \text{ if } A_i = 0 \end{cases} \quad (3)$$

where A_i^* is a latent variable that determines the probability that a farm household i adopts climate change adaptation practices; A_i is a binary variable that equals 1 for farming households that adopt climate change adaptations and 0 otherwise. α is a vector of parameters to be estimated. The error term η with mean zero and variance $\sigma^2\eta$ captures measurement errors and factors unobserved to the researcher but known to the farmer. The vector Z represents farm and household characteristics that influence the farmers' decision to adopt climate change adaptations. The outcome variable (rice yield), y_i, is observed for households in each group where y_{Ai} is for an adapted household and y_{Ni} is for a non-adapted household. x_i is a set of explanatory variables that include production inputs and household and farm characteristics included in Z. β is a vector of parameters to be estimated and ε is the error term. The three error terms η, ε_A, and ε_N are assumed to be jointly normally distributed.

As some unobserved characteristics that affect the probability of adopting adaptation practices could also affect the outcome variable—i.e., the rice yield—the error terms of the selection and the outcome equation may be correlated. To address this issue of endogeneity, we estimated a simultaneous equations model of climate change adaptation and rice yield employing an endogenous switching regression model with full information maximum likelihood [61]. For the model to be identified, it is important to use selection instruments that affect the adaptation decision of farming households but do not affect the rice yield among the households that did not adapt. In our study, the variable 'climate risk perception' was used as the selection instrument. Results in Table 3 and Table A1 show that this variable can be considered as a valid selection instrument. The signs and significance levels of the correlation coefficients (ρ) from the estimates are of particular interest. These are the correlation coefficient between the error term η_i of the selection equation and error terms ε_A and ε_N of the outcome equations, respectively. Specifically, there is endogenous switching if either ρ_A or ρ_N is significantly different from zero and would result in selection bias.

3. Results and Discussion

3.1. Descriptive Statistics of the Study Variables

Table 1 presents the descriptive statistics of the sample. The results show that the average per acre rice yield of the farmers was 37 maunds in a sample where 70% of the farmers were categorized as adapters to climate change. In terms of socioeconomic attributes, most farmers were relatively old—an average of 47 years—and had a lower-medium level of education. The average farm size was 8 acres (3 hectares), with a majority (88%) owning the land they cultivate. In terms of farm-related attributes, 64% reported ownership of an irrigation source (tube well)—a vital factor in rice cultivation in Punjab, as rice is a highly water-dependent crop and cultivated through the flood irrigation method. Farmers further reported ownership of four livestock animals on average, meaning that the farmers were agropastoral—cultivating crops and rearing livestock in parallel. In terms of institutional services, 42% of farmers reported they had access to farm advisory services from public and private sector institutions. The fairly high level of advisory service use could be due to increasingly popular information and communication technologies such as mobile devices, which provide a means for agricultural information delivery [58,62]. In this study, we included advisory services from both public and private institutions, as farmers were unable to differentiate the advisory-providing institutions. Similarly, 32% farmers reported the availability of credit facilities. This study only considered formal credit sources, i.e., banks, to assess the availability of credit services.

We used a risk matrix to further refine farmers' perceptions of climate change. The risk matrix score—based on the likelihood and impact of climate change on rice crops—shows that farmers experienced changes in local climate that affected their rice crops. This finding is in line with a previous study [63] that found that farmers in the Punjab province reported a high likelihood that climate variability would affect farm output.

Table 2 shows a comparison of study variables among adapters and non-adapters. It can be seen that adapter farmers have reported higher rice yields compared with non-adapting farmers. Our results are supported by previous studies [39,45], which revealed that farmers who adapt to climate change attain higher crop yields, suggesting that climate change adaptation enhances crop productivity. It can be further noticed that adapter farmers have higher education levels, larger land size, availability of irrigation source, and access to farm advisory and credit services when compared to non-adapter farmers. As argued by Khanal et al. [39] and Abid et al. [45], the difference in socioeconomic profiles of adapter and non-adapter farmers indicates an endogeneity problem in the sample. This suggests that merely comparing rice yields to assess adaptations' impact is not enough. Hence, we adopted another approach called endogenous switching regression to account for any hidden endogeneity of farmers' attributes while assessing adaptations' impact on rice yield.

Table 2. Mean comparison of adapters and non-adapters.

Variable	Adapters		Non-Adapters		Difference [1]
	Mean	Std. Dev.	Mean	Std. Dev.	
Rice yield maunds/acre	40.014	4.215	31.956	4.338	−8.059
Farmer's age	47.524	12.254	46.600	11.082	−0.924
Farmer's education	7.867	4.704	6.756	3.561	−1.111
Landholding	9.571	6.987	4.578	5.195	−4.994
Land ownership	0.914	0.281	0.822	0.384	−0.092
Tube well ownership	0.800	0.401	0.267	0.445	−0.533
Livestock animals	5.143	3.587	3.289	2.220	−1.854
Advisory	0.590	0.493	0.022	0.148	−0.568
Credit	0.462	0.500	0.011	0.105	−0.451
Climate risk perception					

[1] The difference was calculated by comparing variable means.

Farmers' Climate Change Adaptation Strategies

Table 3 outlines the key adaptation measures adopted by the farmers in the study area. Specifically, a majority of farmers (54%) indicated the use of supplemental irrigation as the major strategy to cope with increasing temperature and declining rainfall. Over the past decades, monsoon rainfall, which used to be a major irrigation source for rice cultivation, has significantly declined [26], leaving farmers no choice but to rely on groundwater to meet the irrigation demands of rice crops. Hence, they tend to apply more irrigation water to cope with rising temperatures and declining precipitation. Shifting crop cultivation dates is also an important strategy reported by many farmers (50%) in the study area. Our findings are similar to those reported in Africa [64] and east Asia [59], implying that rice growers alter sowing and harvesting times in line with the existing or potential climate variability to address negative effects. This apparently is a useful strategy proving great benefits to rice farmers in south Asia [32,39].

Furthermore, 40% of the farmers reported cultivation of climate-smart rice varieties to cope with the changing climate. The use of new rice varieties is based on the notion that previous rice seeds were not water-efficient or did not generate the required yields in the face of rising temperature and declining rainfall. The climate parameters of the study area indicate a decline in rainfall and a rise in temperature over the past two decades, which means that farmers need seed varieties that are heat tolerant and water efficient [26,65]. Our results are supported by previous studies [36,66], which reported the use of climate-smart crop varieties is an effective way to cope with growing variations in temperature and rainfall.

Table 3. Farmers' climate change adaptation measures.

Farmers' Adaptation Strategies	Description	%
Supplementary irrigation	Application of more water in case of exposure to high temperature, heat waves, declining rainfall	54.6
Cultivation dates changes	Shuffling of rice transplantation or harvesting dates, in line with changing climate/weather conditions	50.6
Climate-smart seeds	Cultivation of heat-tolerant/water-efficient rice seeds	40.0
Plot leveling and expansion	Laser land leveling and plot expansion to adapt to water shortages	35.6
Irrigation time changes	Application of water when evapotranspiration is at a minimum	29.3
Adaptation intensity		
Non-adopters	Farmers who did not adopt any adaptation measure	30
Only one adaptation measure	Farmers who adopted one adaptation measure	20
Two or three adaptation measures	Farmers who adopted two or three adaptation measures	22.7
Four or five adaptation measures	Farmers who adopted four or five adaptation measures	27.3

Furthermore, farmers reported expansion and leveling of rice plots to maximize water-use efficiency. Specifically, over one third of farmers said they expanded their rice fields after land leveling so they can minimize the cost of irrigation water. A study in India [67] also reported similar evidence, where land laser leveling was reported as a useful strategy to adapt to climate-induced water scarcity. Some farmers also stated they chose to irrigate their rice fields at times when the evapotranspiration rate is lowest. This practice is based on the belief that less water will be lost from the rice field, which will ultimately deliver savings on the irrigation cost. It is noted that for most farmers, climate change-related concerns and adaptation measures are connected to the use of irrigation water. This is due to the fact that climate change has significantly increased water shortages in the study area—which has become the chief concern of rice farming communities, given that rice is a highly water-dependent crop. Thus, shrinking of water resources directly threatens farmers' food security and livelihoods. There is a great deal of evidence that suggests that the irrigated plains region—one of the three agroecological zones in the Punjab consisting of rice-growing districts—is now among the country's most water-depleted regions [68,69].

We further found that farmers were relying on more than two adaptation measures, which means that adopting only one adaptation measure was not enough to cope with the nature of climate variations (only 20% of farmers stated adoption of only one adaptation measure). These results show a good level of adaptation diversification, which according to Teklewold et al. [70] is a positive determinant of a resilient farming system. In their study in Ethiopia, they found that the adoption of a wide range of adaptation measures helped to minimize the risks more effectively.

3.2. Determinants of Adaptation

In this section, we discuss the findings from the ESR model, which show determinants of adaptation and rice yield among the adapter and non-adapting farmers. This is followed by a discussion of the empirical results of the model, which measures the adaptation impact on rice yield.

Results show that farmers' socioeconomic attributes have had a significant influence on their adaptation decision. For example, results (Table 4) show that farmers' age had a negative influence on farmers' adaptation to climate change, while education showed a significant positive effect on farmers' adaptation strategies. These findings imply that older farmers are less likely to adapt to climate change. This may be because of their conventional beliefs, which according to some studies, obstruct them from changing their farming practices that they have been practicing for years [71]. Similarly, we found a greater likelihood of adaptation among educated farmers: the number of schooling years is shown to be a significant positive determinant of farmers' adaptation decisions. More education would seem to imply that farmers were more aware of climate change and contemporary farming practices, which positively influenced their adaptation intentions.

Previous studies in Africa and Asia also showed very strong evidence that education is a leading determinant of farmers' adaptation behavior [36,41,59].

Table 4. Endogenous switching regression results for adaptation and its impact on rice yields.

Variables	Adaptation	Rice Yield (log)	
		Adapters	Non-Adapters
Constant	−2.141454 *** (0.6907343)	32.96834 *** (1.913511)	30.8733 *** (2.92404)
Farmer's age	0.0083318 (0.0095696)	−0.0182437 (0.0237658)	0.0394303 (0.0410148)
Farmer's education	0.0601768 ** (0.029608)	0.0694225 (0.0712578)	−0.2329372 (0.1533016)
Landholding	0.0539234 ** (0.0219925)	0.0590873 (0.0431596)	0.3191014 ** (0.1474309)
Land ownership	−0.3650691 (0.2887994)	1.857263 * (1.013643)	−0.9821061 (1.162387)
Tube well ownership	0.5121965 ** (0.2108045)	2.503143 *** (0.709404)	2.269663 ** (0.9189126)
Livestock animals	0.18353 *** (0.052029)	0.2316303 *** (0.0748755)	−0.3248071 (0.2353002)
Advisory	0.6163903 ** (0.2513715)	2.926788 *** (0.6679898)	3.615 *** (1.32564)
Credit	0.8310979 *** (0.3033624)	0.5823645 (0.7386949)	−4.721033 ** (1.955272)
Climate risk perception	0.3030073 * (0.1793954)		
Sigma σA		1.244138 *** (0.0527176)	
Sigma σN			1.386696*** (0.1452405)
Rho ρA		−0.1418425 (0.2169182)	
Rho ρN			−1.034068** (0.4932166)

Values in parentheses are standard errors. * Significant at the 10% level. ** Significant at the 5% level. *** Significant at the 1% level.

In addition to these factors, farm-related attributes of farmers show a significant relationship with farmers' adaptation. For instance, farmers' land area is shown to be a significant positive determinant of farmers' adaptation decisions, while land ownership has an insignificant negative relationship. This means smallholder farmers are less likely to be the adapters to climate change. This may be traced to the income limits of those farmers with a limited land area, who are therefore less able to meet the cost of adaptation. Our results are supported by Arunrat et al. [59], who reported that smallholder farmers were less likely to adapt to climate change compared with the big landlords who have higher incomes. We also found that tube well ownership—an essential farm asset in water-depended farming such as rice cultivation—also showed a significant positive correlation with climate change adaptation decisions. For instance, given the types of climate challenges in the study area, such as extreme heatwaves, declining rainfall, and rising temperature [26,72], crops need a constant supply of irrigation to mitigate temperature shocks. Hence, owning an agriculture borewell helps farmers fulfill the water demands of crops. Similarly, livestock is another essential attribute of the rural households in Pakistan, which appears to have a significant positive effect on farmers' adaptation decisions. There is a greater likelihood of adaptation among the farmers having larger herd sizes, which implies that they have sufficient resources—in terms of reserved stock, precautionary saving, and source of organic fertilizer—to meet sudden changes in crop cultivation resources [36]. For instance, if farmers need to buy certain crop inputs, they can utilize the sale of some of their livestock. Our findings, however, are contrary to the results of the study of Shikuku et al. [73], who found a negative relationship between livestock rearing and east African farmers' adaptation intensity.

Besides socioeconomic and farm-related attributes, we further considered important institutional service access such as agricultural advisory and credit services. Our study shows that both attributes positively and significantly affected farmers' adaptation decisions. This means that farmers' access to updated farm management information and their access to credit services expedite their adaptation to climate change. Parallel with these results, Syed et al. [71] also reported advisory services among the leading determinants of farmers' adaptation behavior. That is, agricultural agents, by imparting climate-smart farm management knowledge, positively influenced farmers' adaptation behavior and convinced them to make adaptive adjustments to climate change risks. Our and Syed et al.'s [71] results were not in accord with the findings of Shikuku et al. [73], which showed an adverse effect of farm advisory services on farmers' adaptation.

In this study, credit availability is also shown to be an important influencer and motivator for many smallholders who would otherwise not adapt to climate change, given the financial constraints they face [36]. Easy access to agricultural loans helps them to meet the cost of adaptation and earn additional money from the crops. Therefore, credit positively and significantly affects rice farmers' adaptation to climate change. Masud et al. [41] and Ullah et al. [74] argued that credit services serve as safety nets for poor farm households, which help them meet the cost of adaptation, and suggest that a lack of such services may leave the food producers vulnerable to climate change.

In addition to the aforementioned factors, we measured farmers' climate risk perception as an independent variable to see how it influences their adaptation decisions. The results imply that farmers who perceive climate change as a high risk to their crops and livelihoods are more likely to be adapters of climate change compared to those who think climate change is not a serious risk. In this study, risk perception was based on two indicators—the likelihood and the impact of extreme climatic events. A similar study was conducted in Nepal [32], which reported climate change beliefs were among the key determinants of farmers' adaptation decisions. This is because only those farmers are likely to adjust their cropping operation to changing climate if they consider climate change as a risk to their crops [51,52].

3.3. Impact of Climate Change Adaptation on Rice Yield

In this study, we estimated the impact of adaptation on rice yield using three methods. First, we compared the average rice yields of adapting and non-adapting farmers. This revealed a significant variation in the average rice yield between adapters and non-adapter, with adapters achieving a higher rice yield (Table 2). We then carried out a simple linear regression analysis (Table A2) of adaptation, along with other explanatory variables and farmers' rice yield. We found that farmers' adaptation to climate change has significantly and positively affected rice yields. However, such approaches could be misleading as they assume adaptation as an exogenous factor, which, in fact, is endogenous [75]. However, the yield differences among farmers could be due to their unobservable characteristics [32,39]. Therefore, considering this limitation, we employed a third approach—endogenous switching regression, to count for hidden endogeneity.

The results of the endogenous switching regression model are given in Table 4 (columns 2 and 3) and take into account endogenous switching in the rice yield function. An intriguing finding is the signs and significance levels of the covariance terms ρ_A and ρ_N. The results show that self-selection occurred in adaptation, as the covariance term in the case of adapters is statistically significant. This means that the adaptation may not have the same effect on non-adapters if they had adapted [61,76]. Furthermore, the difference in the coefficient of adapters and adapters farmers' rice yields indicates the existence of heterogeneity in the sample. The results, therefore, show that farmers' access to irrigation sources—an essential determinant of rice cultivation in Punjab—and their access to agricultural advisory services appear to be key determinants of higher rice yields for both adopters and non-adopter farmers. By contrast, other factors such as their land area, livestock holding, and credit service access have differently affected the rice yield of both adopters and non-adopters.

The estimates of climate change adaptation impacts are given in Table 5, which shows rice yield among adopters (A) and non-adopter farmers (B); adapter's expected yield if they did not adapt (C); non-adapters' expected yield if they had adapted (D); estimates of average treatment effects (TT/TU) and heterogeneity effects (BH_1/BH_2). According to these results, farmers who adapted to climate change have achieved yields of nearly 40 maunds/acre of rice compared with 32 maunds/acre achieved by non-adapting farmers. This implies that climate change adaptation has increased the rice yield by 24%. The fourth column of Table 5 shows the average treatment effect of adaptation on rice yields. These treatment effects address the issue of selection bias that is due to the fact that adapters and non-adapters are fundamentally different [76]. The estimates show that farmers who adapted to climate change would have produced 3.1 maunds/acre or 306 kg/hectare (8%) less if they had not adapted to climate change. Similarly, farmers who did not adapt to climate change would have acquired 1.5 maunds/acre (5%) more rice yield if they had adapted to climate change. The statistics of heterogeneity effects are given in the last row of Table 5, which reveals that there are major sources of heterogeneity that enabled adapting farmers to produce a higher rice yield compared to non-adapters. Our results are consistent with the studies of Falco et al. [35] and Khanal et al. [32] suggesting a similar trend in terms of adaptations' impact on crop yield.

Table 5. Impact of adaptation on expected rice yield; treatment and heterogeneity effects.

Sub-Samples	Decision Stage		
	To Adapt	**Not to Adapt**	**Treatment Effects**
Adapters	(A) 39.99873 (0.2213014)	(C) 36.88996 (0.2247148)	(TT) 3.108768 *** (0.335161)
Non-adapters	(D) 33.59364 (0.3218094)	(B) 32.05963 (0.2534699)	(TU) 1.534011 *** (0.4117585)
Heterogeneity effects	BH_1 = 6.405088 *** (0.3793073)	BH_2 = 4.830331 *** (0.371489)	

*** Significant at the 1% level.

These findings infer that adaptation to climate change has a positive impact on rice productivity, given it increases the yields of adapting farmers. Our results are in line with the findings reported in Ethiopia [31] and Nepal [32,39], which also suggest that adaptation enhances farm productivity. However, the extent to which adaptation impacts rice yield is different. For instance, in Khanal et al.'s [39] study, a relatively higher rice yield (33%) was achieved by adapter farmers, while in our case, a 24% increase was achieved. Similarly, their study reported a 22% higher yield for non-adapting farmers if they had adapted, while in our case, this figure is substantially lower at 5%. The difference in estimates may be due to differences in farming systems and ecological features, and the socioeconomic profiles of the farmers.

3.4. Adaptation Implications for Rural Livelihoods and Food Security

In Pakistan, over 80% of the population lives in rural areas, and their livelihood is mainly associated with agriculture and related activities. Crop farming remains the major source of income and provides food for the majority of the population. In particular, major crops such as rice provide food and livelihood to millions of farm households in Punjab—a province producing over 60% of Pakistan's total rice output. Therefore, in these circumstances, adaptation to climate change can play a pivotal role in building the sustainability of rural livelihoods, as it is shown to improve rice productivity. Specifically, an increase in rice yields of 3.1 maunds/acre (or 306 kilograms/hectare) can significantly contribute to rice farm households' income and food security. For instance, on average, a farm household in the study area has a land area of 8 acres or 3 hectares (Table 1). This means that by adapting to climate change, farm households can acquire over 991 kilograms more rice, which, based on the minimum market value in the study area [77], can generate an additional PKR 99,109 (USD 713) in income.

Besides rice, another study has found a positive impact of adaptation on wheat production in the study area [45]. Importantly, rice and wheat remain the major agronomic crops of the region and face significant challenges from climate variability [21]. Adaptation, therefore, needs to be a priority for local and central governments. Although Pakistan has already formulated a climate change adaptation strategy and action plans for the agriculture sector at the federal level, the implementation of the intended adaptation actions remains limited [78]. This study argues for improving the current extent of adaptation action, as currently, most farmers do not adapt to climate change. In this case study, nearly one third of the farm households did not indicate taking any adaptation measure (Table 1). This indicates that there is a good opportunity to improve the extent of adaptation, which would deliver a positive impact on rural households' income and food security. This finding is likely to be relevant to other countries in south Asia whose crop sectors are highly vulnerable to climate change and therefore need to improve the sustainability and resilience of rural households.

4. Conclusions and Recommendations

In this study, we assessed the impact of adaptation on rice yields of farmers in the Punjab province of Pakistan, where climate change is adversely affecting rice crops. We used cross-sectional data of 480 randomly selected rice growers collected through face-to-face interviews. We modeled adaptation impacts on rice yields using three different approaches. First, we compared the average rice yields of adapters and non-adapters, which revealed significant differences, as the adapters' yield was significantly higher. Second, we used linear regression to assess adaptations' impact on rice yields and found a significant positive correlation between farmers' climate adaptation and rice yield. However, these approaches were not enough as they do not account for farmers' characteristics, which means that these results could be misleading and biased. Therefore, we used a third approach and employed the endogenous switching regression model to account for the hidden endogeneity of farmers' attributes.

The results show that farmers' adaptation has a significant positive effect on their rice yields. For example, adapter farmers obtained 24% more rice yield than non-adapting farmers. When we estimated the expected yields of non-adapters if they adapted and adopters if they did not adapt, we found intriguing results. Adapters would have acquired 8% less yield if they had not adapted to climate change, while non-adapters would have acquired a 5% greater yield if they had adapted to climate change. These findings thus indicate that adaptation to climate change has a positive effect on rice yields. The model further indicates farmers' attributes, such as their education, land size, availability of sources of irrigation and access to farm advisory and credit services, to be the positive determinants of their adaptation decisions and rice yields. This indicates the importance of these attributes in the adaptation of farming systems in the study area.

We further assessed farmers' climate risk perception and its relationship with farmers' adaptation decisions. We found that farmers who perceive climate change as a high-level risk to their crops and livelihoods were more likely to adapt to climate change. This implies that farmers' awareness of the climate risks to agriculture positively affects their adaptation behavior. Thus, relevant institutions, such as the agricultural extension department, should play their role in creating farmers' awareness of climate risks in the study area. Furthermore, farm advisory and credit services have a major role in improving farmers' adaptation. This implies that the provincial government and relevant departments should focus on improving these services as they appear to be lacking in the study area.

This study concludes that adaptation is a useful tool to cope with climate variability and changes at the local level. With minimum intervention, farmers' self-perceived and implemented adaptation measures (autonomous adaptation) are shown to be more effective in farming communities. Hence, this study shows that adaptation policies and action plans should embrace indigenous knowledge and local farming practices in the design of relevant policies. Although these findings are limited to the rice-growing regions of Punjab, other regions and countries in South Asia may acquire useful policy implications from this study.

This study has certain limitations. It used a relatively small sample size considering the population of rice farmers and ongoing farming activities; therefore, future research should consider using a larger sample size. Furthermore, this study evaluated the impact of adaptation in general rather than evaluating the effect of specific adaptation strategies; therefore, future studies should consider this aspect while conducting similar analysis using the endogenous switching regression model.

Author Contributions: Conceptualization, N.A.K.; Formal analysis, N.A.K. and A.A.S.; Funding acquisition, M.A.U.R.T.; Investigation, N.A.K. and A.A.S.; Methodology, N.A.K. and A.A.S.; Software, A.A.S.; Writing—original draft, N.A.K.; Writing—review & editing, U.K., C.W., A.A.S. and M.A.U.R.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data supporting reported results can be provided upon request to the interested individuals/researchers.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Validity test of selection instrument.

Variables	Coefficients	Standard Errors	P > |t|
Farmer's age	0.0364216	0.0432418	0.402
Farmer's education	0.2610317	0.1450883	0.076
Landholding	0.0946913	0.0810866	0.246
Land ownership	−2.211316	1.171173	0.063
Tube well ownership	2.875652	0.9516203	0.003
Livestock animals	0.133995	0.2056745	0.517
Advisory	10.70958	2.339443	0.000
Credit	−6.142214	2.322844	0.010
Climate risk perception	1.58667	0.9315362	0.102
F-stat 5.72			
N 144			

Dependent variable = rice yield (maund/acre) of the non-adapter farmers. Model: ordinary least squares (R-squared = 0.3914).

Table A2. Parameter estimates of rice yield equation on the pooled sample.

Variables	Coefficients	Standard Errors	P > |t|
Adaptation	2.125288	0.5478673	0.000
Farmer's age	0.0165303	0.0207599	0.427
Farmer's education	0.0594198	0.0638191	0.353
Landholding	0.125104	0.0412547	0.003
Land ownership	0.7809656	0.7448048	0.295
Tube well ownership	3.400462	0.5331311	0.000
Livestock animals	0.2024927	0.0706375	0.004
Advisory	3.517369	0.5799923	0.000
Credit	0.0177468	0.6709461	0.979
Constant	28.74557	1.377505	0.000
F-stat 46.25			
N 480			

Dependent variable = rice yield (maund/acre) of the pooled sample. Model: ordinary least squares (R-squared = 0.5894).

References

1. Byerlee, D. Technical Change, Productivity, and Sustainability in Irrigated Cropping Systems of South Asia: Emerging Issues in the Post-Green Revolution Era. *J. Int. Dev.* **1992**, *4*, 477–496. [CrossRef]
2. Farmer, B.H. The 'Green Revolution' in South Asian Ricefields: Environment and Production. *J. Dev. Stud.* **1979**, *15*, 304–319. [CrossRef]
3. Conway, G.R. The Properties of Agroecosystems. *Agric. Syst.* **1987**, *24*, 95–117. [CrossRef]
4. Conway, G.R. Agroecosystem Analysis. *Agric. Adm.* **1985**, *20*, 31–55. [CrossRef]
5. Byerlee, D.; Siddiq, A. Has the Green Revolution Been Sustained? The Quantitative Impact of the Seed-Fertilizer Revolution in Pakistan Revisited. *World Dev.* **1994**, *22*, 1345–1361. [CrossRef]
6. Aryal, J.P.; Sapkota, T.B.; Khurana, R.; Khatri-Chhetri, A.; Rahut, D.B.; Jat, M.L. Climate Change and Agriculture in South Asia: Adaptation Options in Smallholder Production Systems. *Environ. Dev. Sustain.* **2020**, *22*, 5045–5075. [CrossRef]
7. Yan, S.; Alvi, S. Food Security in South Asia under Climate Change and Economic Policies. *Int. J. Clim. Chang. Strat. Manag.* **2022**, *14*, 237–251. [CrossRef]
8. Shivakoti, G.P.; Janssen, M.A.; Chhetri, N.B. Agricultural and Natural Resources Adaptations to Climate Change: Governance Challenges in Asia. *Int. J. Commons* **2019**, *13*, 827–832. [CrossRef]
9. Field, C.B.; Barros, V.R.; Dokken, D.J.; Mach, K.J.; Mastrandrea, M.D.; Bilir, T.E.; Chatterjee, M.; Ebi, K.L.; Estrada, Y.O.; Genova, R.C. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*; Cambridge University Press: New York, NY, USA, 2014.
10. Bandara, J.S.; Cai, Y. The Impact of Climate Change on Food Crop Productivity, Food Prices and Food Security in South Asia. *Econ. Anal. Policy* **2014**, *44*, 451–465. [CrossRef]
11. Crane, T.A.; Delaney, A.; Tamás, P.A.; Chesterman, S.; Ericksen, P. A Systematic Review of Local Vulnerability to Climate Change in Developing Country Agriculture. *WIREs Clim. Chang.* **2017**, *8*, e464. [CrossRef]
12. Partey, S.T.; Zougmoré, R.B.; Ouédraogo, M.; Campbell, B.M. Developing Climate-Smart Agriculture to Face Climate Variability in West Africa: Challenges and Lessons Learnt. *J. Clean. Prod.* **2018**, *187*, 285–295. [CrossRef]
13. Pachauri, R.K.; Allen, M.R.; Barros, V.R.; Broome, J.; Cramer, W.; Christ, R.; Church, J.A.; Clarke, L.; Dahe, Q.; Dasgupta, P. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Geneva, Switzerland, 2014; ISBN 9291691437.
14. Shah, A.A.; Khan, N.A.; Gong, Z.; Ahmad, I.; Naqvi, S.A.A.; Ullah, W.; Karmaoui, A. Farmers' Perspective towards Climate Change Vulnerability, Risk Perceptions, and Adaptation Measures in Khyber Pakhtunkhwa, Pakistan. *Int. J. Environ. Sci. Technol.* **2022**. [CrossRef]
15. Eckstein, D.; Künzel, V.; Schäfer, L.; Winges, M. *Global Climate Risk Index 2020*; Germanwatch e.V.: Bonn, Germany, 2019.
16. Lal, M. Implications of Climate Change in Sustained Agricultural Productivity in South Asia. *Reg. Environ. Chang.* **2011**, *11*, 79–94. [CrossRef]
17. Aggarwal, P.K.; Sivakumar, M.V.K. Global climate change and food security in South Asia: An adaptation and mitigation framework. In *Climate Change and Food Security in South Asia*; Springer: Dordrecht, The Netherlands, 2010; pp. 253–275.
18. FAOSTAT. *Food and Agriculture Organization of the United Nations, 2010*; FAOSTAT: Roma, Italy, 2016.
19. Chaudhry, Q.-Z.; Mahmood, A.; Rasul, G.; Afzaal, M. *Climate Change Indicators of Pakistan*; Pakistan Meterological Department: Islamabad, Pakistan, 2009.
20. Abid, M.; Scheffran, J.; Schneider, U.A.; Ashfaq, M. Farmers' Perceptions of and Adaptation Strategies to Climate Change and Their Determinants: The Case of Punjab Province, Pakistan. *Earth Syst. Dyn.* **2015**, *6*, 225–243. [CrossRef]
21. Ahmad, A.; Ashfaq, M.; Rasul, G.; Wajid, S.A.; Khaliq, T.; Rasul, F.; Saeed, U.; Rahman, M.H.; Hussain, J.; Ahmad Baig, I. Impact of climate change on the rice–Wheat cropping system of Pakistan. In *Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project Integrated Crop and Economic Assessments, Part 2*; World Scientific: Singapore, 2015; pp. 219–258.
22. Sarkar, S. Pakistan Floods Pose Serious Health Challenges. *BMJ* **2022**, *378*, o2141. [CrossRef]
23. Shah, A.A.; Gong, Z.; Khan, N.A.; Khan, I.; Ali, M.; Naqvi, S.A.A. Livelihood Diversification in Managing Catastrophic Risks: Evidence from Flood-Disaster Regions of Khyber Pakhtunkhwa Province of Pakistan. *Environ. Sci. Pollut. Res.* **2021**, *28*, 40844–40857. [CrossRef]
24. Shah, A.A.; Gong, Z.; Khan, N.A.; Ali, M.; Ahmad, M.; Abbas, A.; Shahid, A. Reconnoitering School Children Vulnerability and Its Determinants: Evidence from Flood Disaster-Hit Rural Communities of Pakistan. *Int. J. Disaster Risk Reduct.* **2021**, *70*, 102735. [CrossRef]
25. Hina, S.; Saleem, F. Historical Analysis (1981–2017) of Drought Severity and Magnitude over a Predominantly Arid Region of Pakistan. *Clim. Res.* **2019**, *78*, 189–204. [CrossRef]
26. Khan, N.A.; Gao, Q.; Abid, M.; Shah, A.A. Mapping Farmers' Vulnerability to Climate Change and Its Induced Hazards: Evidence from the Rice-Growing Zones of Punjab, Pakistan. *Environ. Sci. Pollut. Res.* **2020**, *28*, 4229–4244. [CrossRef] [PubMed]
27. Khatri, I. Current locust threats and measures in pakistan. *Pak. J. Agric. Agric. Eng. Vet. Sci.* **2019**, *35*, 67–71.
28. Kirsch, T.D.; Wadhwani, C.; Sauer, L.; Doocy, S.; Catlett, C. Impact of the 2010 Pakistan Floods on Rural and Urban Populations at Six Months. *PLoS Curr.* **2012**, *4*, e4fdfb212d2432. [CrossRef] [PubMed]

29. Ullah, F.; Saqib, S.E.; Ahmad, M.M.; Fadlallah, M.A. Flood Risk Perception and Its Determinants among Rural Households in Two Communities in Khyber Pakhtunkhwa, Pakistan. *Nat. Hazards* **2020**, *104*, 225–247. [CrossRef]
30. GoP Government of Punjab. *Statistical Pocket Book of the Punjab*; Bureau of Statistics: Lahore, Pakistan, 2019.
31. Amare, A.; Simane, B. Does Adaptation to Climate Change and Variability Provide Household Food Security? Evidence from Muger Sub-Basin of the Upper Blue-Nile, Ethiopia. *Ecol. Process.* **2018**, *7*, 13. [CrossRef]
32. Khanal, U.; Wilson, C.; Lee, B.L.; Viet-Ngu, H. Climate Change Adaptation Strategies and Food Productivity in Nepal: A Counterfactual Analysis. *Clim. Chang.* **2018**, *148*, 575–590. [CrossRef]
33. Suresh, K.; Khanal, U.; Wilson, C.; Managi, S.; Quayle, A.; Santhirakumar, S. An Economic Analysis of Agricultural Adaptation to Climate Change Impacts in Sri Lanka: An Endogenous Switching Regression Analysis. *Land Use Policy* **2021**, *109*, 105601. [CrossRef]
34. Kabir, M.J.; Alauddin, M.; Crimp, S. Farm-Level Adaptation to Climate Change in Western Bangladesh: An Analysis of Adaptation Dynamics, Profitability and Risks. *Land Use Policy* **2017**, *64*, 212–224. [CrossRef]
35. di Falco, S.; Veronesi, M.; Yesuf, M. Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia. *Am. J. Agric. Econ.* **2011**, *93*, 829–846. [CrossRef]
36. Sertse, S.F.; Khan, N.A.; Shah, A.A.; Liu, Y.; Naqvi, S.A.A. Farm Households' Perceptions and Adaptation Strategies to Climate Change Risks and Their Determinants: Evidence from Raya Azebo District, Ethiopia. *Int. J. Disaster Risk Reduct.* **2021**, *60*, 102255. [CrossRef]
37. Füssel, H.-M. Adaptation Planning for Climate Change: Concepts, Assessment Approaches, and Key Lessons. *Sustain. Sci.* **2007**, *2*, 265–275. [CrossRef]
38. Rahman, H.M.; Hickey, G.M. What Does Autonomous Adaptation to Climate Change Have to Teach Public Policy and Planning about Avoiding the Risks of Maladaptation in Bangladesh? *Front. Environ. Sci.* **2019**, *7*, 2. [CrossRef]
39. Khanal, U.; Wilson, C.; Viet-Ngu, H.; Lee, B. Farmers' Adaptation to Climate Change, Its Determinants and Impacts on Rice Yield in Nepal. *Ecol. Econ.* **2018**, *144*, 139–147. [CrossRef]
40. Joshi, B.; Ji, W.; Joshi, N.B. Farm Households' Perception on Climate Change and Adaptation Practices A Case from Mountain District of Nepal. *Int. J. Clim. Chang. Strat. Manag.* **2017**, *9*, 433–445. [CrossRef]
41. Masud, M.M.; Azam, M.N.; Mohiuddin, M.; Banna, H.; Akhtar, R.; Alam, A.S.A.F.; Begum, H. Adaptation Barriers and Strategies towards Climate Change: Challenges in the Agricultural Sector. *J. Clean. Prod.* **2017**, *156*, 698–706. [CrossRef]
42. Thinda, K.T.; Ogundeji, A.A.; Belle, J.A.; Ojo, T.O. Understanding the Adoption of Climate Change Adaptation Strategies among Smallholder Farmers: Evidence from Land Reform Beneficiaries in South Africa. *Land Use Policy* **2020**, *99*, 104858. [CrossRef]
43. Abid, M.; Scheffran, J.; Schneider, U.A.; Elahi, E. Farmer Perceptions of Climate Change, Observed Trends and Adaptation of Agriculture in Pakistan. *Environ. Manag.* **2019**, *63*, 110–123. [CrossRef] [PubMed]
44. Fahad, S.; Wang, J.L. Farmers' Risk Perception, Vulnerability, and Adaptation to Climate Change in Rural Pakistan. *Land Use Policy* **2018**, *79*, 301–309. [CrossRef]
45. Abid, M.; Schneider, U.A.; Scheffran, J. Adaptation to Climate Change and Its Impacts on Food Productivity and Crop Income: Perspectives of Farmers in Rural Pakistan. *J. Rural Stud.* **2016**, *47*, 254–266. [CrossRef]
46. Ali, A.; Erenstein, O. Assessing Farmer Use of Climate Change Adaptation Practices and Impacts on Food Security and Poverty in Pakistan. *Clim. Risk Manag.* **2017**, *16*, 183–194. [CrossRef]
47. Udimal, T.B.; Liu, E.; Luo, M.; Li, Y. Examining the Effect of Land Transfer on Landlords' Income in China: An Application of the Endogenous Switching Model. *Heliyon* **2020**, *6*, e05071. [CrossRef] [PubMed]
48. Grothmann, T.; Patt, A. Adaptive Capacity and Human Cognition: The Process of Individual Adaptation to Climate Change. *Glob. Environ. Chang.* **2005**, *15*, 199–213. [CrossRef]
49. Tan, S.; Li, T.; Huntsinger, L. Analyzing Herder Adaptive Capacity to Climate Change: A Case Study from an Ecologically Fragile Area in Inner Mongolia, People's Republic of China. *Hum. Ecol.* **2018**, *46*, 399–409. [CrossRef]
50. Engle, N.L. Adaptive Capacity and Its Assessment. *Glob. Environ. Chang.* **2011**, *21*, 647–656. [CrossRef]
51. Bryan, E.; Ringler, C.; Okoba, B.; Roncoli, C.; Silvestri, S.; Herrero, M. Adapting Agriculture to Climate Change in Kenya: Household Strategies and Determinants. *J. Environ. Manag.* **2013**, *114*, 26–35. [CrossRef] [PubMed]
52. Kato, E.; Ringler, C.; Yesuf, M.; Bryan, E. Soil and Water Conservation Technologies: A Buffer against Production Risk in the Face of Climate Change? Insights from the Nile Basin in Ethiopia. *Agric. Econ.* **2011**, *42*, 593–604. [CrossRef]
53. Mitter, H.; Larcher, M.; Schönhart, M.; Stöttinger, M.; Schmid, E. Exploring Farmers' Climate Change Perceptions and Adaptation Intentions: Empirical Evidence from Austria. *Environ. Manag.* **2019**, *63*, 804–821. [CrossRef] [PubMed]
54. Schmitzberger, I.; Wrbka, T.; Steurer, B.; Aschenbrenner, G.; Peterseil, J.; Zechmeister, H.G. How Farming Styles Influence Biodiversity Maintenance in Austrian Agricultural Landscapes. *Agric. Ecosyst. Environ.* **2005**, *108*, 274–290. [CrossRef]
55. Siddiqui, R.; Samad, G.; Nasir, M.; Jalil, H.H. The Impact of Climate Change on Major Agricultural Crops: Evidence from Punjab, Pakistan. *JSTOR* **2012**, *51*, 261–276. [CrossRef]
56. Khattak, M.S.; Ali, S. Assessment of Temperature and Rainfall Trends in Punjab Province of Pakistan for the Period 1961–2014. *J. Himal. Earth Sci.* **2015**, *48*, 42–61.
57. Li, S.; Juhász-Horváth, L.; Harrison, P.A.; Pintér, L.; Rounsevell, M.D.A. Relating Farmer's Perceptions of Climate Change Risk to Adaptation Behaviour in Hungary. *J. Environ. Manag.* **2017**, *185*, 21–30. [CrossRef] [PubMed]

58. Khan, N.A.; Shah, A.A.; Tariq, M.A.U.R.; Chowdhury, A.; Khanal, U. Impact of Farmers' Climate Risk Perception and Socio-Economic Attributes on Their Choice of ICT-Based Agricultural Information Services: Empirical Evidence from Pakistan. *Sustainability* **2022**, *14*, 10196. [CrossRef]
59. Arunrat, N.; Wang, C.; Pumijumnong, N.; Sereenonchai, S.; Cai, W. Farmers' Intention and Decision to Adapt to Climate Change: A Case Study in the Yom and Nan Basins, Phichit Province of Thailand. *J. Clean. Prod.* **2017**, *143*, 672–685. [CrossRef]
60. Grey, S.; Raymond, G.; Phil, W.; Cooper, D. *Project Risk Management Guidelines: Managing Risk in Large Projects and Complex Procurements*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2005; ISBN 978-0-470-02282-5.
61. Lokshin, M.; Sajaia, Z. Maximum Likelihood Estimation of Endogenous Switching Regression Models. *Stata J.* **2004**, *4*, 282–289. [CrossRef]
62. Raza, M.H.; Khan, G.A.; Shahbaz, B.; Saleem, M.F. Effectiveness of Information and Communication Technologies as Information Source among Farmers in Pakistan. *Pak. J. Agri. Sci.* **2020**, *57*, 281–288.
63. Iqbal, M.A.; Ping, Q.; Abid, M.; Kazmi, S.M.M.; Rizwan, M. Assessing Risk Perceptions and Attitude among Cotton Farmers: A Case of Punjab Province, Pakistan. *Int. J. Disaster Risk Reduct.* **2016**, *16*, 68–74. [CrossRef]
64. Amare, Z.Y.; Ayoade, J.O.; Adelekan, I.O.; Zeleke, M.T. Barriers to and Determinants of the Choice of Crop Management Strategies to Combat Climate Change in Dejen District, Nile Basin of Ethiopia. *Agric. Food Secur.* **2018**, *7*, 37. [CrossRef]
65. Mahmood, N.; Ahmad, B.; Hassan, S.; Bakhsh, K. Impact of Temperature ADN Precipitation on Rice Productivity in Rice-Wheat Cropping System of Punjab Province. *J. Anim. Plant Sci.* **2012**, *22*, 993–997.
66. Alauddin, M.; Sarker, M.A.R. Climate Change and Farm-Level Adaptation Decisions and Strategies in Drought-Prone and Groundwater-Depleted Areas of Bangladesh: An Empirical Investigation. *Ecol. Econ.* **2014**, *106*, 204–213. [CrossRef]
67. Khatri-Chhetri, A.; Aggarwal, P.K.; Joshi, P.K.; Vyas, S. Farmers' Prioritization of Climate-Smart Agriculture (CSA) Technologies. *Agric. Syst.* **2017**, *151*, 184–191. [CrossRef]
68. Watto, M.A.; Mugera, A.W. Irrigation Water Demand and Implications for Groundwater Pricing in Pakistan. *Water Policy* **2016**, *18*, 565–585. [CrossRef]
69. Watto, M.A.; Mugera, A.W.; Kingwell, R.; Saqab, M.M. Re-Thinking the Unimpeded Tube-Well Growth under the Depleting Groundwater Resources in the Punjab, Pakistan. *Hydrogeol. J.* **2018**, *26*, 2411–2425. [CrossRef]
70. Teklewold, H.; Mekonnen, A.; Kohlin, G. Climate Change Adaptation: A Study of Multiple Climate-Smart Practices in the Nile Basin of Ethiopia. *Clim. Dev.* **2019**, *11*, 180–192. [CrossRef]
71. Syed, A.; Liu, X.; Moniruzzaman, M.; Rousta, I.; Syed, W.; Zhang, J.; Olafsson, H. Assessment of Climate Variability among Seasonal Trends Using In Situ Measurements: A Case Study of Punjab, Pakistan. *Atmosphere* **2021**, *12*, 939. [CrossRef]
72. Khan, N.A.; Gao, Q.; Abid, M. Public Institutions' Capacities Regarding Climate Change Adaptation and Risk Management Support in Agriculture: The Case of Punjab Province, Pakistan. *Sci. Rep.* **2020**, *10*, 14111. [CrossRef] [PubMed]
73. Shikuku, K.M.; Winowiecki, L.; Twyman, J.; Eitzinger, A.; Perez, J.G.; Mwongera, C.; Läderach, P. Smallholder Farmers' Attitudes and Determinants of Adaptation to Climate Risks in East Africa. *Clim. Risk Manag.* **2017**, *16*, 234–245. [CrossRef]
74. Ullah, R.; Jourdain, D.; Shivakoti, G.P.; Dhakal, S. Managing Catastrophic Risks in Agriculture: Simultaneous Adoption of Diversification and Precautionary Savings. *Int. J. Disaster Risk Reduct.* **2015**, *12*, 268–277. [CrossRef]
75. di Falco, S.; Veronesi, M. How Can African Agriculture Adapt to Climate Change? A Counterfactual Analysis from Ethiopia. *Land Econ.* **2013**, *89*, 743–766. [CrossRef]
76. Abdulai, A.; Huffman, W. The Adoption and Impact of Soil and Water Conservation Technology: An Endogenous Switching Regression Application. *Land Econ.* **2014**, *90*, 26–43. [CrossRef]
77. AMIS Agriculture Marketing Information Service, Directorate of Agriculture (Economics & Marketing) Punjab, Lahore. 2021. Available online: http://Www.Amis.Pk/ViewPrices.Aspx?SearchType=0&commodityId=3 (accessed on 12 January 2022).
78. Khan, N.A.; Gong, Z.; Shah, A.A.; Leng, G. Formal Institutions' Role in Managing Catastrophic Risks in Agriculture in Pakistan: Implications for Effective Risk Governance. *Int. J. Disaster Risk Reduct.* **2021**, *65*, 102644. [CrossRef]