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Impact of Farmers' Climate Risk Perception and Socio-Economic Attributes on Their Choice of ICT-Based Agricultural Information Services: Empirical Evidence from Pakistan

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Abstract: In Pakistan, research on information and communication technologies-based agricultural information services (ICTbAIS) have gained significant attention owing to the overwhelming population of smallholder farmers (whose information needs are unable to be met by the conventional extension services) and the increasing incidence of climatic risk. This study is, therefore, conducted in the Punjab province of Pakistan (mixed cropping region) to explore farmers' use of ICTbAIS and understand the relationship between farmers' socio-economic attributes, risk perception, and choices of ICTbAIS. A sample of 480 farmers was drawn using a multistage sampling approach, and farmers were interviewed face-to-face. To analyze the dataset, a multivariate Probit (MVP) model was employed. The results show that Television (TV) and mobile-based advisory and mobile-based consultations appeared to be the most used ICTbAIS, followed by radio and internet-based advisory. The estimates of the MVP model showed that farmers' age, education, farmland, tenancy status, off-farm income, and climate risk perception are significant determinants of their choices of ICTbAIS. Based on our results, we suggest policymakers and extension agencies to improve the content of ICTbAIS and make efforts for the awareness and training of farmers regarding the use of contemporary ICTs.

Keywords: climate risk; agriculture; internet; social media; communication technologies; Pakistan

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1. Introduction

In recent years, farmers' access to and availability of diverse information sources has improved significantly, thanks to information and communication technologies [1–3]. Conventionally, farmers used to receive advisory from agricultural extension officers or so-called change agents through face-to-face interactions [4,5]. This is challenging in the current century as the population of farmers has grown overwhelmingly. Thus, the ratio of change agents to farmers has shrunken significantly and is unable to meet farmers' growing information requirements [6,7]. In this scenario, ICTbAIS serve a vital role in meeting the information gap between the research-based knowledge and the end-users [8,9]. Particularly in the face of changing climate and induced catastrophes, when farmers' information-seeking behavior and information needs also vary [10,11].

Pakistan is one of the world's five most susceptible countries to the impacts of climate change [12]. The country's climate has changed dramatically in the last 60 years, with the temperature rising by about half a degree Celsius on average [13,14]. As a result of this increase in temperature, rainfall patterns have become significantly variable, worsening the intensity and likelihood of climate-associated disasters such as floods, droughts, and insect/pest assaults [15–17]. Cropping cycles are also greatly disrupted, impacting the yields of main crops in places like Punjab province [18,19]. Farmers' adaptation and risk management techniques are needed in the face of these environmental variances to survive climate change. Adaptation strategies are deemed vital for climate risk management in agriculture. These strategies alter the timing of crop planting and harvesting, as well as the application of agricultural inputsnd soil and water management procedures [20–23].

Farmers' access to weather and climate forecasts is crucial for adequate adaptation actions. Farmers who have comprehensive knowledge of current or anticipated weather patterns can make the necessary crop adjustments to prevent possible pitfalls [10,11]. To accomplish this, they require constant farm guidance and must be aware of current and future climatic patterns. In this connection, institutions play a critical role in increasing farmers' access to the necessary advisory services that assist them in understanding climate change and appropriate reaction strategies [24,25]. In Pakistan, institutions like the Directorate of Agricultural Extension are responsible for providing farmers with the knowledge they need to cope with climate change [26,27]. However, owing to the increasing population of farmers in Pakistan, the ratio of farmers to extension agents has decreased drastically in recent decades [28,29].

In response to this situation, both public and private entities have launched a variety of ICT-based advisory services [9,30]. Thus, farmers' rising information demands are being met by a wide range of advisory through ICT mediums such as radio and television broadcasts and agricultural directorates' helplines (calls and SMS services). Numerous mobile-based advisory services have subsequently been launched, sending daily farm recommendations, weather predictions, and market rates of farm commodities to farmers' cell phones [1,31]. To receive these alerts, a user must be registered to all these services through the mobile phone network operator. As a result of burgeoning internet use by the rural population in Pakistan, there are several online forums and social networking sites where farmers may engage and debate agricultural and animal production problems [32]. In light of the fact that these services are now an essential element of farm advice, it is time to find out how they help farmers satisfy their information needs and also how are the climate risk conditions in the study area by assessing farmers' risk perception.

According to earlier research in Pakistan, farmers' use of ICT-based advising services has been studied without conjunction with farm-level climate risk perception. An illustration of this is in the studies in Punjab [1,9,32,33] that investigated the efficiency of various ICT-enabled agricultural information sources and discovered that the use of ICT-based farm advisory is closely correlated to farmers' digital literacy. Khan et al. [1] studied the constraints that hinder the adoption of mobile phone-based advisories in Pakistan's remote regions. According to their findings, one of the most significant impediments to the adoption of ICT-provided farm advisory is the lack of alignment between the delivered knowledge and farmers' actual needs. Besides, other studies have also looked at the link between farmers' perceptions of risk and their socio-economic characteristics [34–36]. They discovered that farmers' perception of climate risk is influenced by their total land area, irrigation water availability, agricultural extension services, and weather forecasts. Nevertheless, to the authors' knowledge, no prior research has examined the connection between farmers' climate risk perception and socio-economic factors and the usage of ICT-based farm advisory services. The current research fills up this knowledge void.

The focus of this research is to thoroughly examine farmers' usage of contemporary communication methods and advisory services in response to climatic risks. Specifically, the objectives of the research include (1) identifying which farm advisory services and sources of information are most commonly used by farmers; (2) finding out how farmers in the research area perceive risk; and (3) examining the association between farmers' socio-economic factors, their perception of climate risk, and their choices of ICTbAIS usage. This research adds to the global body of knowledge on the human dimension of climate change (climate change risk perception) and the role of information and communication technology for development (ICT4D) (significance of ICT-based agricultural extension services in the deliverance of farm innovations). The current study findings would assist policymakers in establishing policies that encourage using contemporary information technologies to improve farm production.

The remainder of this research is organized as follows. Section 2 describes a theoretical model and conceptual framework on ICT use and its determinants. Sections 3 and 4 provide the research methodology and analytical framework, correspondingly. The results of the study are presented in Section 5, and the discussion is presented in Section 6. The paper's conclusion and ramifications are presented in the final section.

2. Theoretical Model and Conceptual Framework

This study has chosen the technology acceptance model (TAM) as a heuristic for this empirical research [37]. TAM provides the conceptual foundation of our research by exploring the factors that shaped the intention of farmers to use ICT-based farm advisory services. TAM is derived from the theory of reasoned action (TRA), a model to explain people's behavior and intention as they relate to a range of activities [38]. Personal beliefs and subjective norms are the key elements of TRA that affect people's anticipations and attitudes, enhancing their desire to carry out a behavior. Davis et al. [37] employed TRA to explore the behavior of individuals regarding the use of ICT [39] by introducing various factors that shaped the first version of TAM. Over time, the TAM has developed into a conceptual model widely employed by researchers across disciplines and improved by additional external variables (e.g., level of education, age, experience, perceived responsiveness, and institutional support); Legris et al. [40] added organizational support into TAM stating that it is more important in shaping ICT use than user perception of the technology; Amirtha et al. [41] added household characteristics-related variables to TAM, exploring their effects on ICT use; Taherdoost [42] assessed how individuals' acceptance and usage of ICT are determined primarily by their satisfaction with the system's quality. The TAM model has also been used in agricultural extension research that analyzes factors affecting the use of ICT for agricultural information dissemination and utilization by extension agents and farmers; Sivakumar et al. [43] investigated the factors (e.g., age, education, income, job experience) shaping the usage of computers by Indian field workers. However, to our best knowledge, none of any previous research has considered the use of variables related to climate change risk. Climate change affects farmers' livelihoods [44], crops and livestock production, thus may have a major role in farm-related decisions, including the use of ICT types. Therefore, we add farmers' perception of climate change risk as one factor influencing their use of farm advisory through different ICTs.

Building on TAM, the following conceptual framework (Figure 1) is developed, where we have added climate change risk perception as the stimulus of ICT adoption; given the climate variability, farmers perceive the risks shaping their information needs. To elaborate, it shows that the process of adoption of ICTs for climate-smart agriculture information (CSAI) is prompted by climatic change or any uncertainty in crop cultivation. Farmers' risk perception is shaped by the level of exposure to climate change. Climate risk perception then serves as a key factor influencing their information needs. For example, given any crop risks, farmers tend to seek advisory to intensify their crop production or manage posed climatic risks. This determines farmers' information needs and information-seeking preferences, motivating them to look for available agricultural information sources that may assist them in climate-smart management of their farms [45]. Such advisory is generally accessible through various sources such as television, radio, mobile advisories, and the internet [46,47]. Such ICT tools allow actors to communicate farm knowledge, thus enhancing opportunities for shared learning and improvements in agricultural productions. Hence, information-seeking behavior is constructed based on the farmers' actual needs in terms of local cropping patterns, farming strategies, and any possible exposure to production risks, which are pivotal attributes in determining information needs, access, and usage.

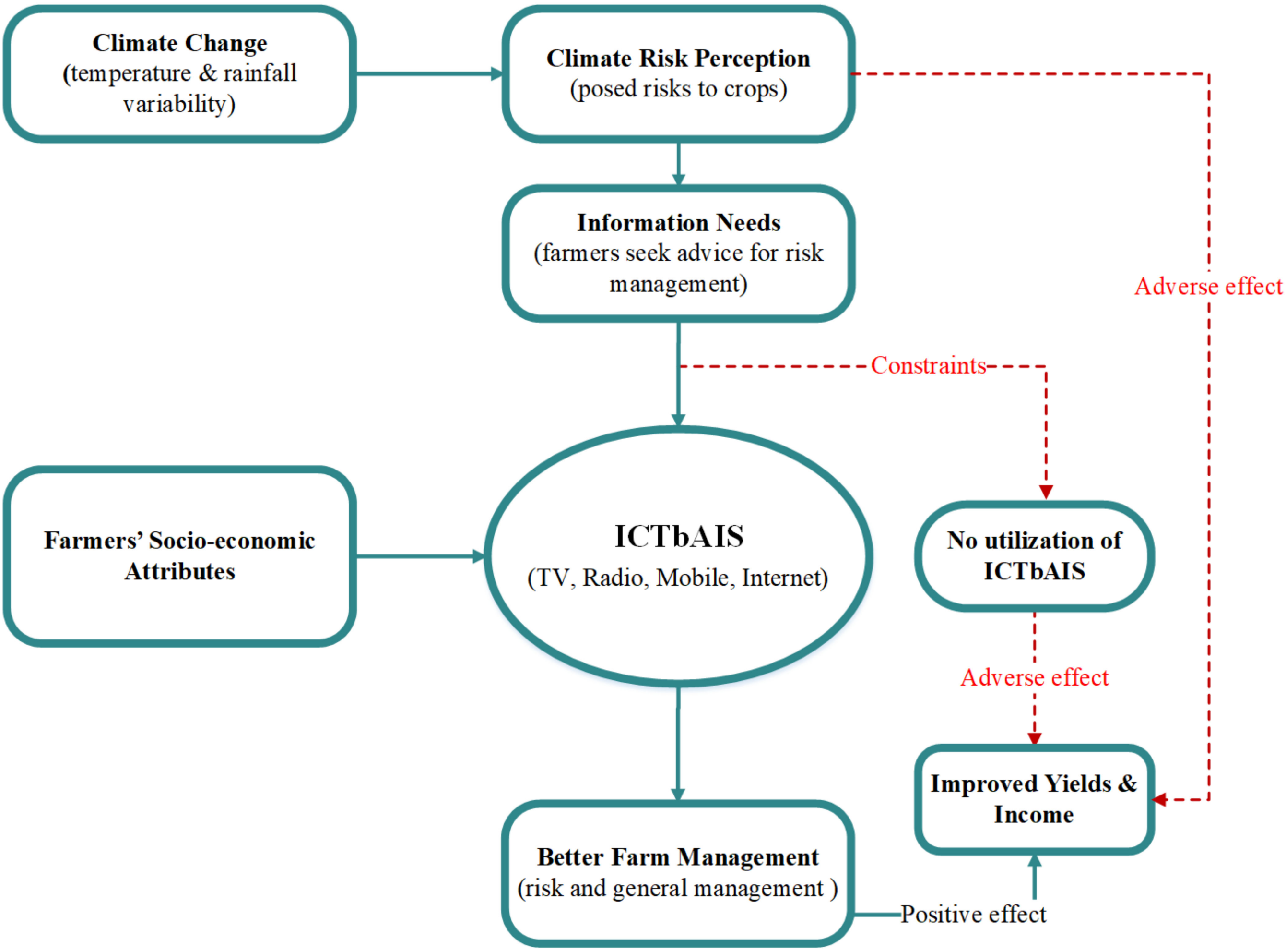

Figure 1. Conceptual framework.

Theoretical perspectives and empirical research further argue that the use of such ICTbAIS varies from community to community in terms of farmers' socio-economic attributes [10,11,45]. As some farmers with low education levels or those mainly relying on their indigenous farm knowledge may not equally utilize such information sources [5,48]. In contrast, farmers eager to implement new knowledge on their farms tend to look for and apply farm innovation delivered through various contemporary communication mediums. Such farmers are usually fairly educated, having basic know-how of modern communication devices such as computers and smartphones (along with the use of the internet). While, if they lack rudimentary skills needed to operate smartphones, possibly owing to certain constraints (varying region to region), they fail to effectively utilize modern communication mediums and the knowledge rendered through them [30]. Lastly, if farmers effectively utilize knowledge across these digital platforms, they are more likely to achieve higher crop production due to the skills they attain through updated agricultural information.

Based on the above discussion, we considered farmers' socio-economic and farm-related attributes and their perception of climate change risks to develop the following hypotheses.

Hypothesis 1. *Adoption of ICTbAIS is influenced by farmers' socio-economic characteristics such as farmers' age, education, family size, primary occupation, and non-farm income.*

Hypothesis 2. *Adoption of ICTbAIS is influenced by farm-related attributes such as farmers' land size, tenancy status, ownership of tube well, and livestock animals.*

Hypothesis 3. *Adoption of ICTbAIS is influenced by farmers' perception of climate change risks.*

3. Methods

3.1. Research Area

This study was conducted in the mixed cropping zone of Punjab province, a region that is known for its agricultural production. Punjab is chosen as the key site for this research owing to its agricultural significance (it produces 70% of total cereal crops and accounts for over half of agricultural GDP) and climate change vulnerability [19,49]. The region has continuously been facing climate variation and meteorological disasters in the past few decade especially the irrigated plains (mixed cropping zone) [25,34]. Resultantly, crop productions are under severe threat from these climate risks. Further, all the contemporary agricultural advisory sources are available in the region, which farmers access to meet their information needs. Thus, we decided to explore farmers' information-seeking behavior (in the light of climate risk) in the mixed cropping zone of Punjab. Punjab is also the most populous province of Pakistan, having the majority of its population residing in the countryside and associated with agricultural and associated ventures [26,49]. Rice and wheat are the major crops cultivated in the study area. Further, farmers also rear livestock (both for commercial and domestic use) along with crop cultivation. Overall, the region has a hot and cold climate.

3.2. Sampling and Data Collection Methods

To select respondents from the study area, a multistage sampling design was used where farmers were selected from different sites in the area. The rationale for using this sampling approach was due to the varying hierarchical level of the local population residing in the study area. Literature advocates the use of such a method when the population is scattered at various levels [50]. Then the sample is selected by choosing respondents from each stage. The key advantages of using this approach include flexibility in deciding the number of stages and methods and the number of sampling units from each stage, which make this approach more convenient in meeting survey re-equipment [51]. Hence following previous studies [14,52], we have selected the respondent involving six stages.

Firstly, we purposely selected the mixed cropping zone of Punjab province. Following this, four districts were randomly chosen using a simple random sampling approach. These districts include Nankana, Sheikhupura, Gujranwala, and Kasur. The map of the study district is shown in Figure 2. At stage three, we chose two sub-districts (towns) from each district, making a total of eight towns. At stage four, we chose four union councils (UCs, the second-smallest administrative unit of local government structure in Pakistan) from each town, comprising a total of sixteen UCs. Stage five involved a random selection of eight villages from each UC, making a total of 32 villages. In addition, at the sixth and last stage, fifteen farmers were randomly selected from each village, making a total sample of 480 farmers. Table 1 provides detailed statistics of the sampled respondents from different localities of the study area. Data were accrued using a predesigned structured questionnaire by face-to-face interviews with farmers. The questionnaire's key parts included information about farmers' socio-economic attributes, climate risk perception, and their use of various ICTbAIS. Data were collected between March and August 2019.

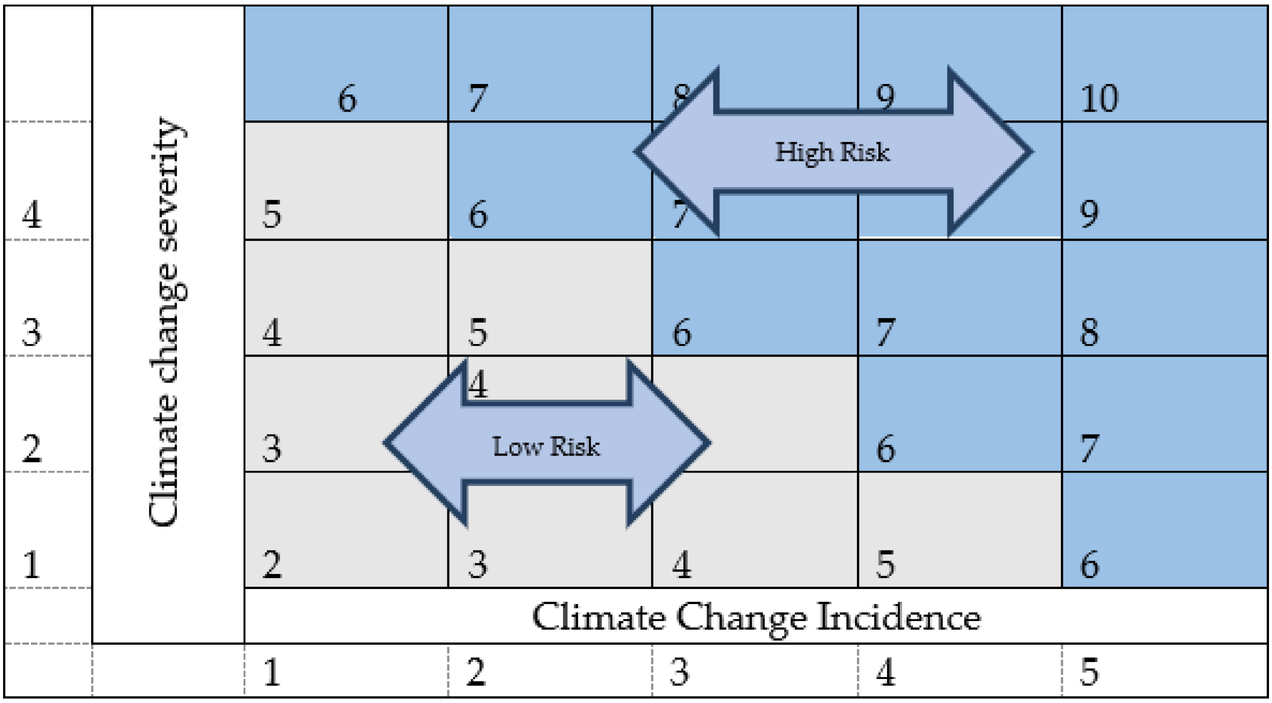

Figure 2. Risk matrix.

Table 1. Distribution of sample and sampling stages.

Districts	Sub-Districts	Union Councils	Villages	Farmers Interviewed
Gujranwala	2	4	8	120
Sheikhupura	2	4	8	120
Nankana Sahib	2	4	8	120
Kasur	2	4	8	120
Total	8	16	32	480

3.3. Analytical Framework and Estimation Model

3.3.1. Climate Risk Perception

Indices in risk and climate change research are widely acknowledged as an efficient technique to represent and quantify complicated data sets. An index is constructed by aggregating datasets that have been standardized before the index is constructed [27]. Following Iqbal et al [34], we employed the risk matrix method to construct a climate risk perception index. As part of the risk matrix method, respondents were asked to rank climate risks on a scale from 1 (very low) to 5 (very high) in terms of their risk incidence and severity. Figure 3 shows a matrix of farmers' responses on the incidence and severity of climate change, which were then pooled against both variables. A cumulative computed score of 2 to 5 was considered low, and a cumulative determined score of 6 to 10 was ranked high. For example, if the sampled farmers had provided an incidence score of 6 and an impact score of 2, then the calculated risk score was 8, considered high risk. After that, we modified the scores on a dichotomous scale: 1 for high climate risk (score range 6–10) and 0 for low climate risk (score range 2–5) [19].

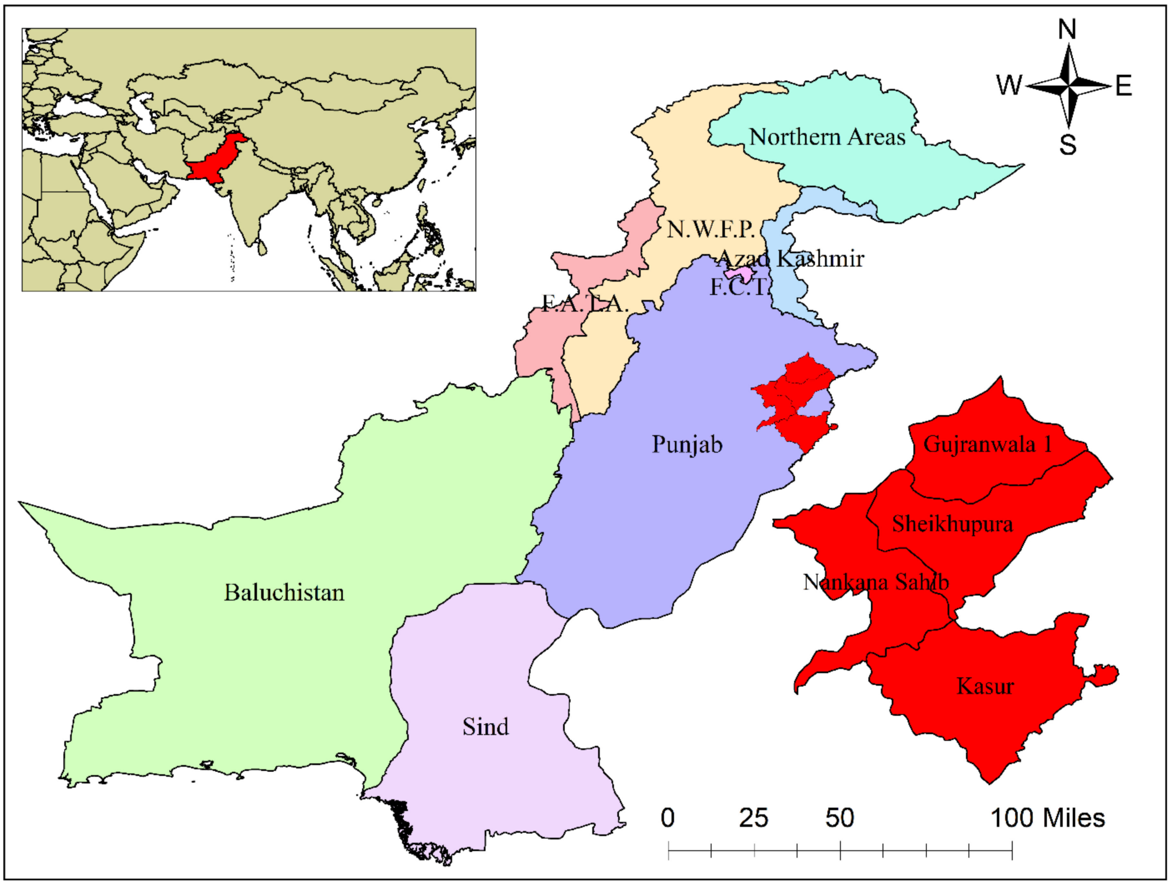

Figure 3. Map of the study area.

3.3.2. Determinants of ICTbAIS Choices: Multivariate Probit Model (MVP)

Since farmers in the study area use multiple information sources to know about farm management strategies to cope with climate variability rather than relying on a single information source; thus, their decisions to use one particular advisory type may depend on the decision to utilize another source—allowing the possibility of correlation between dependent variables (multiple advisory sources). This also implies that the error term of the regression model of one advisory source may correlate with that of another [53]. Therefore, the multivariate probit (MVP) model appeared to be the most suitable to minimize the estimation bias and cover the existence of concurrent correlation among multiple farm advisory services and consequent correlation among error terms [10,53,54].

Consider the i-th farmer (i = 1, ... , N) that is opting for a decision on whether or not to use a certain available farm advisory service. Y_k^* represent the benefit of using the kth advisory, where k represents the choice of Radio-based advisory (RbA), TV-based advisory (TVbA), Mobile-based advisory (MobbA), Mobile-based consultations (MobbC), and Internet-based advisory (IbA). The farmer chooses to access the kth advisory if $Y_{ik}^* = U_k^* - U_0 > 0$, with Y_{ik}^* denoting the net benefit from the use of the k-th advisory. Y_{ik}^* is unobservable because it is subjective. Alternatively, it can be expressed as a latent variable function as follows:

$$Y_{ik}^* = X_i'\alpha_k + C_i\beta_k + CRP_i'\gamma_k + \varepsilon_{ik},\ Y_{ik} = \begin{cases} 1 & if\ Y_{ik}^* > 0 \\ 0 & otherwise \end{cases} \tag{1}$$

where Y_{ik}^* is a latent variable representing the probability of farm advisory service k (k = RbA; TVbA; MobbA; MobbC or IbA). Y_{ik}^* is observed by binary observed variable Y_{ik}, with $Y_{ik} = 1$ if advisory service k is used by farmers and $Y_{ik} = 0$ otherwise. X_i' is the vector of socio-economic attributes related variables (e.g., farmers' age, education level, and farm size); C_i is a dummy variable depicting whether a farmer has owned an irrigation borewell (1 = Yes and 0 = No); CRP_i' is a vector of variables capturing the perception of climate risk as high-risk. α_k, β_k and γ_k are parameters to be estimated; and ε_k is an error term. Equation (1) is estimated by the Geweke–Hajivassiliou–Keane (GHK) simulation method for maximum likelihood estimation, using the Stata commands "mvprobit" [55,56].

4. Results

4.1. Descriptive Statistics of Study Variables

4.1.1. Farmers' Socio-Economic Attributes

The descriptive statistics of farmers' socio-economic attributes are shown in Table 2, which reveals farmers' average age to be 47 years, the majority being middle-aged and old-aged. Education levels further reveal that farmers' attained levels of education are also low (average years of schooling appeared to be 7 years only compared to highest levels of 18). Farmers can hardly read or write the national language (Urdu) at this literacy level. Further, the average size of the farm household was six members, while a significant majority of the farmers were associated with farming as their primary source of income. Furthermore, on average, a farm household owned 8 acres of cultivable land. Most of the farmers owned the land, while one-fifth of the farmers practiced agriculture as tenants. Moreover, tube wells, a major source of irrigation water in the study area, appeared to be possessed by over two-thirds of the farm households. Similarly, the mean of total livestock units (large animals such as cows and buffaloes) reared by a household was four, while the income generated from the non-farming sources was around 11,000 Pakistan rupees.

Table 2. Variable definitions and summary statistics.

Variable Name	Definition	Mean	Std. Dev.	Min.	Max.
	Independent explanatory variables (Socio-economic attributes)				
Farmers' age	Continuous (years)	47.246	11.903	0	82
Education level	Continuous (years of schooling)	7.533	4.415	1	18
Family size	Continuous (household members)	6.580	1.591	3	12
Primary occupation	Dummy (1 = farming, 0 = otherwise)	0.780	0.410	0	1
Land size	Continuous (number of Acres [1])	8.073	6.885	1	40
Tenancy status	Dummy (1 = farmer is owner of the land, 0 = tenant)	0.88	0.32	0	1
Agri Borewell	Dummy (1 = owned a tube well, 0 =No)	0. 640	0.480	0	1
Livestock	Continuous (number of large animals)	4.586	3.344	0	20
Non-farm income	Continuous (monthly income from non-farm sources, 000 PKR [2])	11.050	10.880	0	40
Climate risk perception	Dummy (1= farmer considers climate change as high risk, 0 =No)	0.506	0.500	0	1
	Dependent variables (ICT-enabled advisory services)				
Radio-based advisory	1 = Advisory through radio, 0 = No	0.213	0.410	0	1
Television-based advisory	1 = Advisory through TV, 0 = No	0.480	0.500	0	1
Mobile-based advisory	1 = Advisory through mobile, 0 = No	0.413	0.493	0	1
Mobile consultation	1 = Mobile-based consultation with friends and experts, 0 = No	0.473	0.500	0	1
Internet-based advisory	1 = Advisory through internet, 0 = No	0.213	0.410	0	1

[1] land unit in Pakistan (1 hectare = 2.47 acre); [2] PKR = Pakistani rupees.

4.1.2. Climate Risk Perception

As described earlier, as a part of our study, we also assessed farmers' perception of climate change risk in the study area by employing the risk matrix method. The risk matrix assessed farmers' perception of climate change risk on two indicators, i.e., risk incidence and risk severity. The results show over half of the farmers perceived changing climate as a high risk for their crops. Specifically, most farmers believed that climate change's occurrence (incidence) is larger than its impacts (severity). This translates into the fact that such changes in local weather patterns, especially temperature and rainfall (the main variables of risk matrix perception), have been altered significantly.

4.1.3. ICT-Based Agricultural Information Services in the Study Area

Further, the results of dependent variables, ICTbAIS, show that farmers mostly relied on TV (48%), mobile-based farm advisory (42%), and mobile phone-based consultation (47%) with experts and friends (having more farm knowledge) as their key information source (Figure 4). A mobile-based farm advisory is an SMS alert that is delivered to subscribed customers' mobile phones by local network providers. These services include *Jazz Bakhabar Kissan, Telenor Khushaal Zamindar, Zong Kissan Portal*, and *Ukissan*, which deliver day-to-day market updates on farm inputs and weather forecasts, and other advisories. The use of these services was followed by advisory through radio (21%) and the internet (21%). Specifically, the major source of information through radio were programs being aired on the Lahore Radio Station. In contrast, the prevalent use of the internet for farm information was through the use of social media, where the majority indicated the use of Facebook and WhatsApp (Figure 5), only 1.6% of respondents utilized search or web browsing to access agriculture information.

Regarding the type of accessed agricultural information (Figure 6), most farmers used ICTs to access market rates of farm commodities (82%) and weather forecasts (78%), followed by information relating to harvesting (46%), climate-smart seeds (46%), fertilizer (44%), and water management (42%). In contrast, the least accessed information includes advisory about animal feeds (8%), post-harvest practices (15%), and animal diseases (16%).

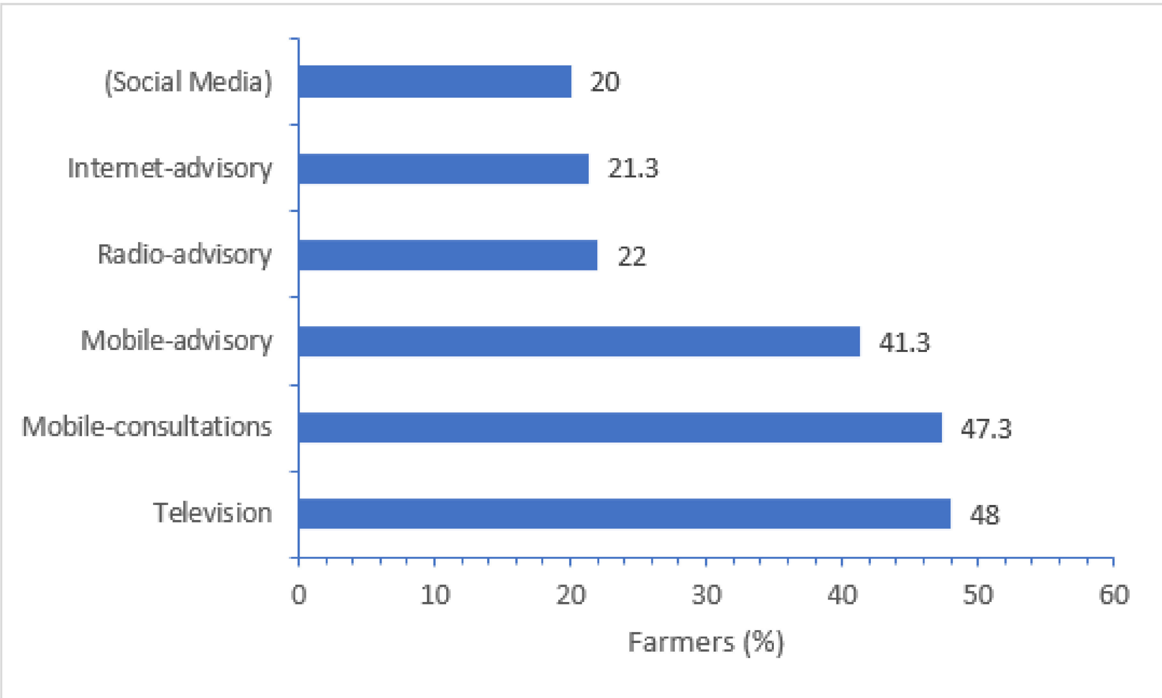

Figure 4. ICT-based agricultural information services (ICTbAIS) used by farmers.

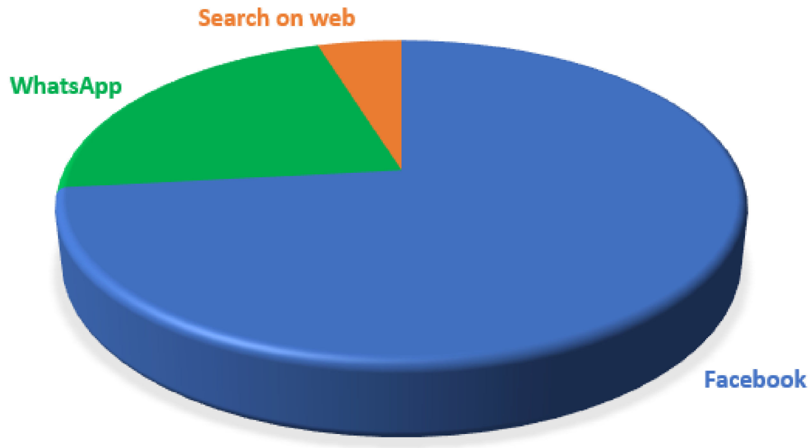

Figure 5. Use of internet for agriculture information access.

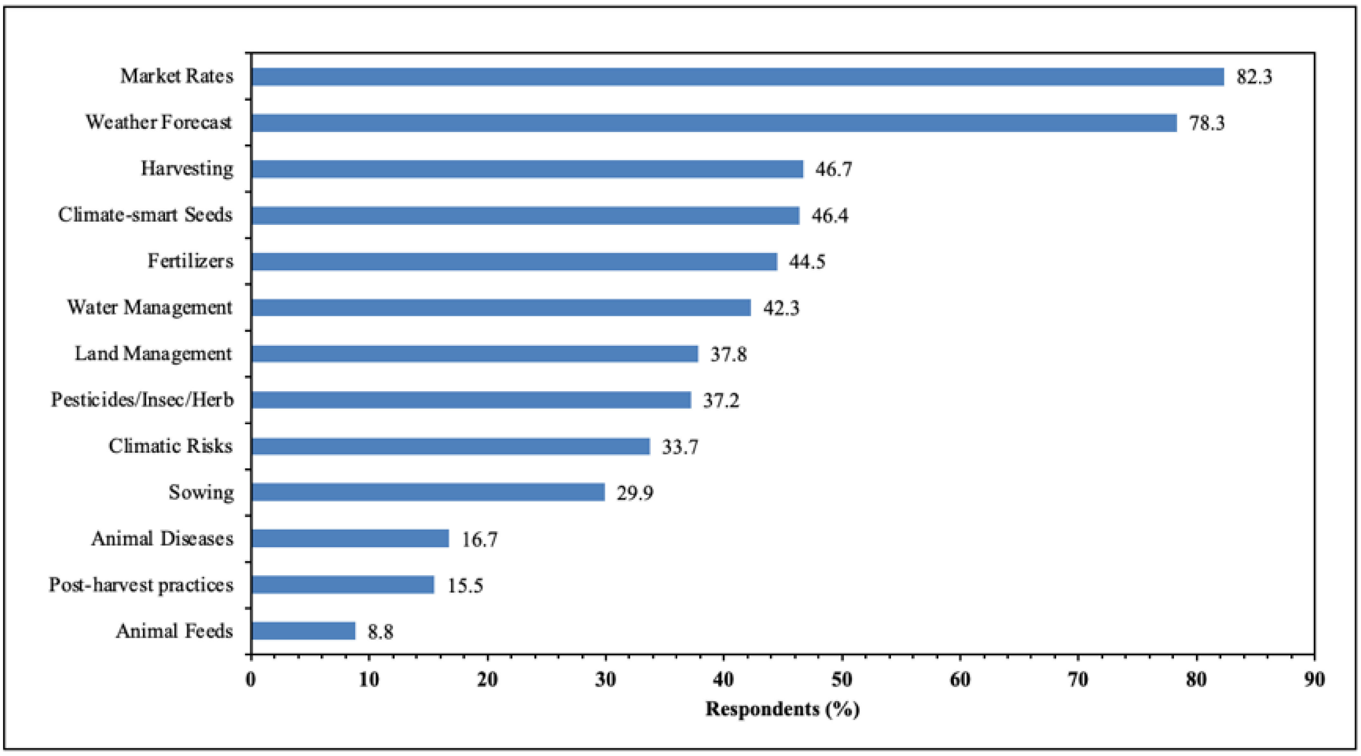

Figure 6. Types of information accessed by farmers.

4.2. Determinants of ICTbAIS

A multivariate probit model is used to assess the relationship between farmers' socio-economic attributes, risk perception, and choices of ICTbAIS. The results in Table 3 (along with the graphical presentation in Figure 7) show that the farmers' age has had a significant positive relationship with the use of advisory through radio and at $p < 0.01$ significance level, while it has negatively influenced farmers' choice of mobile phone-based consultation ($p < 0.05$) and the use of the internet for farm information access ($p < 0.01$). Further, the education levels of the farmers have shown a significant positive effect on the use of mobile agro alerts ($p < 0.01$) and internet-based advisory services ($p < 0.05$). On the other hand, farm household size has not shown a significant correlation with any of the services; however, it has positively influenced most of the services except internet-based advisory. Further, agriculture, the major source of household income (primary occupation), has shown a significant positive impact on farmers' choice of mobile-based agriculture advisory. Similarly, non-farm income, income generated through non-agriculture and livestock sources, also showed a significant positive effect on farmers' use of mobile-based consultation with friends and experts for agriculture advice. Thus, these findings indicate that Hypothesis 1—the adoption of ICTbAIS is influenced by farmers' socio-economic characteristics such as their age, education level, family size, primary occupation, and non-farm income—is largely true, as 4 out of 5 variables showed a significant relationship with farmers use of ICTbAIS.

Similarly, farmers' land size has shown a significant positive correlation with TV-based advisory ($p < 0.01$) and advisory through the internet ($p < 0.1$). Farmers' tenancy status, whether a farmer is an owner or a leased farmer of the land they cultivate, has also positively and significantly influenced internet-based information sources at a $p < 0.05$ significance level. A farmer's ownership of an irrigation water pump (agriculture borewell) is also an important determinant of household decisions. Intriguingly, it has shown a significant negative relationship with radio-based advisory ($p < 0.05$), while it has shown a significant positive correlation with mobile-based consultation ($p < 0.01$). Likewise, the number of livestock animals reared by a household also has shown no significant association with any ICTbAIS; however, it has positively affected the use of all services. Hence, Hypothesis 2—the adoption of ICTbAIS is influenced by farm-related attributes such as farmers' land size, tenancy status, ownership of tube well, and the number of livestock animals— is largely true, as 3 out of 4 variables showed a significant relationship with farmers use of ICTbAIS.

Table 3. Determinants of ICT-based advisory choices: Results from MVP model.

Explanatory Variables	**Radio-Based Advisory**	**TV-Based Advisory**	**Mobile Agro Alerts**	**Mobile Consultations**	**Internet-Based Advisory**
Farmer's age	0.055 ***	0.048 ***	0.012	−0.017 **	−0.115 ***
	(0.010)	(0.009)	(0.008)	(0.008)	(0.018)
Education level	−0.023	−0.017	0.153 ***	−0.035	0.104 **
	(0.031)	(0.027)	(0.029)	(0.027)	(0.043)
Family size	−0.075	0.093	0.048	0.035	−0.102
	(0.071)	(0.060)	0.058)	(0.055)	(0.081)
Primary occupation	0.341	0.358	0.702 ***	−0.069	−0.057
	(0.322)	(0.245)	(0.242)	(0.227)	(0.284)
Land size	0.012	0.033 ***	−0.006	−0.013	0.032 *
	(0.017)	(0.016)	(0.013)	(0.013)	(0.020)
Tenancy status	0.469	−0.437	0.168	−0.122	0.959 **
	(0.321)	(0.288)	(0.300)	(0.261)	(0.462)
Agri Borewell	−0.471 **	−0.292	0.123	0.492 ***	−0.096
	(0.222)	(0.206)	(0.193)	(0.185)	(0.284)
Livestock	0.004	−0.003	0.018	0.003	0.058
	(0.038)	(0.029)	(0.026)	(0.026)	(0.037)
Off-farm income	−0.016	0.007	0.009	0.027 **	−0.021
	(0.012)	(0.010)	(0.010)	(0.010)	(0.014)
Climate risk perception	0.026	−0.161	−0.503 ***	−0.351 **	0.751 ***
	(0.203)	(0.179)	(0.177)	(0.164)	(0.240)
Constant	−3.305 ***	−2.749	−2.995 ***	0.582	2.347 **
	(0.764)	(0.637)	(0.661)	(0.602)	(0.986)
Wald chi2(60)	260.46				
Prob > chi2	0.000				
Log likelihood	−712.522				
Number of observations	480				
Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: chi2(10) = 44.6233, Prob > chi2 = 0.0000					

Standard errors in parentheses, *** represent $p < 0.01$, ** represent $p < 0.05$, and * $p < 0.1$.

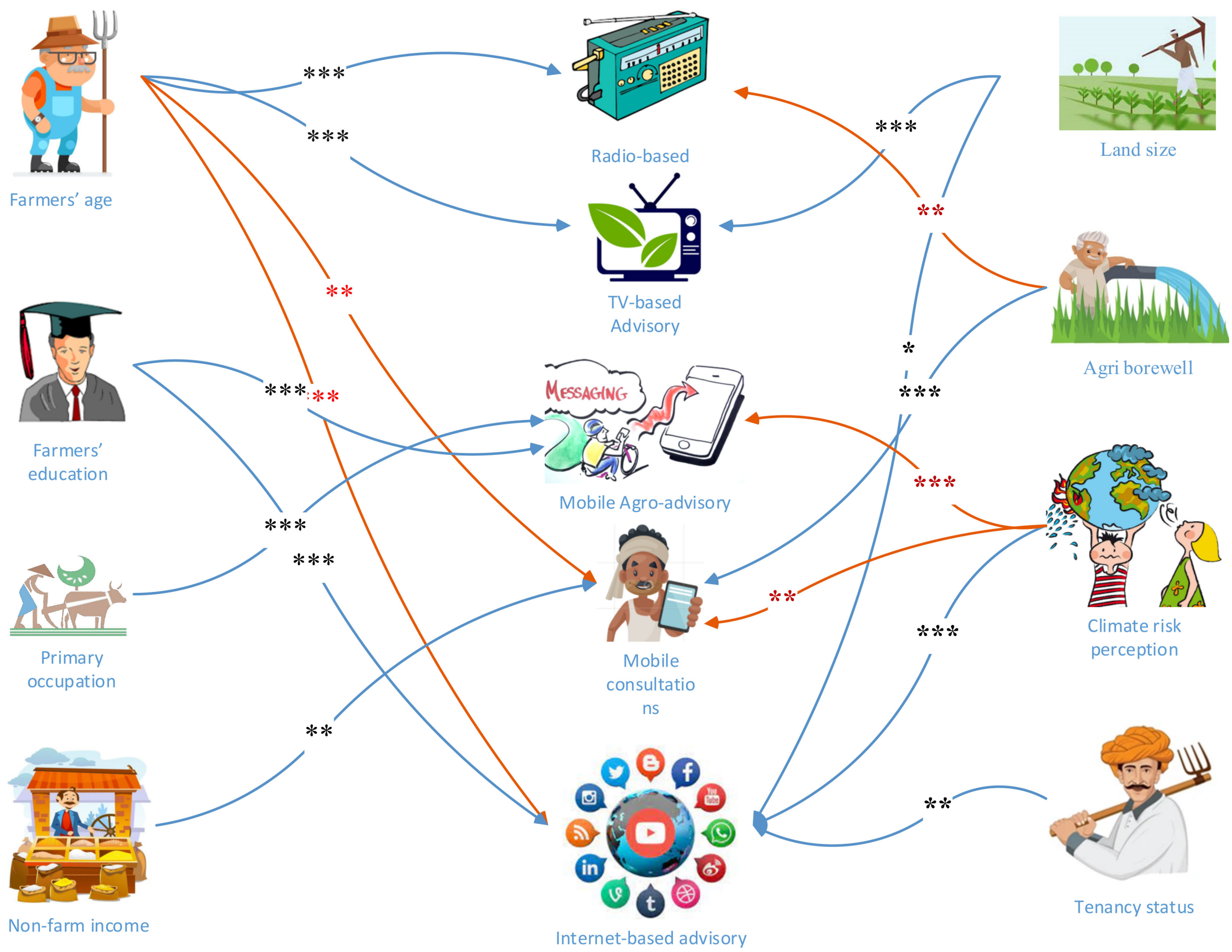

Figure 7. Graphical presentation of the relationship between farmers' attributes, climate risk perception, and ICTbAIS choices. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; Red color presents negative while blue presents positive relationship.

Besides, farmers' risk perception of changing climate also showed varied correlations with their choice of ICTbAIS. For instance, it has positive and significant influenced farmers' use of Internet-based advisory ($p < 0.05$), while it is negatively associated with their use of mobile-based farm advisory ($p < 0.01$) and radio-based farm advisory ($p < 0.01$). Thus, these results confirm that Hypothesis 3 is also true—the adoption of ICTbAIS is influenced by farmers' perception of climate change risks.

5. Discussion

5.1. Farmers' Use of ICTbAIS

ICTbAIS has gained significant attention in Pakistan owing to its utility in reaching farmers' information needs compared with information delivery through conventional sources. However, the adoption rate is still not as high as in developed countries. For instance, our results show that the highly adopted ICTbAIS source is TV, which is still counted among the traditional ICT compared with contemporary mediums such as smartphones and the internet. Most farmers use TV because it is easy to operate, access information, and comprehend the delivered information, given the audio plus video demonstration. It is found that visual aids serve a great deal of understanding if the information is coupled with images, animation, or video clips to demonstrate the practice or farm innovation being rendered.

Our results depict that although the contemporary sources (mobile phones and the internet) were adopted by a considerable portion of the farming communities, the adoption rate is still critically low. For instance, only one-fifth of the sampled respondents use the internet. The same applies to mobile-delivered farm advisory, which has not improved much in recent years and is still used by less than half of the farmers. A similar study [33] was conducted in Pakistan in the year 2019 that reported the use of mobile phone-based farm advisory by 37% of farmers, and yet the adoption rate of mobile-based farm advisories, the leading ICTAIS in Pakistan, is almost the same (41% as per our findings). The reason for lacking significant improvements is believed to be the absence of communication infrastructure, although some studies do not consider it as a constraint in Pakistan anymore [1,33], and farmers' illiteracy in using digital platforms given their low education levels [10,57]. It could also be due to lacking compatibility of farmers' needs with provided information which, according to a study [3] can be improved by collaboration between local departments and farmers. Besides mobile-based farm advisory, farmers utilize mobile devices to hold personal discussion sessions with their friends or expert from the private agricultural companies' officers to consult on different farming matters. They usually make calls to ask a more experienced friend about any possible countermeasure if a pathogen attacks his crops or if there is sudden climate variability or weather fluctuation in the region. Another study in India [58] also showed that such communications are very common among the farmers to consult with experts; perhaps farmers feel more comfortable in personal communication to acquire information.

Radio was also a major source of farm-related information for many respondents, mainly old-age farmers. It was found that the local radio channels, including the national radio stations and local Frequency Modulation (FM) channels such as FM103, are important information sources for farmers. Further, agricultural discussions and advisory, which also contain the advertisement for farm inputs, are the major sources of agricultural information. Khet Khet Haryali and Khushaal Kissan are the key programs aired on these channels. It is widely reported that radio has been a major source of communicating agricultural knowledge to farming communities. For instance, studies in Africa [47,59] show wide evidence of the use of this tool to deliver information to farmers regarding their crop-related decisions and is largely boosting smallholder farmers' agricultural production.

Lastly, the internet use is reported by one-fifth of the farmers, which is improved compared with the previous studies' findings [33,60]. The use internet for agricultural information access is mainly the use of social media platforms such as Facebook and WhatsApp. There are several local groups and pages for agricultural discussion and consultation, such as the Pakistan Agricultural Discussion Forum (a locally managed Facebook group), which farmers reported as the major source of information through the internet. WhatsApp, which is a social media messaging application, is also an important source of personal communication and video/image sharing platform, allowing farmers to communicate complex matters with fellow farmers. Such platforms have gained significant prominence due to increased study area climate risk. For instance, people can disseminate the news in social media groups whenever there are sudden weather variabilities. We have also found evidence of post-disaster assistance communication in the Facebook group. For instance, farmers ask about the possible measure for their crops if they are badly affected by an extreme windstorm and erratic rainfall. Various studies in developed and developing countries, have widely acknowledged the usefulness of such internet-based advisory sources. For instance, Tan et al. [61] argue that in China, farmers access information about the marketing of farm produces using social media platforms such as WeChat, and in Australia, farmers also have a higher usage rate of website browsing [62]. Similarly, in the United Kingdom use of Twitter enables researchers and advisers to interact and share knowledge with farmers [63].

We found that most farmers used these ICTbAIS to acquire information about the marketing of farm produce and weather forecasts (Figure 6). Higher usage of these content reveals that farmers generally require updated market prices of their farm commodities, which they sell to the local markets. In this regard, updated market rates are extremely useful for them; hence, they were accessed the most. Similar findings are reported in

Zimbabwe, where farmer's market information is reported to be the highly used content [64]. Weather information is another most accessed content by the farmers. Since climate variability has made farm production more susceptible to yield losses, farmers tend to stay updated by knowing the potential climate and weather patterns using mobile phone-based weather forecast applications and weather alerts delivered through mobile phones and television. This enables them to stay prepared to cope with potential weather fluctuation [23]. Unlike weather forecasts, only one-third of respondents appeared to access information about potential climate risks such as drought, floods, or heat waves. This could possibly be due to forecasting agencies' lack of accuracy in predicting risks or the lack of information available on these platforms. Khan et al. [33] reported lacking accuracy of meteorological agencies as the key constraint in the usage of climate information.

Similarly, harvest-related information has appeared to be highly used advisory, except for the post-harvest, implying that farmers need information on matters pertaining to harvesting time and harvesting methods. Moreover, less than half of the farmers accessed information related to basic agronomic operations such as sowing, irrigation, and land management. This could be due to their self-sufficiency in indigenous knowledge that does not require them to attain information regarding these aspects.

5.2. Determinants of Farmers' Choices of ICTbAIS

We further examined the influence of farmers' socio-economic attributes and their climate risk perception on their choices of ICTbAIS. We found that these factors have variedly affected their decisions using various ICTbAIS. Specifically, farmers' age appeared to be the key determinant significantly affecting four out of five ICTbAIS. We found that farmers of higher age were more likely to access radio and TV-based advisory, while they had a lesser tendency to use mobile phones and the internet for accessing agricultural information. This is mainly because age depicts crucial factors, such as cultural beliefs of the people and more farming experience. Thus, farmers with higher farming experience (strictly associated with cultural beliefs and having dependence on indigenous knowledge) tend not to utilize contemporary ICT tools. A study in India [10] contradicts our findings revealing that most young farmers prefer using conventional ICT tools such as radio and TV for accessing farm advisory, arguing that the information is more understandable to them on these platforms. This difference might be due to different socio-economic attributes and communication infrastructure in both countries.

We further found the farmers' education levels were likely to increase the adoption of mobile phone and internet-based farm advisory services. This is mainly due to their ability to read and understand content in both English and Urdu, available on social media platforms. In addition, less educated farmers also face more constraints in using ICT devices such as computers and smartphones; thus, they are less likely to use such mediums for accessing agriculture information. Mittal et al [10] also support our findings stating that farmers' education levels are the positive determinants of ICT use for accessing agriculture advisory services, especially the modern ICTs. Furthermore, farmers whose primary livelihood source was agriculture were highly likely to use mobile-based farm advisory delivered to their devices via recorded voice calls (robocalls) or text messages. These services are believed to be used by those farmers who are more concerned about their farm income as they mainly rely on agriculture.

Land size also determined the choice of certain ICTbAIS. For instance, farmers with larger farm sizes were more inclined to use TV-based farm advisory and internet-delivered information. This is mainly because both sources' advisory is usually accompanied by graphics, animation, or video clips, which makes it more understandable for farmers to comprehend the knowledge. Thus, if they have access to these sources, big landlords are more likely to consider such sources to understand their demonstration and then use them on their farms. This could also be due to their increased farmland, forcing them to seek appropriate farm recommendations to be implemented at farms; hence, they prefer using demonstration-based sources.

Having ownership of the land the farmers cultivate largely shapes their decisions regarding various farming-related matters. In our case, farmers who owned the cultivated land were more likely to prefer using the internet to access agricultural information. This might be due to their intentions to make their own land more fertile by accessing advanced soil and water management practices related information through the internet. In addition, since there is increasing use of social media discussion, owner farmers might be more concerned about the overall physiological health of the crops or the soil texture and land structure, which might lead them to rely on advanced communication mediums to acquire farm advisory or risk management information.

Our results are supported by previous studies [10,30] reporting a positive association of farm ownership with farmers' use of internet-based farm advisory services. Their study states that owner farmers are more concerned about earning higher profits and improving their farms. Thus, they take every step to make their land more productive by utilizing the maximum available information resources, including conventional and contemporary ones.

Irrigation also plays an important role in shaping farmers' information-seeking behavior. Our estimates showed that farmers who owned a personal agriculture borewell were more likely to prefer accessing advisory through mobile phone-based communication. In contrast, they were less likely to acquire information using radio. Since mobile phone-based consultations allow farmers to make day-to-day changes in their farming operations owing to the regular weather forecasts, market rates, and risk management information, which in most cases involve irrigation, thus they tend to phone a friend. For instance, if there is a need for fertilizer application, it has to be done with irrigation. Thus, owning agriculture bore well enables farmers to use mobile phones to consult with friends and experts rather than any other ICTbAIS. These findings imply that having an irrigation pump or a stable source of irrigation largely improves farmers' attitude toward information seeking by relying on an advanced medium such as smartphones as compared to conventional ICT sources such as radio. Unlike the studies of Folitse et al [65], livestock did not report any significant association with ICTbAIS in our case.

We further found that farmers' income sources other than farming are also a major determinant of their tendency to use mobile-based farm advisory services. This is mainly because updated market rates, climate information, and other essential information via personal discussions allow farmers to manage associated ventures and thus generate additional income. For example, having information about grain marketing on their phones, a farmer may also become a trader of agriculture and livestock products (not necessarily of his own), which might earn a decent income. Our results are in line with a study conducted in China [66] which reports that marketing information access through mobile phones largely improves farmers' incomes, motivating them to utilize such information using tools such as cellular phones. Similar evidence is reported in Vietnam [67], where farmers living far from local markets and having high incomes have a greater tendency to adopt ICT tools (mobile phones) for fruit marketing.

Climate risk perception is an important attribute of today's farmers, especially in a region like Punjab, where its repercussions are widely seen. In the face of climate risk, farmers are largely different in various farm-related decisions. Regarding the use of ICTbAIS, we found that farmers who considered changing climate as a high risk for their crops were more inclined towards using the internet while they were less likely to utilize simple mobile phone-based communication or advisory via SMS and robocalls. This might be because the farmers who have positive attitudes toward environmental change and consider it a crop risk have higher education and more exposure to advanced knowledge mostly available on websites [35]. Thus, climate risk perception increases farmers' perception of utilizing the internet to access updated information on social media platforms, smartphone applications, and other online blogs.

6. Conclusions and Implications

This research study focused on farmers' usage of information and communication technologies-based agriculture information services (ICTbAIS) in the Punjab province of Pakistan. The region was selected due to its agricultural significance and climate change vulnerability. We employed the risk matrix method to assess farmers' risk perception and a multivariate Probit model to estimate further the relationship between farmers' risk perception (and socio-economic attributes) and their preference regarding ICTbAIS usage.

We found that most farmers used these ICTbAIS to acquire information about the marketing of farm produce and weather forecasts. The key sources of information included TV and mobile phone-based farm advisory services followed by personal consultations, radio, and internet-based farm advisories. The key sources from mobile-based advisory included SMS alerts from the local cellular network providers, while the major internet-based sources included the use of social media platforms such as Facebook and WhatsApp. Television delivered advertisements, advisory, and radio-based programs were key information sources for farmers from TV and radio. Regarding climate change risk perception in the study area, the risk matrix analysis revealed that half of the respondents perceived climate change as a significant threat to their crops and livelihoods. The regression analysis further found that farmers' education, age, farm size, agriculture borewell ownership, and climate risk perception as the key determinants of farmers' choices of ICTbAIS.

In conclusion, young farmers with higher education were more likely to use smart communication tools such as mobile phones and the internet, while old-age farmers with less education prefer conventional ICTs such as radio and TV for accessing agriculture information. Further, farm assets such as farmland size and ownership of a personal tube well also positively affected advisory usage. The perception of climate change as a key risk has also positively affected farmers' usage of advanced ICTs such as the internet. The study further concludes that modern ICTs have limited usage by the farmers, especially mobile phones and internet-based farm advisory; thus, it is implied that efforts should be made to improve the usage of these services to uplift farmers' farm incomes. Further, this study suggests that policymakers and public institutions, particularly agricultural extension departments, should take initiatives to raise farmers' awareness about modern ICTs and their utility and, at the same time, make efforts to change farmers' attitudes towards climate risk as these factors expedite the usage of ICTbAIS.

This research provides important implications for the policymakers, practitioners, and government institutions to consider farmers' literacy while designing ICT-based farm advisory services, as most of the rural population cannot use ICT tools due to their low education levels. Improving farmers' digital literacy is imperative before considering ICT to deliver advisory services. To do so, training campaigns could be launched in rural areas to train the uneducated farmers regarding smartphone and internet use. This study further suggests employing a participatory approach by involving farmers in designing/planning ICTbAIS, enabling more interactive and user-friendly advisory platforms, maximizing usage of agricultural information. Although the findings of this empirical research are limited to Punjab province only, countries and regions with similar agroecological and socio-economic attributes and similar communication infrastructure can also acquire useful implications from this research.

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