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Research article

The economic value of seasonal weather and climate services for maize farmers in Manicaland Province of Zimbabwe

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ABSTRACT

Most rural areas in Zimbabwe are extremely vulnerable to changing climatic conditions, particularly droughts, which threaten smallholder farmers' livelihoods. Seasonal weather forecast services can help farmers adapt, optimise production, and implement risk reduction strategies. To support increased investment in these services, this study seeks to provide quantitative evidence on the economic value of locality-specific seasonal weather forecasts by eliciting maize producers' willingness to pay (WTP) through the contingent valuation approach. The results of the study show that among 502 farmers, 68 % would pay for seasonal weather forecasts, highlighting their perceived economic value and practical utility in agricultural decision-making. On average, farmers were willing to pay one (1) United States dollar (US$1) per month for seasonal weather forecast services. Extrapolating this demand nationally, we estimate an annual economic value of around US$ 53.2 million for these services. This valuation underscores the substantial economic benefits that weather and climate services could offer to Zimbabwe's agriculture sector, justifying the case for increased resource allocation towards the delivery of location-specific weather forecasts. Using the Heckman selection model, the study further identified that maize producers' climate change perceptions, radio ownership, and prior participation in agricultural policy development significantly increased their likelihood of paying for seasonal weather forecasts. These factors highlight the role of both access to information and engagement in policy processes in shaping farmers' valuation of seasonal weather forecasts. Establishing district-level climate change dialogue platforms can significantly enhance maize producers' awareness of climate change, deepen their understanding of the value of weather forecasts, and encourage their participation in policy-making processes. By creating spaces for knowledge exchange and farmer engagement, these platforms not only support informed farm decision-making but also help tailor climate services to farmers' needs. Nevertheless, farmers from the Ndau ethnic group and those in remote areas showed reluctance to pay for seasonal weather forecasts, indicating that factors like ethnicity and remoteness affect WTP. This reluctance highlights how social marginalisation and inadequate infrastructure in remote areas limit access to weather information, thereby reducing farmers' perceived value of these services. Enhanced telecommunication infrastructure and radio signals in rural areas, especially community radios, could help to expand the access and tailoring of forecast messages in local languages, making it understandable and thus supporting informed decision-making across diverse farming communities.

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1. Introduction

1.1. Background

Carbon emissions drive climate change, making farming more challenging and impacting the agricultural sector negatively [1,2,3]. In Zimbabwe, as in many other countries, the increasing intensity of droughts due to changing climatic conditions is hitting maize producers particularly hard as they rely on rainfed farming. Access to seasonal weather forecasts could support farmers to make better-informed farming decisions, including when to plant, what crops to plant, and how to allocate resources to maximise productivity despite uncertain conditions [4,5,6,7,8]. Nevertheless, due to insufficient fiscal disbursements to the Zimbabwe Meteorological Service Department (ZMSD) to deliver locality-specific forecast information, about 46 % of farmers were estimated to have used seasonal forecast information to inform their adaptation strategies [9,10]. The limited understanding of the English language used by meteorologists in broadcasting forecast information and insufficient lead time also impede the use of seasonal weather forecasts [10,11,12].

Given these challenges, ZMSD needs to invest in modern meteorological infrastructure and skilled manpower to provide timely, accurate and downscaled weather forecasts to inform farming decisions. Such investments also call for increased partnerships with private sector players such as telecommunication companies. Public-private partnerships are important to ensure sustainability without jeopardising the provision of public seasonal forecast information to farmers [13]. However, the collaboration between the private sector and ZMSD requires a scientific demonstration of business-case scenarios in which the private sector may recover its costs. As a result, estimating the economic value of seasonal weather forecasts in Zimbabwe is crucial to provide quantitative evidence that will be useful in increasing investments towards the delivery of location-specific weather forecasts to assist farming decisions.

Estimating the economic benefits or value of Zimbabwe's weather and climate forecast services could also help raise awareness of the benefits and encourage users to pay for them. This will also help foster public-private collaborations and shape policy dialogue about the importance of these services in national resilience initiatives and adaptation financing plans. The economic benefit or value of seasonal weather forecast information refers to the monetary measure of welfare changes or changes in utility as a result of changes in the availability or improvements in the delivery of seasonal forecast information [14,15]. In this case, this economic value refers to the sum of money that maize producers are willing to pay to secure an improvement in the production and dissemination of seasonal forecast information [16,17,18].

The key research questions that guided this study were: (a) are maize farmers willing to pay for modern seasonal weather and climate services in Zimbabwe? (b) What are the socio-economic characteristics which influence the WTP amounts by maize farmers for modern seasonal weather forecast services in Zimbabwe? and (c) what farming and non-farming benefits do maize farmers and their households gain from the utilisation of modern seasonal weather and climate services in Zimbabwe? For this study, weather and climate services refer to the production and delivery of weather & climate forecast information and other related services for use in farming and non-farming decision-making [19,20,21,22]. Throughout the remainder of this study, the words "weather and climate services" and "seasonal weather forecasts" are used interchangeably to denote the same thing.

The contribution of this study is threefold. First, estimating the economic value of seasonal weather information provides a quantitative rationale for increasing investment in the delivery of timely and location-specific weather forecast information to inform farming decisions.

Second, the findings of this study might help improve lobbying efforts with Parliament and the Ministry of Finance to boost the allocation of funding to ZMSD. Increased investment in the delivery of timely and actionable weather forecasts is consistent with the Early Warning for All initiative of the United Nations, which intends to ensure that all people on the earth have access to early warning information by 2027.

Thirdly, the WTP values can also be used to make a business case for fostering public-private partnerships between the ZMSD and private sector entities to upgrade weather forecast infrastructure. Collaboration and partnerships with the private sector could assist secure the long-term delivery of location-specific seasonal weather forecast services to farmers. The dissemination of timely and context-specific weather forecast information can strengthen farmers' resilience against climate change by implementing optimal coping strategies and boosting agricultural production for national food security and increased exports.

1.2. Literature review

1.2.1. Economic valuation of seasonal weather and climate services

The existing literature showed that the weather and climate services are crucial in shaping farming decisions, including the choice of crop varieties and scheduling of optimal planting dates [8,16]. The main techniques used to value the economic benefits of weather and climate services are contingent valuation and crop yield simulation modelling [16,23,24,25,26]. Given its extensive use, simplicity and applicability in the Zimbabwe context, where seasonal weather forecasts are delivered as a public good, the contingent valuation method was adopted in this study [16,25,26,27,28,29]. Nevertheless, choice experiments and travel cost methods, although not widely used, are gaining momentum in estimating the economic benefits or value of seasonal forecast information [14,30,31].

Generally, weather and climatic services have substantial economic value. For instance, Ref. [16], using a contingent valuation technique, estimated the annual economic value of seasonal weather information in Benin to be US$66.5 million. Likewise, the economic value of an early warning delivery system in the United States of America is estimated to be US$1.56 billion [26]. Using a contingent valuation, the annual economic value of climate information services in Bangladesh is estimated at US$222.75 million [27].

In China and Vietnam, the economic benefits of weather forecasts are estimated at US$6.966 billion and US$45.52 million per annum, respectively [28,32]. However, huge investment gaps in weather forecasting infrastructure, data, human capital and early warning systems exist in many countries, including Zimbabwe [9,33,34]. This significantly constrains the delivery of timely and accurate weather forecasts to support farming decisions. This presents an urgent call for policymakers to enhance investments and prioritise weather and climate services forecasting and delivery as part of the climate change adaptation and resilience agenda. Despite limited awareness among policymakers of the economic value of weather and climate services, existing literature lacks comprehensive insights into how political economy factors affect investment in these services and their uptake by farmers and communities. Understanding these influences is essential, as political economy factors such as ethnicity and remoteness significantly shape farmers' WTP and use of seasonal weather forecasts.

Earlier research studies were mainly based on neoclassical theories, with limited incorporation of political economy elements into the analysis [16,27,28,29]. As a result, this study fills this knowledge gap by integrating political economy factors into the analysis. Recognising that access and utilisation of weather information are deeply influenced by social and religious contexts, this study examines how these broader dynamics impact WTP for weather forecast information. By accounting for the political and socio-cultural factors that shape climate service delivery, this research provides a more comprehensive understanding of the conditions necessary for inclusive weather forecast information delivery, thereby informing policies that can enhance accessibility and relevance for diverse farming communities. In this case, the political economy factors of interest were remoteness as measured by distance from the district capital, the role of religious preferences, ethnicity, and perceptions of governance systems as measured by farmers' participation status in national policy-making decision processes such as budget consultations. By considering these factors, the study provides insights

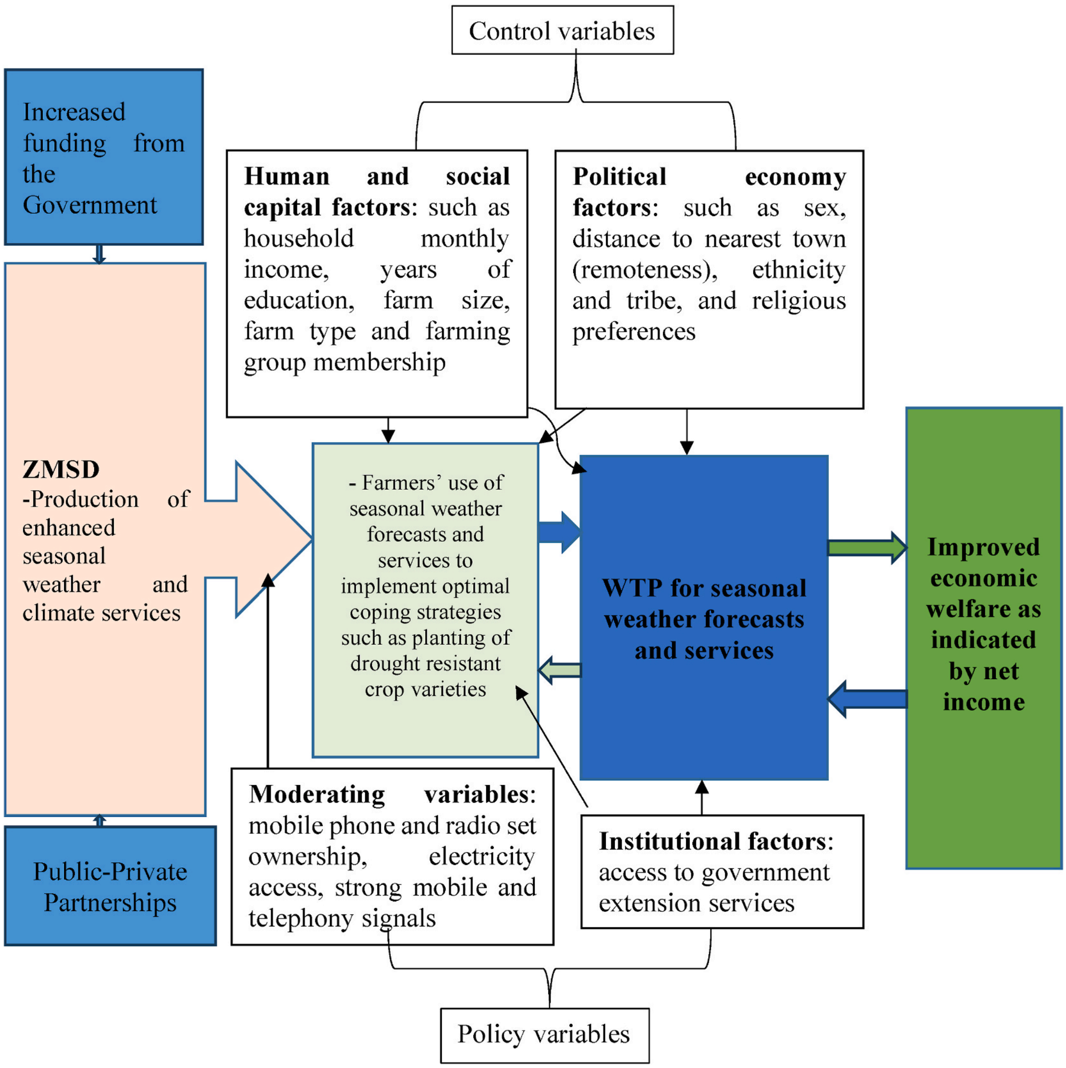

Fig. 1. Conceptual framework.
Source: Authors' compilation

into the social and cultural obstacles that limit access to climate services, helping to inform the design of more inclusive and accessible weather information systems.

1.2.2. Conceptual framework

Fig. 1 illustrates the conceptual framework of this study and provides a synoptic illustration of the interrelationships of key variables assumed to have a significant effect on farmers' WTP for seasonal weather forecasts. The framework starts with the underlying relationships between the first set of independent variables (moderating variables) and the WTP decision for these services (the dependent variable). These independent variables that moderate or strengthen this relationship include access to mobile phones, radio set ownership, electricity services, and the strength of the telephony signals received by farmers. Lack of mobile phones, weak mobile phone network signals and inadequate access to electricity services would limit farmers' access to weather forecast services and disincentivise farmers' WTP for these services. By investing in these key moderating variables, the government can significantly boost the uptake of seasonal weather forecasts produced by a financially strengthened ZMSD.

However, other factors such as human capital variables (years of education), income and membership in farmer-based organisations and social groups could also affect the WTP for these services. In this study, these factors are labelled as a set of control variables. The WTP for seasonal weather forecasts leads to the uptake of improved adaptation strategies to produce maize by farmers. This use of adaptation strategies results in increased farm incomes and the economic welfare of farmers.

The WTP amount for the seasonal weather information is also shaped by control variables, including farmers' years of education and income levels. Higher education and income generally increase WTP, as these factors may enhance farmers' understanding of the value of climate information and their financial capacity to invest in it. Further, it is also influenced by a second set of control variables, which are largely described as political economy variables. These variables are related to remoteness, ethnicity, and sex.

This study is divided into five main sections. Following the introduction, the second section outlines the methodologies used to address the research questions. The third section details the key findings, while the fourth discusses these results. Finally, the conclusions and recommendations are presented in the fifth section.

2. Methodology

2.1. Study area

The study was conducted in Zimbabwe's Manicaland province, focusing on Mutare Rural, Buhera, Makoni, Chimanimani and Chipinge districts (Fig. 2). The province's primary ethnic group is the Shona, with the Manyika subgroup being predominant. Agriculture is the province's cornerstone economic activity, with maize as the staple crop among smallholder farmers. Other key crops produced by farmers include bananas, tobacco, tea, and coffee. Mining also contributes significantly to the province's economic activities, particularly diamond mining in the Marange areas of Mutare Rural district [35]. Tourism is another vital industry, with major attractions such as the Nyanga, and Vumba Mountains, along with Nyagombe and Mutarazi Falls [36].

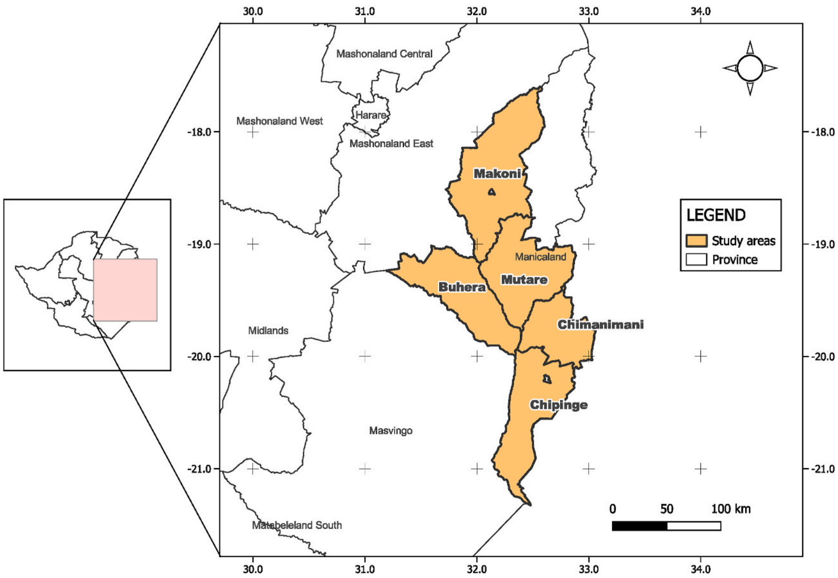

Fig. 2. Map of Manicaland province.
Source: Authors based on Government archival sources

2.2. The hypothetical market for contingent valuation

Farmers' WTP for context-specific and co-produced seasonal weather information was elicited based on the contingent valuation approach. A hypothetical market was established to allow farmers to express their WTP and the sum of money they were willing to pay for forecast information among those who were willing to pay. In this hypothetical market, a maize farmer was envisioned receiving, but at a premium, context-specific and co-produced seasonal weather forecast services. The advantage of context-specific and co-produced seasonal weather forecast services is that they would provide location-specific weather forecast information linked to other services that meet farmers' needs such as advice on suitable maize seed variety in a specific area rather than the current broad geographic weather forecast information.

The iterative bidding game technique was employed for the hypothetical market to fully reflect the typical Zimbabwean market situations where economic agents negotiate before a final price is settled [37]. Unlike the payment card method where respondents are provided a range of bids on a card and are requested to select one, in this case, a starting bid was chosen by the farmer himself/herself and then progressively higher (or lower) bids are offered until there was a mutually agreed final bid. This nature of the market situation is also common in many African economies [16,19,38].

To eliminate starting-point bias, the open-ended iterative bidding process was utilised, with no suggested starting bid. Thus, after expressing a positive WTP, maize producers were asked to offer the maximum amount of money they were willing to pay based on an open-ended format where no price bid was suggested. In the second stage, the open-ended bid provided by the farmer was then used as the starting bid. This was increased (or reduced if the farmer preferred a lower bid) by 50 per cent per month until the enumerator and farmer mutually agreed on the maximum amount a farmer was willing to pay. The most frequently stated prices were then coded in Kobo Collect software.

Apart from the implementation of a pilot survey, data collection was also conducted in a manner that helped to eliminate other biases common in implementing contingent valuation assessment, such as hypothetical bias and payment vehicle bias. The approach was based on the strict guidelines suggested to ensure the usefulness of the contingent valuation method as recommended by various research workers [24,39]. For instance, to eliminate payment vehicle bias, farmers were informed that the monthly payment would be made as a direct debit and the fee would be deducted when the farmer recharged his/her SIM card. This institutional payment mechanism is commonly used in weather forecast service delivery or market information dissemination to farmers [40]. To avoid hypothetical bias, farmers were reminded of their budget constraints and a clear description of seasonal weather forecast services was provided to them to fully understand the good in question.

2.3. The data collection methods

The study targeted smallholder farmers involved in maize production across Mutare Rural, Buhera, Makoni, Chimanimani and Chipinge districts of Manicaland province. From district farmer lists, 502 farmers were randomly selected for interviews. Data were collected using a household questionnaire as the primary instrument, administered by eight trained enumerators utilizing the KoBo Collect software. While the questionnaire was in English, enumerators conducted interviews in farmers' preferred language—English or local dialects like Ndau—to ensure clear communication. Responses given in local dialects were translated into English and entered into the KoBo Collect tool. Data collection took place between October and December 2023, following a pre-test survey conducted in October. Insights from the pre-test were used to refine the questionnaire, ensuring questions were easily understood. Verbal consent was obtained before confidentially interviewing each household head or their representative. Household head interviews were conducted at times and locations convenient for the participants. If the household head was unavailable after three attempts, the secondary decision-maker was interviewed instead. Ethical approval for the study was obtained from the Ethics Committee for Basic and Applied Sciences (ECBAS) at the University of Ghana, Legon, Accra (ECBAS 002/23–24). Additionally, permission to conduct data collection was secured from relevant authorities, including the Ministry of Agriculture in Manicaland Province and district authorities.

The questionnaire was divided into five key sections:

a. Valuation of Indigenous seasonal weather forecasts: This section captured all expenses incurred by farmers in obtaining indigenous weather forecast information within their community. However, the results from this section are not included in the study.
b. Contingent valuation of seasonal weather forecast information: Farmers were presented with a hypothetical market to assess their WTP for forecast information. Results from this section are included in the study.
c. Farmers' preferences for the attributes of seasonal forecast services: Using choice experiments, this section explored farmers' preferences for different forecast attributes. The results are not included in this study.
d. Farming enterprises: This section gathered information about farmers' general agricultural activities.
e. Demographic characteristics: Focused on farmers' demographic details, including sex, income, and religious affiliations.

2.4. Theoretical and analytical framework

2.4.1. Theoretical framework

The theoretical framework for contingent valuation employed to explore farmers' WTP for weather forecasts is based on the Random Utility Model developed by McFadden [41]. Following the Marshallian demand concept, the key assumption here is that the maize producer is a quasi-rational human being who attempts to maximise her/his utility subject to income constraint [42,43]. In the case of agricultural production, with its inherently risky outcomes, the farmer is assumed to be a quasi-rational economic agent who attempts to maximise her/his utility from production activities through his/her demand for selected inputs. Due to the inability of a researcher to observe all relevant variables that affect the individual farmer's utility, the indirect utility function of a farmer (Ui) is decomposed into a deterministic component (Vi) and stochastic component (ε_i) [43]. The stochastic component represents unobserved factors which are only known to the maize producers but not to the researcher. This stochastic component could also include non-rational behavioural attributes, such as aggressiveness, emotions, and neurosis, which are known to the farmer, not the researcher, and which could interfere with the farmer achieving the maximum possible profits from production though the farmer could still achieve his/her maximum utility.

In this study, a smallholder farmer is hypothesised to decide to pay for seasonal forecasts as an attempt to maximise his/her utility subject to a budget constraint. A quasi-rational maize producer is unlikely to pay for seasonal climate and weather services unless the perceived economic benefits outweigh the associated costs. This produces two distinct scenarios: a baseline situation in which a farmer maintains the status quo and one in which a farmer uses seasonal weather forecast services. A status quo situation can be depicted as follows in Equation (1).

$$Uij = Vij\ (Xij) + \varepsilon_{ij} \tag{1}$$

Where U_i is the level of utility, the deterministic component (Vi) is assumed to have a linear relationship with the attributes (X) of the j different alternative goods in the choice set facing the respondent i (Xij). The socioeconomic characteristics such as income, sex and educational level are included in the choice set attributes (Xij) since they are the same across choice occasions for any given individual; and ε_i is the random error term. A scenario where a farmer uses improved seasonal weather and climate services is depicted in Equation (2):

$$U_{ik} = Vik\ (Xik) + \varepsilon_{ik} \tag{2}$$

Therefore, a maize farmer will pay for enhanced seasonal weather forecast services if the indirect utility from using these services is greater than the indirect utility attributed to not using these services as expressed in Equation (3):

$$Vij\ (Xik) + \varepsilon_{ik} > Vij\ (Xij) + \varepsilon_{ij} \tag{3}$$

It is therefore assumed that the sum of money a maize farmer is willing to pay is related to the difference between the utility that a farmer attains after using the improved seasonal weather forecast services and the baseline utility that exists when a farmer maintains the status quo condition.

2.4.2. Analytical framework

The study used descriptive statistics, including means and percentages, to analyze the proportion of farmers willing to pay for seasonal weather forecasts and the WTP amount. Descriptive statistics were also employed to examine the farm and non-farm uses of these services that interested maize farmers. To identify the socio-economic factors influencing WTP, the Heckman selection model was applied. This model comprises two equations: the selection equation and the outcome equation. In the selection model, the dependent variable represents maize farmers' WTP decision for seasonal weather forecast information, taking a value of one (1) if yes and zero (0) otherwise. The selection equation can be expressed as shown in Equation (4):

$$y_i = X_i\gamma + \mu_i \tag{4}$$

where y_i denotes maize farmer's WTP decision (1 = yes and zero, otherwise); X_i is a vector of independent factors affecting WTP decision; γ_1, γ_2 and γ are parameters to be estimated; and μ_i is the error term.

The outcome equation explains the factors affecting WTP amount and can be expressed as shown in Equation (5):

$$\text{Ln}\ WTP\ amount = Z_i\beta + \lambda + \upsilon_i \tag{5}$$

where *WTP* denotes the sum of money maize producers are willing to pay expressed in log form; where Z_i is a vector of independent factors that affect WTP amount; β_1, β_2 and β are vectors of coefficients to be estimated; and υ_i is a normally distributed error term. However, *WTP*, the dependent variable, is only observed if the maize farmer decides to pay.

The parameter $\lambda = \sigma\rho$, is the inverse Mills ratio and is estimated in the selection equation and added in the outcome equation as one of the independent variables to control for selection bias. The Heckman selection model was estimated through a maximum likelihood estimation approach. The estimation starts with the selection equation where the probit regression model was estimated, and then the inverse Mills ratio λ, the error from the probit model, is calculated based on the probit regression results. The second step consisted of the outcome equation, which was a log-linear regression model estimating the factors affecting WTP amount. The loglikelihood test and hypothesis testing for the independence of outcome and selection equation models were used to determine if the model fits the data well.

Several socio-economic factors were assumed to influence farmers' WTP for seasonal weather and climate services (Table 1). Firstly, it was assumed that the income level of a household influences a farmer's WTP decision and WTP amount. The literature indicates that the farmers' income is one of the main factors affecting WTP for seasonal weather forecasts among farmers [44]. The access to agricultural extension services was also assumed to affect farmers' WTP decision and WTP amount. Farmers in Benin with access to extension services were more willing to pay for seasonal forecast information than their counterparts who did not have access to extension services [16]. Likewise, farmers' WTP decisions were anticipated to be influenced positively by their level of education;

educated farmers are expected to make more informed decisions based on scientific logic.

Furthermore, having a mobile phone was expected to influence farmers' WTP for seasonal weather forecasts. Access to mobile phones generally enhances farmers' access to seasonal weather forecasts and hence positively influences WTP for seasonal forecasts [40,44]. The location of the farmer also affects his/her WTP for seasonal weather forecasts. For instance, farmers in agroecological areas four and five, where rainfall is very low, will be more willing to pay for seasonal forecast information to help them make better farming decisions.

3. Results

3.1. Socio-economic characteristics of farmers

The majority of the interviewed farmers were female (63 %), with an average age of approximately 52 years. Just over half (51 %) had completed secondary school, averaging nine years of education. Their average monthly income was 75 United States Dollars (US$) (refer to Table 2 for more detailed information).

The average household size was six, with most farmers (86 %) identifying as Christians, while 14 % follow African Traditional Religions. Among those subscribing to African Traditional Religions, 10 % also participated in Christian activities and 1 % in Muslim activities, indicating mixed religious preferences. All 502 respondents were part of the Shona ethnic group, with 77 % belonging to the Manyika subgroup and 23 % from the Ndau tribe.

Table 1
A priori expectations for the Heckman selection model.

Variables	Description	Expected sign	Explanation of expected sign
Dependent variable			
The selection equation	WTP decision (1-yes, 0-no)		
The outcome equation	WTP amount in US$		
Independent variables			
Income	Farmers monthly income (continuous)	+	Maize producers with high income levels are more likely to be willing to pay
Sex	1 if a household head is male and 0, female	+	The male headed households are more likely to have more income.
Distance to nearest town	Distance in kilometres to the nearest town (continuous)	–	Remoteness disincentivize WTP
African Traditional Religion (ATR)	1 if a farmer subscribes to ATR and 0, otherwise	–	The maize producers who follow ATR are more likely to use traditional forecasts
Ndau tribal member	1 if a farmer is Ndau tribe member and 0- Manyika tribe member		The minority ethnical group members are less likely to be willing to pay due to social marginalisation issues
Farming in low rainfall area	1 if a farmer is located in low rainfall area (agro-ecological regions four and five) and 0, otherwise	+	Due to frequent droughts, farmers located in low rainfall areas are more likely to be willing to pay to receive seasonal weather forecasts
Mobile phone ownership	1 if a farmer owns a functional mobile phone and 0, otherwise	+	Farmers with mobile phone are more likely to be willing to pay
Radio ownership	1 if a farmer owns a functional radio sets and 0, otherwise	+	Farmers with functional radio sets are more likely to be willing to pay as they receive forecasts
Years of education	Years spent in education (continuous)	+	More educated farmers are assumed to understand the importance weather forecasts and actively seek forecasts
Access to electricity	1 if a farmer's homestead is connected to electricity from the national grid	+	Access to electricity stimulate WTP as the farmer has access to power to charge mobile phone
Perceiving strong mobile phone network	1 if a farmer is perceiving the mobile network is strong in his/her area and 0-otherwise	+	Strong mobile network signal stimulates WTP as the farmer can easily receive or make phone calls/text
Farmer's age	Age of the farmer (continuous)	–	Elderly farmers are more likely to rely on indigenous weather forecasts
Perceiving climate change	1 if a farmer perceived that climate has change over the past ten years and 0-otherwise	+	Farmers aware about climate change are likely to seek for adaptation measures
Participated in policy processes	1 if a farmer participated in agricultural policy processes and 0-otherwise	+	Participating in policy formulation might incentive WTP
Farming group member	I if member and 0-otherwise	+	Farmers who are a member of a farming group are likely to be aware of the importance of forecast information
Land ownership	I if a farmer owns the land and 0-otherwise	+	Owning land likely to stimulate active seeking for weather forecasts
Farm equipment	1 if a farmer owns at least 4 farm equipment and 0- otherwise	+	More assets allow effective use forecasts such as land preparation
Small-scale commercial farming	1 if a farmer is a small-scale commercial farmer and 0-otherwise		Farming as a business stimulate active seeking for weather forecasts to plan
Years of maize farming	Years of maize farming experience (continuous)	+	Experienced farmers are more likely to understand importance of forecasts
Access to extension	1 if a farmer has access to extension services and 0- otherwise	+	Due to strengthened understanding of the value of weather forecasts

Farmers who were willing to pay for forecast information were more likely to be Manyika tribe members, engage in small-scale commercial farming, have higher monthly incomes, possess agricultural equipment, and have larger farm sizes. The farmers willing to pay were also older and participated in prior policy formulation and consultation workshops, including national budget consultation processes. On the other hand, farmers who owned their land had more years of maize farming experience, were members of a farming association and unwilling to pay for weather forecast information (Table 2).

3.2. Access to seasonal weather forecast services

Among the interviewed farmers, 92 % accessed seasonal weather forecasts during the 2022/23 farming season. Disaggregating seasonal forecast information access by the district showed that the majority of farmers in Chimanimani district access seasonal forecasts (97 %), followed by Chipinge district (95 %), Mutare rural (94 %) and then Makoni district (91 %) and lastly Buhera district (83 %). These variations can be explained by the recent Cyclone Idai, which resulted in increased early warning dissemination initiatives in the devastated districts of Chimaminani and Chipinge.

Most farmers (79 %) accessed modern seasonal weather forecasts through radio. They primarily relied on three national radio stations with nationwide coverage: Radio Zimbabwe, National FM, and Star FM. Community radio stations also played a crucial role in delivering seasonal weather forecasts. In Manicaland province, four community radio stations were identified: Chimanimani FM (covering only the Chimanimani district), Vemuganga FM and Ndau FM (serving only the Chipinge district), and Diamond FM (covering the entire province). Additionally, agricultural extension officers and fellow farmers, each contributing 30 %, were key sources of weather forecast information for the farmers (Table 3).

Farmers also received modern seasonal weather forecasts via mobile phones, television, and through channels of projects implemented by non-governmental organisations. Notably, the Takunda and Participatory Integrated Climate Services for Agriculture projects, which are being implemented by CARE Zimbabwe and the World Food Programme (in collaboration with the University of Reading), respectively, were identified as the primary projects disseminating seasonal weather information to farmers in the study area. Farmers mostly watch Zimbabwe Broadcasting Corporation Television station and South African Broadcasting Corporation channels for national and regional seasonal weather forecasts, respectively. Aside from seasonal weather forecasts, the ZMSD provides ten-day forecasts, daily forecasts, and instant forecasts for extreme weather events to the public.

3.3. Use of seasonal weather forecasts in maize production

Among farmers with access to modern seasonal weather forecasts, 96 % used the information to take anticipatory actions. The primary actions included selecting suitable maize varieties (82 %), scheduling planting dates (59 %), and planning land preparation dates (39 %). Farmers also utilised seasonal weather forecasts to schedule various farm operations such as the application of fertiliser (3 %) and agrochemicals (1 %) and the determination of harvesting dates (1 %), amongst other activities. Seasonal weather forecasts were also used to reduce land allotment for maize production (15 %) if drought is anticipated, and schedule irrigation dates (7 %) to supplement rainfall and reduce agricultural losses due to moisture stress (see Fig. 3).

Table 2
Farmers' characteristics disaggregated by WTP.

Variables	All farmers	WTP		
		Yes	No	Difference
Small-scale commercial farming (1 = yes, 0, no)	14 %	17 %	6 %	11 %***
Years of maize farming experience (continuous)	21	20.5	23	−2.5**
Access to extension (1 = yes, 0, no)	82 %	83 %	79 %	4 %
Distance to district capital (kilometres)	39	39	37	2
Connected to electricity (1-yes, 0, otherwise)	26 %	23 %	33 %	−10 %***
Located in low rainfall area (1 = yes, 0, otherwise)	45 %	44 %	48 %	−4%
Perceiving the mobile network is strong (1 = yes, 0, otherwise)	63 %	64 %	60 %	4 %
Sex of household head (1 = male, 0, female)	37 %	38 %	34 %	4 %
Land ownership (1 = yes, own the land, 0, otherwise)	89 %	87 %	93 %	−6%**
Total landholding (ha)	2.2	2.3	1.8	0.5***
Household monthly income (US$)	75	83	57	26***
Owning at least four farm assets (count)	2	2	1	1***
African Traditional Religions (1 = subscribe to ATR, 0, Christianity)	14 %	15 %	13 %	2 %
The years of education (continuous)	9	9	9	0
Farmer's age (continuous)	52	53	51	2**
Perceiving climate change (1 = yes, 0, no)	96 %	98 %	93 %	5 %***
Mobile phone ownership (1 = yes, 0, no)	93 %	94 %	91 %	3 %
Radio ownership (1 = yes, 0, no)	68 %	74 %	56 %	18 %***
Participated in agricultural policy processes (1 = yes, 0, no)	7 %	9 %	2 %	7 %***
Belong to Ndau tribe (1 = Ndau tribe, 0, Manyika tribe)	23 %	14 %	42 %	−28 %***
Farm group member (1 = yes, 0, no)	27 %	21 %	40 %	−19 %***

***p<0.01, **p<0.05, *p<0.1.
Source: Survey data, 2024

Table 3
Awareness, access and source of seasonal weather forecasts.

Variables definition	Variable description	Percentage
Access		
Access to modern seasonal weather information	1 if maize producer accessed modern seasonal weather forecasts during 2022/23 farming season and 0, otherwise	92 %
Dissemination channels of modern seasonal weather information		
Radio	1 if the farmer accessed forecasts through radio and 0, otherwise	79 %
Other farmers	1 if the farmer accessed forecasts through other farmers and 0, otherwise	30 %
Agricultural Extension Officers (AGRITEX)	1 if the farmer accessed forecasts through AGRITEX and 0, otherwise	30 %
Mobile phone (WhatsApp or short message services)	1 if the farmer accessed forecasts through a mobile phone and 0, otherwise	22 %
Television (TV)	1 if the farmer accessed forecasts through TV and 0, otherwise	12 %
Non-Governmental Organization (NGO)	1 if the farmer accessed forecasts through NGOs and 0, otherwise	3 %

Source: Survey data, 2024

3.4. Use of weather forecast information in non-farm activities

The majority of farmers (83 %) also used weather forecasts to schedule various tasks, including general household activities such as washing (57 %), outdoor activities (26 %) such as clearing drainage channels around homes to avoid flooding when heavy rains occurred, and for social events (9 %) such as birthday celebrations. Farmers also used weather forecasts to plan labour and rest time allocation and to plan recreational activities. The general work tasks were prioritised on sunny days while farmers rested on rainy days (5 %) and planned family vacations and recreational activities, such as visits to national wildlife parks (3 %) based on weather forecasts. Weather forecasts also influenced farmers' clothing choices, particularly during the winter season and on days when high temperatures were anticipated (Fig. 4).

3.5. The economic value of seasonal weather information

Among the interviewed farmers, 68 % were willing to pay to receive seasonal forecast information. Farmers' WTP for modern seasonal weather forecasts was high at low prices and declined with increasing prices consistent with the Marshallian law of demand (Fig. 5). Only 10 % of farmers were willing to pay US$5 per month, while the majority (52 %) were willing to pay US$0.20 per month for modern seasonal weather forecasts. The average willingness to pay (WTP) was US$1.00 per month.

The average WTP of US$1 per month translated to US$12 annually. Given that among the interviewed farmers, 68 % were willing to pay for the forecasts, an annual value of US$4104 was derived for the seasonal forecast information for the interviewed farmers in the Manicaland Province. This value could be extrapolated to an estimated annual economic value of US$ 53,235,229 (about US$53.2 million), assuming 68 % of all the farmers in Zimbabwe are willing to pay for the modern seasonal weather forecasts. Factoring in maize producers' socio-economic diversity across the country and calculating economic value at the lowest observed WTP amount of US$0.20, the estimated economic value still stands at US$10, 647, 046 (approximately US$11 million). These figures highlight the substantial economic value that investing in weather forecast services could bring, underscoring their potential value to Zimbabwe's agricultural sector.

3.6. The drivers of farmers' WTP

The results of the major drivers of the WTP for modern seasonal forecast information based on the Heckman selection regression model are reported in Table 4. The hypothesis testing of independence of the selection (WTP decision) and outcome (WTP amount)

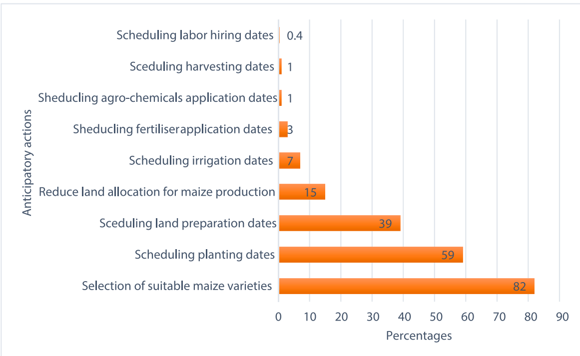

Fig. 3. Anticipatory actions implemented by farmers.
Source: Survey data, 2024.

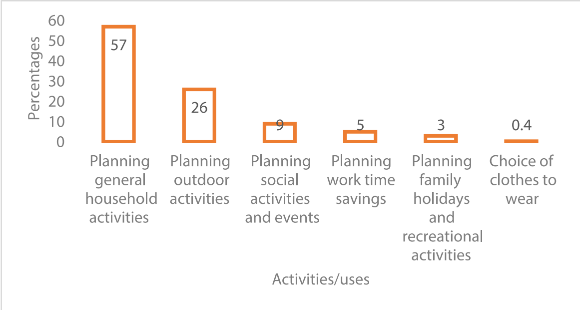

Fig. 4. Other uses of weather forecasts.
Source: Survey data, 2024.

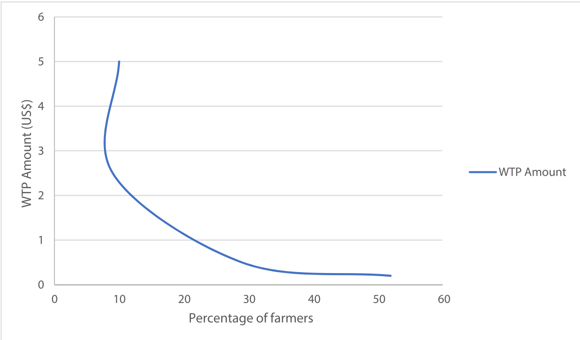

Fig. 5. WTP for modern seasonal weather forecasts.
Source: Survey data, 2024.

models was rejected ($p<0.05$). This result demonstrated that the Heckman selection model was suitable for examining the factors influencing the WTP decisions and WTP amount. As expected, this also meant that the WTP amount depended upon the decision to pay. Thus, modelling farmers' WTP for modern seasonal weather forecasts was regarded as a two-stage process: WTP decision and WTP amount.

As indicated in Table 4, three independent variables have a positive and statistically significant relationship with maize producers' WTP for seasonal weather forecasts. These were (1) perceptions of climate change, (2) radio ownership, and (3) prior participation in agricultural policy formulation processes. On the other hand, farming experience, farming group membership and belonging to the Ndau tribe reduced the likelihood of farmers' WTP for modern seasonal weather forecasts.

3.7. Factors affecting WTP amount

Seven explanatory variables significantly influenced the amount of money farmers were willing to pay for seasonal weather forecasts. Factors that positively impacted willingness to pay included being a small-scale commercial farmer, owning at least four farming assets, residing in low-rainfall areas, and having access to extension services. Conversely, factors such as the distance to the nearest town (district capital), access to electricity, and land ownership negatively affected the WTP amount (Table 4).

Farmers with at least four farm assets, such as sprayers and disc ploughs, were willing to spend 26 % more than those with less farm equipment. Farmers' WTP amount also increases when they are small-scale commercial producers, suggesting that small-scale commercial farmers use seasonal weather forecasts as a risk management service. Access to agricultural extension services has a positive effect on WTP amount. Access to extension services increases the amount of money farmers are willing to pay by 28 % ($p<0.05$).

The WTP amount also increases among farmers living in low-rainfall areas. In particular, the amount of money maize producers were willing to pay increases by 79 % among producers in low rainfall areas such as agroecological regions four and five compared to farmers in agroecological areas one, two, and three, which receive a lot of rainfall. About 86 % of the farmers who use forecast information to inform maize farming decisions, such as selecting suitable varieties, live in low rainfall areas.

Surprisingly, electricity access negatively affects the amount farmers were prepared to pay for modern seasonal weather forecasts. Connected to the national grid significantly reduced the WTP amounts. As expected, the WTP amount declines as the distance to the nearest town (a proxy for remoteness) increases. Land ownership is inversely associated with farmers' WTP for modern seasonal weather forecasts. The WTP amount declines by about 51 % ($p < 0.01$) among farmers who own the land compared to those who rent their land.

Table 4
Factors affecting WTP for modern seasonal weather forecasts.

Independent variables	Selection model (WTP decision)		Outcome model (WTP Amount)			
	Regression		Regression		Marginal effects	
	Coef.	St. Err.	Coef.	St. Err.	Coef.	St. Err.
Small-scale commercial farming	.205	.244	.596	.204	0.596	0.204***
Years of maize farming experience	−.011	.006*	.001	.005	0.001	0.005
Access to extension	.096	.17	.278	.134	0.278	0.134**
Distance to nearest town	−.002	.003	−.013	.003	−0.013	0.003***
Distance to nearest agro-shops	–	–	−.005	.004	−0.005	0.004
Connected to electricity	–	–	−.229	.136	−0.229	0.136*
Located in low rainfall area	–	–	.793	.162	0.793	0.162***
Perceiving the mobile network is strong	−.176	.142	−.045	.098	−0.045	0.098
Sex of household head	.048	.138	.009	.103	0.009	0.103
Land ownership			−.506	.174	−0.506	0.174***
Total landholding (ha)	.07	.045	−.038	.033	−0.038	0.033
Household monthly income	.002	.001	.001	.001	0.001	0.001
Owning at least four farm assets	–	–	.258	.147	0.258	0.147*
African Traditional Religion	.096	.199	.055	.156	0.055	0.156
Years of Education	.014	.021	.006	.015	0.006	0.015
Farmer's age	.017	.031	−.04	.026	−0.040	0.026
Farmer's age square	0	0	0	0	0.000	0.000
Perceiving climate change	.885	.318***	–	–	–	–
Mobile phone ownership	.24	.241	–	–	–	–
Radio ownership	.312	.141**	–	–	–	–
Participated in agricultural policy processes	.783	.413*	–	–	–	–
Belong to Ndau tribe	−.746	.184***	–	–	–	–
Member of a farming group	−.517	.157***	–	–	–	–
Constant	−1.387	.915	.731	.694		
/athrho	−.458	.197**				
ρ	−.1					
Mean dependent variable (selection model	0.681		SD dependent variable (selection model)		0.466	
Number of observations	502		Chi-square		190.274	
Prob > chi2	0.000		Akaike crit. (AIC)		1471.284	

Notes: Wald test of independence of eqns. $(\rho) = 0$ $\chi 2$ (1) = 5.39 Prob > $\chi 2$ = 0.02.
***p<0.01, **p<0.05, *p<0.1.
Source: Survey data, 2024

4. Discussion

4.1. Access and use of seasonal forecast information

Most of the farmers accessed seasonal weather forecast information through radio, extension officers, and fellow farmers in the village. These findings also correspond with other African studies which demonstrated that the most dissemination channels of seasonal weather forecasts to farmers are radio, extension officers, and fellow farmers, particularly through community or village gatherings [7,16,40].

Among those who accessed the seasonal weather forecasts, most used the forecast information to choose optimal varieties of maize and schedule planting dates amongst other farm operations. Similar findings were also reported in Ghana and South Africa [19,45]. In Ghana, farmers utilised weather forecast information to schedule days for sun-drying crops such as maize and cassava [19]. In addition to the timing of fertiliser application and harvesting dates, farmers in South Africa used weather forecast information to alter the quantity of fertilisers and types of agrochemicals they applied [45]. Since farmers also used seasonal weather forecasts to reduce land allotment for maize production if drought is anticipated and schedule irrigation dates to supplement rainfall, these findings also highlighted the relevance of seasonal weather forecasts in improving farmers' adaptation to climate change. Similar results were also observed in Benin, Ghana, Senegal and Zambia [7,16,46,47]. Farmers in Ghana, for example, used seasonal weather forecasts to schedule irrigation and planting dates, as well as choose appropriate crop varieties. [47]. Likewise, in Zambia, farmers used seasonal weather forecasts to select drought-tolerant crops and varieties [46]. As a result, improving farmers' access to seasonal weather forecasts could lead to improved farm decisions and strengthen farmers' climate change adaptation.

The maize producers also utilised seasonal weather forecasts to schedule a variety of duties, including regular household operations such as washing and clearing drainage channels around homes to prevent flooding, as well as social occasions such as birthday celebrations. The social benefits of weather forecasts have also been reported in other studies around the globe. In Ghana, households also utilise weather forecast information to plan laundry and sun drying of agricultural products, as well as take preparatory actions to protect their property from extreme weather [19]. If flooding is predicted, households in Southern and East Africa, as well as South Asia, frequently clean or dig drainage channels to mitigate the effects of flooding [48]. Other researchers in Ghana and South Korea have reported that individuals choose clothing based on weather forecasts [19,49].

4.2. Economic value of seasonal weather forecast information

A larger proportion of farmers were willing to pay to receive seasonal forecast information, underscoring the importance of forecast information in supporting farming decisions. The finding is consistent with other research in the literature, which indicates a significant number of farmers willing to pay for seasonal forecast information [16,44,50,51].

The estimated economic value of seasonal weather forecast information is approximately US$53.2 million, demonstrating the significant economic value of modern seasonal weather forecasts. This particular finding of this study was also corroborated by other studies concerning the immense economic value of modern seasonal weather forecasts (refer to studies reported by Refs. [16,27,44,50,51,52]. For instance, Benin's estimated US$66.5 million annual value and Bangladesh's US$222.75 million underscore the critical role of these forecasts in regions where agriculture is vital to the economy and highly sensitive to climate variability [16,27]. Likewise, in Nigeria, the annual economic value of weather forecasts is projected to be US$39 million [44]. In China, the annual economic value of weather forecasts is estimated at US$4.03 billion in the labour sector alone [52]. These consistent findings across diverse geographic and economic contexts provide strong evidence for investing in seasonal weather forecasting infrastructure and making such services widely accessible. With demonstrated substantial economic value, integrating these services into national climate adaptation strategies could be a high-impact approach to fostering resilience and driving sustainable economic growth, particularly in developing countries like Zimbabwe.

4.3. The drivers of farmers' WTP for modern seasonal weather forecasts

Farmers who perceived climate change over the past decade were more willing to pay for modern seasonal weather forecasts than those who did not recognize climate change. This awareness of climate change fosters a sense of urgency, prompting farmers to invest in resources that help them manage unpredictable conditions and build resilience to climate variability. This finding aligns with other studies, which have shown that the perception of climate change significantly influences farmers' decisions to adopt various adaptation strategies, including seasonal weather information [53,54]. These findings are also consistent with the view that weather information supports farmers to make more informed decisions, such as the choice of crop varieties. This, in turn, helps to minimise losses associated with climate change, such as droughts, as farmers select drought-tolerant crop varieties. This further suggests that enhancing climate literacy and helping all farmers recognize the tangible signs of climate change could be an effective strategy for increasing the use of seasonal weather information. As a result, incorporating climate education into extension services and community engagement could help improve climate literacy and promote the wider use of forecast information.

Prior participation in policy formation workshops, enhanced farmers' WTP decisions for seasonal weather forecasts. When farmers are actively involved in policy discussions, they gain insights into the broader significance and practical benefits of seasonal weather forecasts. This engagement not only raises awareness but also fosters trust, as farmers see their perspectives reflected in policy decisions, which can lead to a stronger sense of ownership and a clearer understanding of how weather forecasts align with their needs. This aligns well with political economy literature that emphasises the positive relationship between civic engagement in policy processes and citizens' perceptions of government performance and transparency [55,56]. Involving farmers in these processes demonstrates a commitment to inclusivity and shared decision-making, which can dispel scepticism and build trust. As a result, farmers may become more WTP for seasonal weather forecasts, viewing them as valuable tools shaped by their contributions and voices. This finding underscores the value of inclusive, participatory governance in climate adaptation efforts. Actively engaging farmers at grassroots levels in policy formation and implementation processes can enhance the legitimacy and acceptance of climate services, ultimately fostering more informed, and empowered farming communities.

Owning a radio set positively affects farmers' WTP for seasonal weather information. This highlights the crucial role that radio plays as an accessible and trusted source of weather forecast information. As most farmers currently receive seasonal weather forecasts via radio, the medium has proven effective in delivering the forecast information that helps farmers optimise their agricultural decisions. This aligns with similar findings in countries like Nigeria and Mali, where radio ownership is also positively associated with a WTP for weather forecasts [44,57]. This trend suggests that farmers perceive radio-based forecasts as highly valuable and reliable, given that radio reaches rural communities without requiring internet connectivity or significant technical knowledge. Farmers' WTP for this service demonstrates both its perceived utility and the demand for continuous access to this information. Expanding radio signal access and integrating more detailed, downscaled seasonal forecasts into radio programming could further increase forecast uptake among smallholder farmers.

Being a member of the Ndau sub-ethnic group, the minority Shona tribe in Manicaland is associated with a lower likelihood of farmers paying for modern seasonal weather forecasts compared to the majority Manyika Shona tribe. This finding highlights important considerations from a political economy and social inclusion perspective regarding the dissemination of seasonal weather forecasts. The lower WTP among Ndau farmers may indicate social exclusion, with two key factors contributing: a language barrier and limited participation in policymaking processes. These barriers may hinder access to essential services, such as weather forecasts for the Ndau sub-ethnic group.

Another plausible explanation is related to the historical and socio-political factors around land distribution and ownership. A recent study found that Ndau members in Chimanimani and Chipinge districts felt socially excluded from benefiting from the land reform program and related government services [58]. Such perception of exclusion from the benefits of the land reform program could have fostered distrust in government-related initiatives, potentially diminishing their WTP for seasonal weather forecasts. This disparity highlights the need for tailored approaches that bridge gaps in access to weather forecasts across different sub-ethnic groups. For instance, broadcasting seasonal weather forecasts in the Ndau dialect through community radio stations like Ndau FM and actively engaging Ndau community leaders in forecast dissemination efforts, could help build trust and ensure relevance. Addressing such social and cultural differences in forecast dissemination can help ensure inclusive access to weather forecast information, regardless of ethnicity.

The members of a farmer-based organization were less likely to be WTP for modern seasonal weather forecasts. This finding could suggest that farmers who were members of groups probably relied on other members for seasonal weather forecasts via the traditional forecast information and, therefore, were less willing to pay. This finding contradicted the conclusion established in Benin and Mali which indicated that farmers' WTP for seasonal weather forecasts was positively associated with membership of farming-based organisations [16,57].

Years of maize farming experience were also negatively related to farmers' WTP for modern seasonal weather forecasts. The findings may imply that as years of maize farming increase, farmers master a diversity of risk management methods based on indigenous knowledge systems, including the use of traditional forecast information. In this case, 88 % of farmers with at least ten years of maize farming experience used traditional forecasts to inform their maize farming decisions making them more reluctant to pay. Similar findings were also established in Botswana and Kenya, where elderly farmers with more farming experience were reported to rely largely on indigenous weather forecasts; this resulted in less demand for modern seasonal weather forecasts [59,60].

4.4. Factors affecting WTP amount to receive seasonal weather forecasts

Ownership of more farm assets was positively associated with farmers' WTP amount. This finding suggested that the increased capital base of farmers could allow for increased profits from farming operations based on the use of this capital base with modern seasonal weather forecasts. Land preparation, planting, and pesticide application are all more effective when undertaken with modern technology and equipment, and acquiring seasonal weather forecasts would make these tasks even more efficient. Another study supported up this finding, claiming that agricultural implement ownership influenced the choice of climate change adaptation techniques [54].

Farmers' WTP amount also increases when they are small-scale commercial producers. This demonstrates that modern seasonal weather forecasts are a significant service for farmers who pursue farming as a business rather than subsistence farming. This is because small-scale commercial farmers have more farm income than subsistence farmers and are thus prepared to pay more to acquire seasonal weather forecasts rather than being without them.

Access to agricultural extension services boosts farmers' WTP for seasonal weather forecasts. This finding underscores that, beyond serving as a dissemination channel, access to extension services equips farmers with the knowledge to use modern seasonal weather forecasts for making informed farming decisions, such as selecting appropriate crop varieties. Consequently, farmers with access to extension services are more willing to pay for these forecasts compared to those without access. A similar trend was observed in Benin, where farmers with extension service access demonstrated a higher WTP for weather forecasts than those without such services [16].

The WTP amount also increases among farmers living in low-rainfall areas. Thus, seasonal weather forecasts are an important service for managing climate risks in low rainfall areas, and farmers are willing to pay more to get seasonal weather forecast information.

Connected to the national grid significantly reduced the WTP amounts. A likely explanation is a contextual situation where data were collected; most days when the survey data were collected were characterised by considerable electricity load shedding and unreliable electricity supply. As a result, this acted as a disincentive to WTP for modern seasonal weather forecasts because farmers did not have the power most days to listen to the radio, watch television, and charge their mobile phones to get weather forecasts. As a result, access to an unstable source of electricity lowered the WTP amount.

Farmers' WTP amount also significantly decreases as the distance to district capital increases. Due to their remoteness and lack of access to mobile networks and other critical services, farmers in rural remote locations are more inclined to rely on traditional weather information and hence unwilling to pay for modern weather information. Most rural locations, including study areas, have limited telecommunication infrastructure and weak national radio or television signals [61,62]. Farmers find it difficult to obtain modern seasonal weather forecasts via mobile phones or radio, thus they are unlikely to pay to receive them.

Land ownership is inversely associated with farmers' WTP for modern seasonal weather forecasts. This result may indicate that farmers who own their land are more likely to invest in alternative climate change adaptation strategies, such as irrigation, which could reduce their reliance on seasonal weather forecasts. As a result, these farmers might perceive less value in paying for the forecast information compared to those who lack such resources and are more dependent on forecast information for their farming decisions.

This study has several limitations. Some of the key criticisms of the contingent valuation technique employed in this study are the hypothetical and information biases, which lead to WTP values being skewed upwards. Although we tried to reduce these biases by incorporating a consistent budget constraint remainder in explaining the WTP scenario in detail as well as employing the iterative bidding process to mimic the real market scenario in Zimbabwe, nevertheless, we still acknowledge potential hypothetical and budget constraints biases associated with contingent valuation in general which remain applicable to this study. Another limitation of this study is its scope, focusing solely on Manicaland province and utilizing cross-sectional data. Future research could address this by employing panel data to examine how farmers' WTP evolves over time and across different regions of the country, providing a more comprehensive understanding of trends and regional variations.

5. Conclusion and recommendations

This study offers valuable insights into the economic value of seasonal weather forecasts for maize farmers, highlighting the crucial role that forecast information plays in agricultural decision-making. The finding that 68 % of farmers are willing to pay approximately US$1 per month demonstrates a strong demand for these services, reflecting their practical utility in helping farmers adapt to climate variability. Farmers use weather forecasts to schedule planting dates, select suitable varieties of maize, and plan household activities, underscoring the forecasts' importance in supporting agricultural resilience.

The estimated annual economic value of US$53.2 million for seasonal weather forecasts indicates the substantial role these services could play in the national agricultural economy. This economic evidence makes a compelling justification for increasing national resource allocation to ensure the timely dissemination of location-specific seasonal weather forecasts to farmers. This evidence further supports the need for innovative funding approaches, such as public-private partnerships to bolster investment in state-of-art meteorological infrastructure.

The observed farmers' WTP for seasonal weather forecasts was high at low prices and declined with increasing prices consistent with the Marshallian law of demand. Thus, it can be concluded that the maize farmers in the study areas behave rationally as economic agents.

Given these findings, there is an urgent need to prioritise smallholder farmers' access to seasonal weather forecasts as part of Zimbabwe's climate change adaptation agenda and resilience strengthening. Enhancing seasonal weather forecast access through multiple channels, including extension agents and digital platforms like WhatsApp, is critical to bolster farmers' resilience. Diverse channels ensure that more farmers, regardless of location or technology access, receive timely and relevant weather information. This multi-channel approach not only broadens reach but also allows farmers to choose the most convenient and accessible sources, enabling them to make better-informed decisions for climate adaptation and risk management in agriculture.

Concurrently, strengthening telecommunication infrastructure and leveraging community radio stations, like Chimanimani FM, Ndau FM, and Diamond FM, can be a powerful way to expand access to weather forecasts in Manicaland province. Community radio is especially effective in reaching rural populations who may not have access to internet connectivity but rely on radio for timely information. By broadcasting in local dialects and integrating cultural contexts, community radios make forecast information more relatable and understandable for the audience, boosting its relevance and impact. Thus, ensures that forecast information reaches those who need it most and empowers diverse farming communities to make informed, climate-resilient decisions. Disseminating weather information through the community radios also paves the way to further enhance these services by integrating feedback loops, allowing farmers to communicate their information needs and preferences, and providing insights for even more tailored forecasts.

Accelerating rural electrification is also essential for advancing equitable access to forecasts and enhancing rural resilience to climate change. Access to electricity enables farmers in remote rural areas to use radios and mobile phones to receive timely weather information. Without electricity, many farmers are cut off from this information, limiting their ability to make data-driven decisions to mitigate climate risks.

Considering the commercial production status' positive effect on farmers' WTP, pricing segmentation in public-private partnerships to offer farmers weather forecast information at a premium could be considered. Targeting farmers engaged in agriculture for commercial purposes compared to subsistence farming is a suggested price segmentation strategy to balance the goal of reaching a large audience and cost recovery for financial sustainability.

Since prior participation in agricultural policy formulation processes was also found to have a significant effect on farmers' WTP, sub-national policy dialogues, particularly at the district and ward levels, are essential for increasing knowledge about the various policies being implemented to support climate change adaptation. Establishing district-level climate change dialogue platforms thus can significantly enhance maize producers' climate change awareness, deepen their understanding of the value of weather forecasts, and encourage their participation in policy-making processes. By fostering knowledge exchange and active engagement, these platforms empower farmers to adopt more effective adaptation strategies and ensure that climate services are better aligned with local needs.

To sustain district dialogue platforms, the Ministry of Agriculture can extend the National Agricultural Policy Framework Pillar Dialogue Platforms currently operating at the national level to district levels. This approach would provide a structured, ongoing forum for climate-related discussions and decision-making, fostering local engagement and alignment with national agricultural policies. By cascading these platforms downwards, the Ministry can ensure that farmers at the grassroots level have a voice in policy discussions and access to tailored climate and agricultural information, strengthening adaptation efforts and resilience within communities.

Declarations: The consent was obtained from each household head or their designated representative before conducting the interview. The verbal consent was deemed sufficient since the study is not a human clinical study and does not involve any human data, the survey was also deployed in a manner that maintained confidentiality and anonymity of responses as the questions did not include identifiers such as the names of the respondents. The study was also conducted in a manner that complied with all the ethical considerations including ethical approval from the University of Ghana, Legon, Accra, Ghana (ECBAS 002/23–24). Before the interview, participants were briefed on the study's objectives and assured that their involvement was entirely voluntary. They were informed that choosing not to participate would not affect their access to any benefits, and they could withdraw from the study at any time without any consequences. Interviews were conducted only with farmers who agreed to participate and gave their verbal consent.

CRediT authorship contribution statement

Joseph Manzvera: Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Kwabena Asomanin Anaman:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Data curation, Conceptualization. **Akwasi Mensah-Bonsu:** Writing – review & editing, Visualization, Validation, Supervision. **Alfred Barimah:** Writing – review & editing, Visualization, Validation, Supervision.

Data availability

The data used in this study is available from the corresponding author upon reasonable request.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e40781.

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