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Economic Assessment of Meteorological Information Services for Capture Fisheries in Taiwan

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Abstract: This study evaluates the economic benefits of meteorological information services (MISs) provided by the Central Weather Administration (CWA) in Taiwan, specifically for Taiwan's capture fishery industry. Using the contingent valuation method (CVM) and conducting in-person interviews, we collected questionnaires from capture fishery practitioners nationwide to gather their subjective evaluations of the meteorological information services provided by the CWA. Based on these evaluations, we further investigated the respondents' willingness to pay (WTP) for the CWA's meteorological information services. An empirical analysis of the bid function was conducted to identify the key factors influencing the respondents' bidding behavior. The empirical findings indicate that the primary factors affecting bids include subjective perceptions (such as forecast accuracy ratings and the ratings of the impacts on fishing production), working location, fishing vessel tonnage, and fishing methods. The median WTP for Taiwanese capture fishery practitioners is Taiwan dollar (TWD) 2111.12 per person per year. Based on the number of capture fishery practitioners in Taiwan in 2019, the total annual economic value of applying MIS in coastal and offshore fisheries is estimated to be between TWD 376 million and TWD 496 million per year.

Keywords: meteorological information services; capture fisheries; economic valuation; willingness to pay; contingent valuation method

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1. Introduction

The "2019 State of Climate Services", issued by the World Meteorological Organization (WMO) [1], highlights that improving climate change forecasting and water resource conservation technologies could boost global production by an estimated USD 30 billion annually and save USD 2 billion in losses. Related research also shows that the benefits of developing climate services can be dozens of times their costs [2]. The WMO recommends that countries follow the Global Framework for Climate Services (GFCS) to construct and develop meteorological information services, thereby enhancing strategies and measures to mitigate climate change risks [3]. Additionally, the WMO believes that economic methods can reveal the value of meteorological services, further clarifying the socioeconomic benefits these services bring to the public or specific users [2].

The literature shows that the application of meteorological information services in fishery management allows for the early adoption of risk mitigation measures, ultimately reducing losses in fishery production, machinery, and life safety [4,5]. Moreover, some studies highlight the impacts of climate change on fisheries, such as rising sea levels, increasing sea surface temperatures, and ocean acidification, which indirectly lead to a decline in fishery resources [6–10]. Additionally, the target fish species of most fishermen are affected by climate change, prompting habitat shifts. Unless fishermen identify new target species, relocate their fishing areas, or develop new fishing equipment, they may struggle to adapt to the impacts of climate change [11,12]. The abundance of marine fishery resources depends on changes in marine ecosystem mechanisms, making it crucial to monitor meteorological information changes. Meteorological data support capture fishery practitioners in production and risk management operations [13–15].

In response to the impact of global climate and ocean changes on marine biological resources and society, the National Marine Fisheries Service (NMFS) in the United States advocates the use of meteorological information services and applications to mitigate adverse effects on fisheries and enhance the resilience of marine resources. The customized application of climate services has become a global trend, helping developing countries lessen the impact of climate change [16]. Therefore, providing practical and timely information to fishermen as a reference for operations and improving catch efficiency and operational safety has become an essential issue in fishery meteorological services.

This study targets Taiwan's coastal and offshore capture fisheries to understand how coastal and offshore fishermen use meteorological information, and to reveal their WTP for these services. Several related studies have used the CVM to estimate the economic benefits of meteorological information applications in Taiwan's livestock, agriculture, and aquaculture industries [17–19]. However, the economic benefits of meteorological information applications in Taiwan's coastal and offshore capture fisheries are still under exploration. Our aim is to reveal the WTP of capture fishery practitioners for meteorological information services provided by the Taiwan Central Weather Administration and to estimate the total value created by these services in capture fishery production, highlighting the national-level benefits of these applications.

Regarding research evaluation methods, this study uses data from Taiwan's quinquennial agricultural, forestry, fishery, and livestock census, specifically, the 2015 capture fishery census. We conducted stratified random sampling based on the top eleven capture fishing methods/tools and fishing vessel tonnage, extracting 600 survey samples. After in-person interviews, 515 questionnaires were recovered, with 512 being valid after excluding invalid extreme samples. Three invalidated questionnaires were excluded because of their responses with missing data or outlier values for WTP. We aim to (a) estimate the economic value of climate services for coastal and offshore capture fisheries using CVM, and (b) collect the sociodemographic characteristics of practitioners (gender, age, work location, subjective perceptions, etc.), establish bid functions, and use the unconditional quantile regression model (UQR) for empirical analysis to understand the characteristics influencing WTP variability.

The remainder of this paper is organized as follows. Section 2 provides a literature review. Section 3 covers materials and methods. Section 4 analyzes the empirical results, and Section 5 comprehensively discusses the findings. Section 6 offers conclusions and suggestions.

2. Literature Review

In most countries, meteorological information services are provided by the government or public sector, making this information freely accessible to the public. Meteorological information possesses characteristics of public goods, such as non-excludability and non-rivalry, aligning with economic definitions of public goods [20]. The WMO's 2015 report, "Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services", reviews international studies and cases on the benefits of meteorological and hydrological services, offering frameworks, processes, and methods for assessing these benefits [2].

To evaluate the value of meteorological information, the CVM and conjoint analysis can be used to examine stated preferences. For revealed preferences, methods such as the averting behavior method, travel cost method, and hedonic pricing can be employed. Among these, the hedonic pricing method treats climatic conditions or air quality as characteristic attributes, estimating their value through the rental or sale prices of nearby properties. Additionally, economic analogs, decision analysis, equilibrium simulation, avoided cost analysis, and benefit transfer methods are also applicable.

In Taiwan, the Central Weather Administration primarily provides meteorological information services, offering free access to the public, including fishery practitioners. Lin et al. [19] identified Taiwan's fishery meteorological information services as quasi-public goods without a direct market for valuation. When direct evaluation is not feasible, economists often use the CVM to estimate the value of non-market goods by creating a hypothetical market and assessing respondents' WTP. This involves assessing respondents' willingness to pay for information or services that would typically require payment, allowing economists to infer the value of goods or services without a direct market price. Although some scholars question the CVM, citing concerns about questionnaire design, bidding techniques, and response biases, many experts believe that, when the CVM follows strict design and research guidelines, it can reduce biases related to free-riding and social desirability, thereby enhancing the reliability of its results [21–26]. The CVM is also one of the methods proposed by the WMO for evaluating the value of meteorological services [2].

The CVM was first introduced by Ciriacy-Wantrup [27] in 1947 to evaluate public goods through the concept of willingness to purchase. According to the international literature and case reviews, the CVM is widely used in various fields, such as environmental economics for valuing natural resources, compensating for environmental damages, and conducting cost–benefit analyses of environmental protection policies. In public health, it assesses the value of specific health policies or public health measures. In urban and regional planning, it evaluates the value of facilities or urban redevelopment projects and the public's use of meteorological information.

CVM studies on meteorological information services generally address topics such as the public application of meteorological information [28], climate change issues [29], environmental protection [30], and applications by agricultural and fishery producers [18,19,31]. We summarize relevant CVM studies in meteorological information in Table 1.

In the public application of meteorological information, Anaman et al. [28] evaluated the economic value of public weather services for business personnel in Ghana, with an average annual WTP of USD 51.96 per person. In climate change issues, Park and Woo [29] assessed South Koreans' WTP for flood prevention policies and policies protecting vulnerable populations under climate change, finding an average annual WTP of USD 19.92 for flood prevention and USD 18.76 for vulnerable population protection. In environmental protection, Srisawasdi et al. [30] examined the WTP for reducing air pollution in the Mae Mo district, Thailand, showing that reducing major air pollutants by 50% and 80% resulted in an average annual WTP of USD 8.4 and USD 10.3 per person, respectively, translating to USD 336,294 and USD 412,096 for the entire population. In agriculture and fishery applications, Chiueh et al. [31] assessed the value of rice fields in Taiwan using remote sensing to measure temperature drops during non-planting periods. The CVM evaluation found that Taiwanese people are willing to pay an additional USD 8.89 per kilogram of rice annually, with the total annual benefit of a 1 °C temperature drop in local microclimates estimated at USD 9.693 billion.

Previous research has also applied the CVM to evaluate the economic value of meteorological information in Taiwan's livestock, agriculture, and aquaculture sectors. In the livestock sector, the average annual WTP for meteorological services ranged from USD 168.43 to USD 191.18 per person, with total annual benefits estimated between USD 3.707 million and USD 4.175 million [17]. In agriculture, the average annual WTP was between USD 56.06 and USD 90.92 per person, with total annual benefits estimated between USD 28.06 million and USD 45.51 million [18]. In aquaculture, the average annual WTP was USD

108.68 per person, with total annual benefits estimated between USD 4.820 million and USD 6.417 million [19].

In addition, the literature has utilized the CVM to explore fishery-related issues, including WTP for fishery insurance [32], fishery resource conservation [33–36], and fishery management [37]. Table 1 provides a summary of research on CVM applications in various fields. It shows that the CVM has been widely applied across various fields and used to investigate different target groups (sectors/industries/households/individuals). The application of the CVM aims to understand the WTP of various groups and ultimately estimate the overall value of an industry. Among these fields, fisheries and aquaculture are highly vulnerable to natural events, including storms, tsunamis, floods, droughts, heatwaves, ocean warming, and acidification. Capture ecosystems are particularly vulnerable to the intensity and frequency of marine heatwaves. When marine ecosystems and biodiversity are compromised, fish stock levels are likely to decline [6,8,9]. Since the availability of fishery resources depends on the dynamics of marine ecosystems, monitoring these changes—such as ocean currents and fish migrations—using meteorological data is crucial. It can inform strategies to mitigate the impacts of climate change on fisheries [11,38]. In this paper, we focus on the capture fishery sector, analyzing the WTP of coastal fishermen in Taiwan for meteorological information services provided by the Central Weather Administration and the value created by these services. The following section will introduce the questionnaire design and research methodology in this study.

Table 1. Summary of research on CVM applications.

Source	Countries	Objects to Be Valued	Willingness to Pay (WTP) Estimates
Meteorological applications for the public			
[28]	Ghana	Public weather services to formal services sector	USD 51.96 per person per year
[30]	Thailand	Air quality improvement and pollutant reduction	50%: USD 8.4 per person per year 80%: USD 10.3 per person per year
Issues on climate change			
[31]	Taiwan	Cooling benefits of paddy fields	USD 8.89 per kg rice per year
[29]	Korea	Flood control policy/ populations vulnerable	Flood control policy: USD 19.92 per person per year Populations vulnerable: USD 18.76 per person per year
Issues on environmental protection			
[33]	Korea	The conservation value of biodegradable fishing nets in fisheries	USD 3.85 per household per year
[34]	Indonesia	The conservation value of fish biodiversity	USD 15 per person per year
[35]	Malaysia	The conservation value of fishery resources	USD 100 per person per year
[36]	United States	Conservation and improvement of migration pathways for fish to reach spawning habitats	USD 18 to 21 per person per year
Applications for agricultural and fishery producers			
[17]	Taiwan	Meteorological information services to animal husbandry	USD 168.43~191.18 per household per year
[32]	China	Aquaculture insurance	USD 90.05 per household per year
[18]	Taiwan	Meteorological information services to farmers	USD 56.06 to 90.92 per household per year

Table 1. *Cont.*

Source	Countries	Objects to Be Valued	Willingness to Pay (WTP) Estimates
[37]	Korea	Willingness to pay for the creation of marine ranches and development of marine forests	Marine ranches: USD 3.35 per household per year Marine forests: USD 5.66 per household per year
[19]	Taiwan	Meteorological information services to inland aquaculture fisheries	USD 108.68 per household per year

Note: 1 USD = 32.61 TWD; 1 USD = 1378.05 KRW; 1 USD = 3.018 RM.

3. Data and Methods

This study conducted a survey of practitioners in Taiwan's coastal and offshore fisheries. This section will explain (i) the design of the questionnaire for coastal and offshore capture fisheries and (ii) the CVM evaluation method.

3.1. Questionnaire Design

To understand how respondents apply meteorological information in their fishing operations, data were collected through a questionnaire. The questionnaire was designed in four parts: awareness and experience with marine meteorological forecasts, damage caused by meteorological events, the valuation of meteorological information, and the basic demographic information of the respondents.

3.1.1. Questionnaire Structure

The first part concerns the awareness and experience of marine meteorological forecasts. We investigate respondents' experiences with applying marine meteorological forecasts, including the frequency of using various meteorological information channels, commonly used forecast items, and types of forecast information needed. The second part concerns damage caused by meteorological events. It surveys how respondents handle and respond to meteorological disasters, including the types of meteorological disasters encountered and the measures taken to cope with them. The third part is the valuation of meteorological information, assessing respondents' subjective perceptions of the application of meteorological information (such as the accuracy of forecasts and their impact on fishing operations) and the respondents' willingness to pay for meteorological information. The last part collects basic demographic information about the respondents including gender, age, years of work experience, education level, fishing methods, and income.

3.1.2. CVM Evaluation Survey Design

The CVM often asks respondents to evaluate or express their willingness to pay for a non-market good under specific scenarios. Since respondents typically have no real market transaction experience with such goods, the researcher first establishes a "contingent or hypothetical market" for the non-market good in question. The market is designed to be as plausible as possible [23]. Therefore, as [25] indicates, respondents are asked to indicate their value for a public good, usually by specifying the maximum amount they would be willing to pay to obtain or to retain it.

This study employs the double-bounded dichotomous choice with a follow-up open-ended format, a method proven in the literature to be both efficient and effective in eliciting responses for the formal questionnaire's valuation section. The double-bounded dichotomous choice method will be used initially for the value assessment, with ten sets of appropriate bid levels designed. Respondents will first go through a two-stage dichotomous choice question, from which the range of possible WTP can be inferred based on their responses. This will be followed by an open-ended question to collect more precise WTP amounts, which will serve as the basis for subsequent analysis.

3.1.3. Sample Collection

This study conducted a survey targeting practitioners in Taiwan's coastal and offshore fisheries. To ensure sufficient representativeness, this research collaborated with Taiwan's Directorate-General of Budget, Accounting, and Statistics (DGBAS). Using the 2015 National Agricultural, Forestry, Fishery, and Livestock Census conducted by DGBAS as a foundation, we established a sample for coastal and offshore capture fisheries through random stratified sampling.

According to the 2015 National Agricultural, Forestry, Fishery, and Livestock Census, Taiwan's fishery industry can be categorized into (1) Fishing Fishery, (2) Aquaculture Fishery, and (3) Transition Leisure Fishery. The Fishing Fishery category includes Far Sea Fishery, Offshore Fishery, Coastal Fishery, and Inland Fishery. The Census indicates that there are a total of 40,166 households engaged in fishery work, with the population of coastal and offshore fisheries comprising 13,472 households.

Upon determining the population size, we conducted stratified sampling based on fishing methods and vessel tonnage to understand meteorological information's application and subjective perception across different fishing modes. We selected the top 11 fishing methods used in coastal and offshore areas of Taiwan and stratified the samples by vessel tonnage. The DGBAS provided 600 household samples based on this stratification. The survey was conducted via in-person interviews between July and October 2020, resulting in 512 completed questionnaires. Before analyzing the WTP, the 512 questionnaires were categorized into two main groups: WTP $\neq 0$ and WTP = 0. The WTP $\neq 0$ group represents valid samples, while the WTP = 0 group was further divided into protest samples and non-protest samples.

Protest samples include respondents who recognize the value of meteorological information but are unwilling to pay for it or cannot assess its value. Including these samples in the analysis would affect the accuracy of the evaluation, so they were excluded. This study identified 134 protest samples. Non-protest samples consist of respondents who either see no value in meteorological information (47 respondents) or have other means of obtaining it for free (78 respondents), resulting in a WTP of zero. In summary, after excluding protest samples and those with indeterminate responses, the final valid sample size for analysis was 388 out of the 512 surveyed.

Based on the socioeconomic background statistics of the respondents, this national survey of 388 questionnaires reveals that approximately 95% of those engaged in coastal and offshore fisheries are male, with only 20 female respondents making up about 5% of the total sample. About 54% of the respondents are aged between 46 and 64, with an overall average age of 54.8 years. Most respondents have a middle school education, accounting for about 33%. Specifically, for fishing methods like pole-and-line, harvesting fish and shellfish juveniles, tuna longlining, and gillnetting, over 35% of the practitioners have only an elementary school education. The respondents have worked in the fishing industry for an average of 29 years. The number of days spent at sea varies across different fishing methods, with an overall average of about 3 days. Table 2 presents the socioeconomic background characteristics of the respondents.

Table 2. Socioeconomic characteristics of coastal and offshore fishery practitioners (N = 388).

		Gender (%)	Age (%)			Average Age	Education Level (%)							Years of Experience	Average Days at Sea
	Sample	**Male**	**18–45**	**46–64**	**65+**		**Illiterate**	**Primary School**	**Middle School**	**High School**	**Associate Degree**	**Bachelor**	**Post-Graduate or above**		
Total Sample	388	95%	23%	54%	23%	54.8	1%	27%	33%	27%	5%	7%	1%	29	3.0
Fishing method															
Small trawlers	41	98%	46%	29%	24%	50.9	-	22%	32%	24%	15%	7%	-	27	1.7
Tuna longlining	37	100%	32%	59%	8%	51.6	3%	32%	30%	30%	3%	3%	-	31	17.3
Pole-and-line	9	100%	44%	33%	22%	48.1	-	44%	-	22%	11%	22%	-	25	7.2
Gillnetting	114	93%	18%	57%	25%	56.6	2%	33%	33%	23%	3%	4%	2%	31	1.2
Mixed fish longlining	33	100%	18%	61%	21%	54.5	-	27%	33%	33%	-	6%	-	32	2.7
Handlining	127	94%	18%	56%	26%	55.6	-	19%	40%	28%	2%	10%	-	28	1.1
Troll lining	4	50%	50%	50%	-	48.3	-	25%	25%	25%	25%	-	-	14	0.9
Set netting	3	33%	33%	67%	-	42.7	-	-	-	33%	33%	-	33%	12	1.7
Other net fishing	9	100%	11%	44%	44%	61.7	-	33%	22%	33%	-	11%	-	36	1.4
Trap fishing	4	100%	25%	50%	25%	56.3	-	25%	25%	25%	25%	-	-	28	1.3
Harvesting fish and shellfish juveniles	7	100%	-	71%	29%	58.7	-	43%	14%	29%	14%	-	-	36	1.0

Source: Compiled by this study.

3.2. Methods

Meteorological information is typically considered a non-market good, primarily provided by government agencies or non-profit organizations to ensure public safety and well-being [18,39,40]. Various methods can be used to assess the economic benefits of non-market goods, with the CVM being the most widely applied analytical tool.

Since most meteorological services do not have an actual trading market, it is necessary to create a hypothetical market to evaluate the transaction value of meteorological information services. This approach allows us to ask respondents about their WTP for these services. Additionally, this study analyzes the factors that potentially influence WTP through a bid function analysis based on the respondents' valuation of meteorological information services. This analysis aims to provide policymakers with insights for designing effective policies.

We use the CVM with a dichotomous choice method as the inquiry model for price evaluation. This approach has been proven to reduce the proportion of protest and non-response samples [41]. It is also considered more effective in assessing value than open-ended and payment card methods [42].

In applying the dichotomous choice method, bid prices are presented to respondents in a two-stage inquiry process. Providing these bid prices induces respondents to reveal their genuine WTP. However, in practical terms, respondents may perceive these bid amounts as the market price of the goods being evaluated, which can influence their actual WTP and lead to a value bias effect known as starting point bias [42–45].

To mitigate the impact of starting point bias, the characteristics of the CVM questionnaire tool must be considered during bid function analysis, and appropriate adjustments should be made based on the estimation results. According to the correction model proposed by Herriges and Shogren [43], when applying the double-bounded dichotomous choice model, respondents use the bid amount provided by the interviewer as a reference in determining their WTP. In the second stage, the WTP_i^2 is a weighted combination of the actual WTP (WTP_i) and the initial bid amount (Bid_i^1), with the weighting factor γ_i representing the anchoring effect coefficient. This coefficient, which ranges from 0 to 1, $0 \leq \gamma_i \leq 1$, indicates the extent to which the initial bid influences the second-stage WTP. If γ_i is close to 1, it suggests that the second-stage WTP_i^2 is heavily influenced by the initial bid (Bid_i^1), indicating a strong anchoring effect and thus a significant starting point bias. Conversely, if γ_i is close to 0, it means that minimal starting point bias affects the WTP estimation, and the second-stage WTP_i^2 is closer to the actual WTP (WTP_i), indicating a negligible impact from the starting point. The conceptual formula is as Equation (1).

$$WTP_i^2 = (1 - \gamma_i) * WTP_i + \gamma_i * Bid_i^1 \quad (1)$$

To establish an empirical model for the bid function based on Equation (1) and to estimate the anchoring effect coefficient (γ_i), we need to use the survey data. Once the value of γ_i is estimated, we can apply Equation (2) to calibrate the initial WTP values and back-calculate the respondents' actual WTP (WTP_i).

$$WTP_i = \left(WTP_i^2 - \gamma_i * Bid_i^1\right) / (1 - \gamma_i) \quad (2)$$

When the anchoring effect occurs in the application of the CVM, the Tobit model can be a useful analytical tool. However, the Tobit model has several prerequisites, such as the data needing to satisfy the assumption of normal distribution to enable effective estimation. In practical applications, not all empirical data meet these conditions. Therefore, this study adopts the "least absolute deviation" (LAD) method, which does not require data distribution assumption and uses the median as the solution target for estimating the bid function.

The traditional LAD estimation results are primarily interpreted as the effect of a specific explanatory variable on the dependent variable, assuming other explanatory variables remain unchanged. However, to simulate the impact of changes in more than one explanatory variable on the dependent variable, we cannot directly use the LAD estimation results for such calculations. To address this issue, this study uses the generalized quantile regression estimator (GQR) developed by Powell [46], combined with the Markov chain Monte Carlo (MCMC) method, to estimate the coefficients of the bid function and examine the changes in explanatory variables.

4. Meteorological Information Application and Empirical Analysis

In this section, we will first explain the application of meteorological information, followed by the bid function model and analysis results.

4.1. Meteorological Information Application

Coastal and offshore fishermen primarily focus on specific types of meteorological forecast information, with wind force levels (approximately 88.9%), typhoons (approximately 85.8%), wave height (approximately 80.7%), and wind direction (approximately 80.4%) being the most critical. Wind force levels are particularly important as they directly impact the safety of fishing vessel navigation, making it the most frequently used piece of meteorological information. Table 3 presents the types of meteorological forecast information prioritized by coastal fishermen. The focus on meteorological information usage varies between different sectors. Taiwan's agriculture and aquaculture sectors prioritize typhoons, rainfall, temperature, and wind direction, whereas the capture fishery sector emphasizes wind force levels, wave height, and wind direction [18,19].

Table 3. Types of meteorological forecast information prioritized by coastal and offshore fishermen (N = 388).

	Wind Force (Level)	**Typhoon**	**Wave Height**	**Wind Direction**	**Tides**	**Gusts (Level)**	**Rainfall**	**Temperature**	**Visibility**
Total Sample	88.9%	85.8%	80.7%	80.4%	64.2%	61.6%	32.2%	17.8%	13.4%
Method									
Small trawlers	87.8%	95.1%	68.3%	80.5%	56.1%	58.5%	43.9%	19.5%	14.6%
Tuna longlining	97.3%	97.3%	67.6%	81.1%	29.7%	62.2%	24.3%	18.9%	10.8%
Pole-and-line	84.6%	92.3%	76.9%	92.3%	61.5%	69.2%	53.8%	46.2%	38.5%
Gillnetting	91.2%	86.8%	87.7%	80.7%	68.4%	64.0%	28.1%	15.8%	13.2%
Mixed fish longlining	93.9%	84.8%	84.8%	84.8%	63.6%	72.7%	33.3%	15.2%	12.1%
Handlining	84.3%	79.5%	81.1%	79.5%	71.7%	55.1%	32.3%	16.5%	13.4%
Troll lining	100.0%	75.0%	75.0%	50.0%	75.0%	75.0%	25.0%	-	-
Set netting	66.7%	66.7%	66.7%	66.7%	66.7%	66.7%	-	33.3%	-
Other net fishing	80.0%	40.0%	80.0%	60.0%	60.0%	80.0%	20.0%	-	-
Trap fishing	100.0%	100.0%	75.0%	100.0%	75.0%	75.0%	50.0%	-	-
Harvesting fish and shellfish juveniles	85.7%	100.0%	100.0%	71.4%	85.7%	57.1%	42.9%	42.9%	14.3%

Source: Compiled by this study.

4.2. Bid Function Model and Analysis Results

In this paper, we examine the willingness to pay for meteorological information services among coastal and offshore fishery practitioners by considering five key aspects: "individual socioeconomic characteristics", "subjective perceptions of meteorological information services", "work location", "type of fishing method", and the "initial bid amount" used to test for the presence of starting point bias. Our model incorporated these variables to estimate the WTP for meteorological information services.

4.2.1. National Bid Function Model for Meteorological Information Application in Capture Fisheries

Equation (3) presents the final chosen functional form after analyzing different combinations and considering the model fit indicators. The variables exhibit linear relationships, and the estimated coefficients are the basis for subsequent inferences.

$$\begin{aligned} WTP_i = \ & \beta_0 + \beta_1 * degree + \beta_2 * effect + \beta_3 * gender + \beta_4 * age + \beta_5 * edu + \beta_6 * exp + \beta_7 * cofam + \\ & \beta_8 * major + \beta_9 * income + \beta_{10} * ton + \beta_{11} * north + \beta_{12} * central + \beta_{13} * south + \beta_{14} * type1 + \\ & \beta_{15} * type2 + \beta_{16} * type3 + \beta_{17} * type4 + \beta_{18} * type5 + \beta_{19} * type6 + \beta_{20} * type7 + \\ & \beta_{21} * type8 + \beta_{22} * type9 + \beta_{23} * type10 + \beta_{24} * bid1 \end{aligned} \quad (3)$$

In the above equation, β_i represents the estimated coefficients for each explanatory variable. "*east*" is selected as the reference point among the work location dummy variables, and for the type of fishing method, "*type11*" (harvesting fish and shellfish juveniles) is used as the reference point. We utilize the LAD method to estimate the coefficients of the bid function in Equation (3). The LAD method minimizes the sum of absolute deviations, providing a robust estimation that is less sensitive to outliers compared to ordinary least squares (OLSs). The resulting coefficients offer insights into the factors that significantly influence the willingness to pay for meteorological information services among coastal and offshore fishermen. The definitions and descriptive statistics of the variables are provided in Tables 4 and 5.

Table 4. Variables' definitions and description.

Variable	Definition and Description
Independent Variable:	
WTP	Continuous Variable: Respondents' monthly willingness to pay (WTP) for meteorological information (TWD), as answered in an open-ended format
Explanatory Variable:	
Initial Bid Amount	
bid1	Continuous Variable: Initial bid amount in the double-bounded dichotomous choice model (TWD)
Subjective Perception of Meteorological Information	
effect	Ordinal Variable: Respondents' subjective perception of the impact of meteorological information on fishing operations, with a score range of 1–10
degree	Continuous Variable: Respondents' subjective accuracy rating of the meteorological information currently used, with a score range of 0–100
Socioeconomic Background Characteristics	
gender	Dummy Variable, Male = 1, Female = 0
age	Continuous Variable: Respondents' age (years)
exp	Continuous Variable: Respondents' experience in coastal and offshore fisheries (years)
edu	Continuous Variable: Respondents' education level, with the following scale: Illiterate = 0, Self-study = 3, Elementary School = 6, Middle School = 9, High School = 12, Associate Degree = 14, Bachelor = 16, Post-Graduate and above = 18
cofam	Continuous Variable: Number of household members also engaged in the fishery industry
major	Dummy Variable, Main income source from fishery = 1, otherwise = 0
income	Continuous Variable: Respondents' annual income from coastal and offshore fisheries, with the following scale: Below 500,000 TWD = 25; 500,000–1,000,000 TWD = 75; 1,000,000–2,000,000 TWD = 150; 2,000,000–3,000,000 TWD = 250; 3,000,000–4,000,000 TWD = 350; 4,000,000–5,000,000 TWD = 450; 5,000,000–6,000,000 TWD = 550; 6,000,000–7,000,000 TWD = 650; 7,000,000–8,000,000 TWD = 750; 8,000,000–9,000,000 TWD = 850; 9,000,000–10,000,000 TWD = 950; Above 10,000,000 TWD = 1050
Locational Characteristics	
north	Dummy Variable, Work location in northern Taiwan = 1, otherwise = 0
central	Dummy Variable, Work location in central Taiwan = 1, otherwise = 0
south	Dummy Variable, Work location in southern Taiwan = 1, otherwise = 0
east *	Dummy Variable, Work location in eastern Taiwan = 1, otherwise = 0

Table 4. *Cont.*

Variable	Definition and Description
Fishing Methods and Vessel Tonnage	
ton	Vessel tonnage, with the following scale: 1 = Less than 5 tons; 2 = 5 to less than 10 tons; 3 = 10 to less than 20 tons; 4 = 20 to less than 50 tons; 5 = More than 50 tons
type1	Dummy Variable, small trawlers = 1, others = 0
type2	Dummy Variable, tuna longlining = 1, others = 0
type3	Dummy Variable, pole-and-line = 1, others = 0
type4	Dummy Variable, gillnetting = 1, others = 0
type5	Dummy Variable, mixed fish longlining = 1, others = 0
type6	Dummy Variable, handlining = 1, others = 0
type7	Dummy Variable, troll lining = 1, others = 0
type8	Dummy Variable, set netting = 1, others = 0
type9	Dummy Variable, other net fishing = 1, others = 0
type10	Dummy Variable, trap fishing = 1, others = 0
type11 *	Dummy Variable, harvesting fish and shellfish juveniles = 1, others = 0

Note: * indicates the reference group for analysis. Source: Compiled by this study.

Table 5. Variables' descriptive statistics.

Variable	Min	Max	Average or Ratio	Standard Deviation
Independent Variable				
WTP	0	10,000	527.11	868.41
Initial Bid Amount				
bid1	200	1400	747.68	369.1
Subjective Perception of Meteorological Information				
effect	1	10	6.7	2.76
degree	0	100	70.95	19.03
Socioeconomic Background Characteristics				
gender	0	1	0.95	0.22
age	19	86	54.75	12.26
exp	1	68	29.44	16.38
edu	0	18	9.72	3.19
cofam	0	10	2.09	1.33
major	0	1	0.76	0.43
income	25	1050	103.67	127.31
Locational Characteristics				
north	0	1	27%	-
central	0	1	7%	-
south	0	1	55%	-
east *	0	1	11%	-
Fishing Methods and Vessel Tonnage				
ton	1	5	2.16	1.37
type1	0	1	11%	-
type2	0	1	10%	-
type3	0	1	2%	-
type4	0	1	29%	-
type5	0	1	9%	-
type6	0	1	33%	-
type7	0	1	1%	-
type8	0	1	1%	-
type9	0	1	2%	-
type10	0	1	1%	-
type11 *	0	1	2%	-

Note: * indicates the reference group for analysis. Source: Compiled by this study.

4.2.2. Empirical Results

The bid function estimation revealed that the estimated coefficient for the bid amount (*bid1*) is statistically significant, indicating the presence of starting point bias in the survey results. To eliminate this bias, we need to address the anchoring effect coefficient, which, in this study, is estimated at 0.34. This suggests that respondents' final WTP is a weighted mix of their actual WTP and the initial bid amount in a ratio of 0.66:0.34. Therefore, the estimated coefficients for each variable must be calibrated to remove the impact of the anchoring effect. The adjusted coefficients and results for each explanatory variable are summarized in Table 6.

Table 6. Empirical of the bid function for meteorological information among coastal and offshore fishery practitioners.

Variable	Estimated Coefficient	Variable	Estimated Coefficient
bid1	0.3416 ***	*south*	−287.1955 ***
degree	6.1999 ***	*type1*	−126.0860 *
effect	64.7038 ***	*type2*	144.6012 ***
gender	−76.8796 *	*type3*	−150.2364 *
age	0.9047	*type4*	19.6030
edu	−22.9685 ***	*type5*	−121.3168 ***
exp	−1.0227	*type6*	20.0427
cofam	55.5434 ***	*type7*	−380.4450 ***
major	38.3835 *	*type8*	−139.7822
income	0.5231 ***	*type9*	80.8648
ton	9.1977	*type10*	−167.1668 ***
north	−353.5233 ***	*constant*	−237.9044 ***
central	−259.9068 ***		

Note 1. The final valid sample size for empirical analysis was 388. Note 2. * and *** represent significance levels of 0.1 and 0.01, respectively.

Overall, the independent variables in the bid function show a significant relationship with the median willingness to pay, indicating that the coefficients can explain the changes in WTP for each unit change in the variables. The empirical estimation results reveal that variables such as subjective accuracy (*degree*), subjective impact (*effect*), family members in the fishery industry, fishing as the primary income source, and annual income have a positive significant impact on the WTP for meteorological information. This means that an increase in these variables leads to a higher WTP among respondents.

For example, the regression coefficient for subjective accuracy (*degree*) is 6.19, indicating that the monthly WTP for meteorological information services increases by TWD 6.19 for each one-point increase in subjective accuracy. Similarly, an increase of one point in subjective impact (*effect*) results in a monthly WTP increase of TWD 64.70. The number of family members involved in the fishing industry (*cofam*) also shows a significant impact on WTP, with each additional family member increasing the monthly WTP by TWD 55.54. Annual income (*income*) has a significant positive effect as well, where each unit increase in income corresponds to an additional TWD 0.52 in monthly WTP.

Conversely, some variables show a significant negative impact on WTP. These include gender, education level, fishing region, and certain fishing methods. For gender, female practitioners have a higher WTP for meteorological information compared to males. Regarding education level (*edu*), each additional year of education decreases the monthly WTP by TWD 22.96, indicating that respondents with lower education levels are more willing to pay for meteorological services, possibly because higher educated individuals believe they can access weather information through other means.

Geographical location and fishing methods also exhibit significant negative impacts on WTP. For geographical location, the coefficients for the north, central, and south regions are all significantly negative, indicating a lower average WTP than the reference group (*east*). Regarding fishing methods, small trawlers (*type1*), pole-and-line (*type3*), mixed fish longlining (*type5*), trolling (*type7*), and trap fishing (*type10*) have lower average WTP compared to the reference group (harvesting fish and shellfish juveniles, *type11*). This may be due to the varying degrees of dependency on meteorological information across different fishing methods. For instance, trap fishing involves setting traps at fixed ocean floor locations, requiring less meteorological information. On the other hand, methods like small trawling, mixed fish longlining, and trolling involve more flexible operations that can quickly adapt to weather changes, reducing their reliance on weather information. Pole-and-line fishing, typically conducted at night using fishing lights to attract phototactic fish into nets, is highly mobile and less dependent on meteorological conditions.

In summary, this study highlights the varying levels of dependence on meteorological information among different fishing methods and regions, influencing their willingness to pay for such services.

5. Discussion

5.1. Estimation of the Benefits of Meteorological Information Services for Capture Fisheries

To calibrate the estimation of WTP, based on Equation (3), the relationship between WTP and the initial bid amount exhibits a mixed price relationship. Thus, the median of the actual WTP should be revised as shown in Equation (4) and calibrated using Equation (5).

$$WTP_i^2 = (1 - \widehat{\gamma_1}) * WTP_i + \widehat{\gamma_1} * Bid_{1i} \tag{4}$$

$$\widehat{WTP}^{med} = \left(WTP_i^2 - \widehat{\gamma_1} * Bid_{1i}\right) / (1 - \widehat{\gamma_1}) \tag{5}$$

By applying the bid function to the calibration estimation of WTP, we obtained a median monthly WTP ($\widehat{WTP}^{med}$) of TWD 175.93 per person, resulting in an annual WTP of TWD 2111.12 per person. If we were to calculate the average value without calibration, the respondents' monthly WTP for meteorological information would be significantly higher than the calibrated bid estimation, with an overestimation margin of 1.99 times. Failure to calibrate this bias would substantially overestimate the subjective perceived value of meteorological information among coastal and offshore fishery practitioners.

To understand the WTP among practitioners using different fishing methods, this study uses the coefficient estimates from the bid function along with the explanatory variable values for each sample point to calculate the calibrated median WTP for each fishing method. From Equation (5), the calibrated monthly WTP per person can be obtained, and the same calculation method is applied to the various fishing methods. By using the bid function to calibrate the WTP for each fishing method and then determining the calibrated median WTP for each, we can provide accurate estimates.

For example, for small trawlers (*type1*), the calibrated WTP ranges from TWD 12.04 to TWD 659.79, with a median monthly WTP of TWD 110.42 per person, resulting in an estimated annual WTP of TWD 1325 per person. Based on the median WTP of coastal and offshore fishery practitioners, the total economic value (TEV) of applying meteorological information to Taiwan's coastal and offshore capture fisheries can be calculated using Equation (6):

$$TEV = \widehat{WTP}_i^{median} * N_i \tag{6}$$

where $\boldsymbol{i}$ represents different fishing methods and N_i is the number of practitioners using the i-th fishing method. $\widehat{WTP}_i^{median}$ is the annual median WTP for meteorological information by practitioners of the i-th fishing method.

For the TEV calculation of meteorological information in coastal and offshore fisheries, we considered two scenarios regarding the number of willing payers, as shown in Table 7.

Table 7. Estimated total economic value (TEV) of meteorological information for coastal fisheries under optimistic and conservative scenarios (in TWD).

WTP (TWD/year) (A)	Optimistic Scenario		Conservative Scenario	
	# of Willing Payers (B)	TEV (TWD million/yr) (C) = (A) × (B) × 10^{-6}	# of Willing Payers (D)	TEV (TWD million/yr) (E) = (A) × (D) × 10^{-6}
small trawlers (*type*1) = 1325	24,846	33	18,828	25
tuna longlining (*type*2) = 3972	20,780	83	15,747	63
pole-and-line (*type*3) = 1331	4969	7	3766	5
gillnetting (*type*4) = 2874	68,664	197	52,035	150
mixed fish longlining (*type*5) = 1974	20,780	41	15,747	31
handlining (*type*6) = 1128	75,892	86	57,512	65
troll lining (*type*7) = 2612	1807	5	1369	4
set netting (*type*8) = 4419	1807	8	1369	6
other net fishing (*type*9) = 2860	4969	14	3766	11
trap fishing (*type*10) = 2943	2259	7	1712	5
harvesting fish and shellfish juveniles (*type*11) = 3611	4517	16	3423	12
Total Economic Value:	TWD 496 million/year		TWD 376 million/year	

Scenario 1: Optimistic Scenario

Under this scenario, we assume that "protest samples" have the same WTP as non-protest samples. Under these conditions, the total economic value of meteorological information services shows an annual benefit of TWD 496 million (approximately USD 15.23 million).

Scenario 2: Conservative Scenario

Under this scenario, we adjust the number of willing payers by assuming that the "protest samples" will not participate in the valuation. The total economic value of meteorological information services shows an annual benefit of TWD 376 million (approximately USD 11.54 million).

5.2. Comparison of the Benefits of Meteorological Information Services in Taiwan's Agriculture, Aquaculture, and Capture Fisheries

Previous research has conducted nationwide evaluations of the value of meteorological information services across different sectors in Taiwan, including agriculture [18] and aquaculture [19]. Here, we summarize the findings of these evaluations and include the results of this study for comparison and discussion.

We used the CVM as the analytical tool in our studies on agriculture, terrestrial aquaculture, and capture fisheries. Each study sample is representative of its population, making them suitable for cross-sectoral benefit comparisons. Table 8 shows the average WTP of households in various industries for meteorological information, sorted according to the amount of prices. The industry with the highest WTP is aquaculture, at USD 108.68 per household per year. Next is agriculture practitioners, with an average annual WTP between USD 56.06 and USD 90.92. Capture fishery practitioners follow with an average yearly WTP of USD 65.87.

Practitioners from these sectors recognize the importance of meteorological information, but exhibit different WTP values. Aquaculture's higher WTP is due to its reliance on meteorological information for production control. For example, water temperature directly affects the physiological mechanisms of farmed fish, such as growth rate, reproduction, and spawning [47]. Managing climate-sensitive factors in aquaculture operations can reduce climate risks and costs, ensuring profitability [48]. In contrast, the lower WTP among Taiwanese agriculture practitioners might be attributed to the earlier adoption of agricultural technology, including AIoT (Agricultural Internet of Things) and biotechnology, to adapt to various levels of climate change [49,50]. For the capture fishery industry, the primary impacts of meteorological information are on ocean current changes and navigation safety. Ocean current changes can indirectly cause the movement of target fish species. Through technological development and innovative applications, the industry can adapt to both long-term climate change and short-term meteorological disasters, reducing the risks of capture operations [51].

Table 8. Comparison of estimated total economic value (TEV) of meteorological information under optimistic and conservative scenarios (in USD).

Average WTP (USD/Year/Household)	TEV (Optimistic Scenario)		TEV (Conservative Scenario)	
	# of Households	Benefits of Meteorological Information (USD million/yr)	# of Households	Benefits of Meteorological Information (USD million/yr)
Aquaculture 108.68	62,584	6.41	47,055	4.82
Agricultural 56.06 to 90.92	705,198	39.52–64.10	500,691	28.06–45.51
Capture Fisheries 65.87	231,290	15.23	175,274	11.54

Note 1. Average WTP is presented as the average value for each category. Note 2. The number of willing payers is the sum of individuals in each sector. Note 3. The 2019 agricultural benefit evaluation was presented in USD. For comparison, the 2021 aquaculture and this study's results were converted to USD. Note 4. Agriculture practitioners' average annual WTP is between USD 56.06 and USD 90.92. We take these numbers times the number of households to obtain the range of estimated benefits of meteorological information services, which is from USD 39.52 million to 64.10 million.

Table 8 presents the estimated economic benefits of meteorological information services for different industries under optimistic and conservative scenarios. In the 2019 agricultural study [18], only the conservative scenario was calculated. Given that the bid proportion in the conservative scenario is 71%, we can estimate the optimistic scenario's annual benefits to be approximately USD 39.52 million to USD 64.10 million.

From the perspective of population structure and TEV estimation by industry, Taiwanese agriculture households are approximately 700,000; capture fisheries households are approximately 230,000; and aquaculture households are approximately 60,000. Under the optimistic scenario, assuming that all respondents are willing to pay for meteorological information, the total economic benefits are estimated as follows: in agriculture, the annual total economic benefit ranges from USD 39.52 million to USD 64.10 million, with a 95% confidence interval. In capture fisheries, the annual economic benefit is approximately USD 15.23 million. In aquaculture, the annual economic benefit is roughly USD 6.41 million.

In contrast, under the conservative scenario, assuming that only a portion of the respondents are willing to pay for meteorological information, the total economic benefits are estimated as follows: in agriculture, the annual total economic benefit ranges from USD 28.06 million to USD 45.51 million, with a 95% confidence interval. In capture fisheries, the annual economic benefit is approximately USD 11.54 million. In aquaculture, the annual economic benefit is roughly USD 4.82 million.

6. Conclusions

This study uses the CVM to survey Taiwan's coastal and offshore capture fisheries. Through in-person sampling surveys, we collected 512 valid responses, of which 388 questionnaires were included in the bid function analysis after excluding protest responses. Coastal and offshore capture fishery practitioners were asked to evaluate the meteorological information services provided by the Central Weather Administration and infer the economic value of applying these services to their operations.

Based on the empirical results, the subjective impact of meteorological information services on coastal and offshore fishing activities is statistically significant. For each one-point increase in subjective impact, the median WTP increases by TWD 64.70, resulting in an annual increase of TWD 776.4. The demand for meteorological information also varies across different geographical locations. In capture fisheries, the WTP for meteorological information is significantly higher in the eastern region compared to other areas. This suggests the need for a deeper understanding of the specific needs of different practitioners based on their geographic location.

Moreover, there are significant differences in WTP among practitioners using different fishing methods. Considering the number of practitioners using various fishing methods and estimating the total value, the annual economic value range of applying meteorological information to coastal and offshore fisheries is estimated to be between TWD 376 million and TWD 496 million.

Comparing the survey results with the related literature, it is evident that the accuracy of meteorological forecasts has a positive and significant impact on agriculture, aquaculture, and capture fisheries. However, the effectiveness of forecasts in aiding production is significant only in the capture fishery sector [18,19]. Additionally, an interesting age-related phenomenon emerges in the analysis of WTP for meteorological information in aquaculture and capture fisheries: younger respondents in the capture fisheries sector exhibit a higher willingness to pay, while the opposite is observed in the aquaculture sector.

Finally, this study analyzes the WTP for meteorological information, identifying the factors influencing it. From a policy management perspective, it is crucial to explore the meteorological application needs of different fishing methods and geographic locations. Providing tailored meteorological information for coastal and offshore fisheries can reduce the impact of extreme weather events on fishery production, enhance production efficiency and safety for fishermen, and promote the sustainable development of coastal fisheries.

It is indeed challenging to understand the potential mechanisms behind variations in WTP among different demographic groups working in aquaculture and capture fisheries. These variations may be influenced by unique challenges faced by each group, which warrant further exploration. Additionally, future studies should investigate the impact of real-time weather information on production efficiency, as this could significantly enhance the sustainability of coastal fishing. Building a comprehensive meteorological information service system that offers real-time weather conditions and warning information can help fishermen respond promptly to extreme weather events, thereby strengthening the value of meteorological information applications.

However, this study has certain limitations. The sample may not fully represent the diverse demographic and socioeconomic backgrounds of all fishermen, limiting the ability to generalize the results across different regions or fishing communities. Future research should aim to include a broader range of participants and take regional differences into account to improve the applicability of the findings.

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