Risk Management of Marine Capture Fisheries under Climate Change: Taking into Consideration the Effects of Uncertainty

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Abstract: Multiple changes in marine resources (e.g., abundance, movements, distribution, biomass) caused by climate change are critical operational risks, leading to production uncertainty for capture fisheries. Therefore, risk management measures of coastal and offshore fisheries are critical issues in terms of operational sustainability. In this study, a questionnaire survey data set collected from fishers was analyzed using descriptive statistics, factor analysis, and a structural equation model (SEM) to examine fishers’ perceptions and the relationships among risk sources, production uncertainty, and adaptation measures. The results revealed that significant negative impacts existed between risk sources and adaptation measures, which means risk sources cannot directly influence risk management measure selection. However, production uncertainty could be an important mediator for risk management, thus most respondents think that mitigating production uncertainty is necessary. Eventually, the results could provide managerial implications for the fishery operators, policymakers and the government agencies.

Keywords: climate change; marine capture fisheries; uncertainty; risk management; adaptation; structural equation model

1. Introduction

Elevated CO2 levels due to climate change have resulted in a significant correlation between ocean acidification, sea level rise, changes in ocean circulation, abnormal weather, and rise in sea surface temperature (SST) [1]. In its Fourth Assessment Report (AR4), the Intergovernmental Panel on Climate Change (IPCC) reported that the global temperature rose by 0.74 °C over the last 100 years, and that this trend is unstoppable despite efforts to reduce greenhouse gas emissions [2]. The 2014 Fifth Assessment Report (AR5) indicated that extreme weather events (e.g., torrential rain and typhoon) will become more frequent and intense. Hence, ocean temperature, heat capacity, and sea level changes are likely to severely impact the marine environment [3]. The effect of climate change on marine fisheries will be elucidated by changes in biological (e.g., primary productivity, biodiversity, species distribution, and habitat), physical (e.g., wind speed, ocean current, and temperature), and chemical (e.g., salinity, oxygen saturation, ocean acidity) factors [4]. In addition, the effects of climate change on coastal countries are characterized by the long-term effects of global warming (e.g., sea level rise, ocean warming, and change in precipitation) and the real-time effects of extreme weather events (e.g., typhoon, extreme rainfall, and saltwater intrusion) [3]. Therefore, global climate change significantly impacts marine and coastal environments, particularly marine fisheries and the livelihood of fishers. Marine fisheries must address not only overfishing problems but also operational risks caused by the environmental impact of climate change, for example, fishers need to go farther and spend more time in more extreme environments. These risks are a result of
changes in the distribution of fishery resources, fish migration routes, and reproductive behavior. Nevertheless, these effects will also lead to production uncertainties for fishery operators and in turn influence the supply of aquatic products and food safety [5]. In other words, the effect of climate change on the management of operational risks of fisheries warrants extensive investigation from the perspective of production uncertainty. Previous studies typically analyzed the effects of climate change on fishery resources [6], whereas there is a dearth of research regarding the effects of climate change on the operations of coastal and offshore fishing industries. To reduce the uncertainties in fishery production, furthermore to continuous research on marine fishery resources, fishery operations should be explored from a risk management perspective to provide valuable information as reference for fishers, fishery operators, and policy makers. Grafton (2010) [7] indicated that risk management approaches are generally used to avoid the effects of climate change on fishery operations. In this study, it also mentioned that climate change is responded to by building ex ante resilience and implementing ex post adaptation or adaptive management. Therefore, the risk management behaviors of fishers, how perceived uncertainties affect these behaviors, and the subsequent decisions are key research topics that should be addressed when investigating the various sources of climate change-related risks (e.g., changes in ocean temperature, changes in ocean circulation, and extreme weather) [8–10].

The effects of climate change on fishery resources can include primary productivity and habitat deterioration, as well as changes in the ocean environment and ocean circulation system, biodiversity and species distribution, and the physiological functions of marine organisms [6]. These effects of climate change on marine resources can be regarded as key sources of risks to ocean fisheries. Generally speaking, risks can be defined as a measure of the probability and intensity of an adverse effect or a measure describing the possibility and consequences of harmful results [11]. Risks have been classified into two types: external risk, which originates from natural factors and systemic risks outside of the human society; and manufactured risk, which is produced by knowledge that is being generated continuously [12]. In the management of natural resources, risks refer to the degree of financial loss resulting from force unforeseeable external factors and the possibility of such loss occurring. Uncertainty refers to the inability to predict an event by rule of thumb. Therefore, uncertainty exists in fishery production when risks are unknown. From the perspective of fishery management, uncertainty stems from biological, economic, and policy factors [13]. If fishery operations are viewed from a risk management perspective, the first step is to identify the source of fishery risks [14]. Miller et al. (2010) [15] indicated that building resilience and implementing adaptation are the primary means to avoid the uncertainties and impacts of climate change on fishery systems. Natural disasters and climate change in the complex system of nature, coupled with the aforementioned risks and uncertainty factors, render prediction of future risks in fishery production difficult. Extreme weather events causing changes to marine resources may include tsunamis, typhoons, floods, and cold-water intrusion [16]. Furthermore, climate change puts more pressure on fisheries by introducing factors that cause uncertainty such as schooling of fish, primary productivity, migration pattern, the mutual effects of nutrition, and the vulnerability of fish species [17].

A report concerning the effects of climate change on key fishery resources in Taiwan [6] revealed that the change in fishing sites and migration of flathead grey mullet were a result of rising ocean temperature. The northward migration of temperate fish and cold water fish such as juvenile anchovy and the reduced recruitment of dominant species (Japanese anchovy) have caused a shift in the regimes of recruits. Regarding the effects of extreme weather events on fisheries in Taiwan, previous studies found that short-term climate extremes have caused significant income loss to fisheries in Taiwan, including those involved in eel larvae, flathead grey mullet, and multiple species in Penghu [6,18]. Another study determined that typhoons are key factors influencing the sea surface temperature (SST) in the Southeast China Sea, which increases the upwelling phenomenon and primary productivity, thereby affecting the species composition of the catches of stick-held dip net
fishers [18]. In 2008, the cold-water intrusion event in Penghu significantly impacted the production of local cage cultures and capture of wild fish, leading to serious losses and the deaths of 73 metric tons of marine fish in the sea around Penghu and 80% of cage-cultured fish [19]. Based on these studies, the effects of climate change on coastal and offshore fisheries in Taiwan have been proven and are still ongoing.

Currently, the Taiwanese government implements some fishery resources management measures, but lacks comprehensive policies to deal with climate change impacts on fisheries. Therefore, how fishery operational risks are managed as coastal and offshore fishers face production uncertainty is a critical topic requiring immediate attention. This study focused on three main coastal and offshore fishing areas in the northeast of Taiwan: New Taipei City, Keelung City, and Yilan County. Literature analysis based on applicable theories was performed to identify how various risks cause uncertainties in the production of coastal and offshore fisheries, and to determine how these risks and uncertainties further influence the decision-making behaviors of fishery operators in response to risks. In this study, we propose risk management measures for coastal and offshore fisheries, investigate how resilience to climate change is fortified through risk management, and explore how adaptation to climate change is achieved by ex post management, which in turn mitigates the uncertainties and risks caused by climate change to coastal and offshore fisheries and strengthens the sustainability of fisheries under the impact of climate change. We hope that this study will provide useful information to support decision making by government agencies, policy makers and fishery operators concerning the risk management of marine capture fisheries under climate change.

2. Research Hypothesis

Uncertainties about fishery productions are associated with other key factors, such as overfishing [20,21] or pollution [22], which also influences fishery resources. In addition, spawning period and quantity of harvests are related to the recruitment of fishes. The size of recruitment is affected by a number of environmental factors, including climate, food, predators, and ocean currents. According to literature reviews, this study therefore proposes the following hypotheses:

**Hypothesis 1 (H1).** Risk sources lead to production uncertainties.

The sources of risks also lead to uncertainties about fishery production, including output variations, composition of harvests, and production benefits. These uncertainties must be properly managed to keep them under control and reduce the probability and severity of their occurrence, thereby ultimately promoting the sustainability of fisheries.

**Hypothesis 2 (H2).** Production uncertainties influence fishers’ risk management measures.

According to the literature review, the effects of climate change on fisheries primarily stem from changes in primary productivity and habitat deterioration, as well as the ocean environment and ocean circulation system, biodiversity and species distribution, and the physiological functions of marine organisms. These effects can be regarded as sources of risks, and different risk sources influence fishers’ decisions about measures for managing the risks of fishery operations. Furthermore, the sources of climate change-related risks also influence the generation of uncertainties about fishery production, including output variations, composition of harvests, and production benefits. Hence, this study infers that production uncertainties as a result of climate change are also the decisive factor influencing risk management measures.
Hypothesis 3 (H3). Risk sources influence fishers’ risk management measures.

However, we cannot easily determine whether the factors that decide the fishers’ risk management measures are dependent on the type and source of risk or on production uncertainties, because these relationships are not yet supported by empirical analysis.

Hypothesis 4 (H4). Production uncertainty enhances the effects of risk sources on fishers’ risk management measures.

Based on the aforementioned literature, we infer that production uncertainty affects the measures taken by fishers in response to different risks. Hence, production uncertainty was set as the mediating variable to verify whether production uncertainty strengthens the relationship between risk sources and risk management measures.

After factor analysis, the research hypotheses can be configured in Section 4.4.

3. Method

3.1. Study Area

Coastal (within 12 nautical miles from the shoreline) and offshore (12 to 200 nautical miles) fisheries in Taiwan had flourished for some time. Coastal and offshore fisheries in Taiwan operate a number of fishing activities, including gillnetting, trawling, longline fishing, pole and line fishing, troll line, pot fishing, fishing light attractors, seine fishing, purse seining in reef fisheries, and set net fishing. Prior to 2005, annual fishery production outputs were maintained at 200,000 to 250,000 metric tons. After 2005, the average yearly total fishery outputs fell below 200,000 metric tons [23]. Coastal and offshore fisheries are encountering problems from not only a single source but multiple sources, such as overfishing, pollution, habitat destruction, and climate change. New Taipei City, Keelung City, and Yilan County in the northeastern part of Taiwan are the main areas where coastal and offshore fisheries operate (Figure 1). In these areas, the coastal and offshore fishery outputs make up roughly 30% and 70% of the total catch in Taiwan, respectively. Offshore fisheries mainly operate Danish seine fishing and trawling, whereas coastal fisheries catch fish primarily by using set net, fishing light attractor, and pole and line fishing. According to governmental statistics in 2018 [23], New Taipei City, Keelung City, and Yilan County generated a total of 9639.4 metric tons in coastal fishery output, which accounted for 36.5% of the output of the entire coastal fisheries in Taiwan. Concerning offshore fisheries, New Taipei City, Keelung City, and Yilan County produced 41,294.2 metric tons, 37,938.2 metric tons, and 56,223.5 metric tons of output, respectively, accounting for 83.9% of the total output across Taiwan. These governmental statistics show that New Taipei City, Keelung City, and Yilan County play a pivotal role in the coastal and offshore fishery industry in Taiwan. Also, several studies indicated that these areas have diverse and abundant fishery resources and fishing styles [24–27] and are therefore the focus of this study.
3.2. Questionnaire Survey

This study is a continuation of our previous research [28]. We adopted the same questionnaire to conduct further empirical analysis to meet our research purpose. The questionnaire adopted several factors collected from the literature, and was grouped into three dimensions based on our research design: risks of climate change to fisheries; fishery production uncertainties under the impact of climate change; and management measures taken in response to climate change (Table 1). The questionnaire adopted a 5-point Likert scale, where 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. This scale served as variable measurements when respondents completed the questionnaire based on personal opinions or actual situations. This study selected New Taipei City, Keelung City, and Yilan County as the study areas, with the respondents involved in the coastal and offshore fishing boats or fisheries. Most Taiwanese offshore and coastal fishers are always busy fishing or involved in fisher-related work, thus random sampling is difficult to process in this area. To meet our research needs, this study adopted purposive sampling in selecting suitable, representative and experienced fishers based on the researcher’s judgments about the study. Purposive sampling was carried out by distributing questionnaires in the study area or mailing the questionnaires to fishers who engage in coastal and offshore fishing in New Taipei City, Keelung City, and Yilan County. The study period began on 1 December 2015 and ended on 30 July 2016. In total, 362 survey participants, 89 participants provided answers that were not appropriate, and 273 participants provided effective responses. According to Hatcher’s (1994) [29] suggestion, the sample size should be more than 200 samples or five times the estimated parameters for ensuring the validity of factor analysis. Therefore, a total of 273 samples is acceptable for further analysis in this study.
### Table 1. The list of variables.

| Aspect                  | Code | Variable                                                                 | Reference        |
|-------------------------|------|-------------------------------------------------------------------------|------------------|
|                         |      | **Risk Perceptions**                                                    |                  |
|                         | A1   | Changes in spawning ground of commercial fish species                  |                  |
|                         | A2   | Changes in season of commercially important fish species               |                  |
|                         | A3   | Changes in fishing depth of commercial fish species                     |                  |
|                         | A4   | Decrease in annual total catch                                          | [8,22,25–33]     |
|                         | A5   | Changes in fishing area of commercially important fish species         |                  |
|                         | A6   | Increase in frequency and intensity of heavy rains                      |                  |
|                         | A7   | Increase in frequency and intensity of typhoons                         |                  |
|                         | A8   | Increase in frequency and intensity of cold-water intrusions           |                  |
|                         | A9   | Changes in direction of currents                                        |                  |
|                         | A10  | Changes in ocean turbidity and water color                             |                  |
|                         | A11  | Changes in intensity and position of upwelling                         |                  |
|                         |      | **Production Uncertainties**                                           |                  |
|                         | B1   | More time needed for operations due to uncertain conditions in fishing |                  |
|                         | B2   | More time needed to find fish caused by the movement of fishing grounds |                  |
|                         | B3   | Decrease in fishing days caused by extreme weather events              |                  |
|                         | B4   | Increased chances of equipment and hull damage caused by extreme weather|                  |
|                         | B5   | Increased chances of fishing gear loss and damage caused by extreme weather|                  |
|                         | B6   | Increase in the number of bycatch (non-target species)                 | [25,26,28,30,34–37]|
|                         | B7   | Increased fishing effort due to fishing harvests decreasing             |                  |
|                         | B8   | Changes in composition of fishing harvests                              |                  |
|                         | B9   | The total catch is not as expected                                     |                  |
|                         | B10  | Difficulty in deciding when to go fishing due to uncertainties of fishing|                  |
|                         |     | season and location                                                     |                  |
|                         | B11  | Sizes and numbers of fish are not as expected, and lead to lower prices |                  |
|                         |      | **Management Measures**                                                |                  |
|                         | C1   | Deployment of Artificial reefs                                          |                  |
|                         | C2   | Planning and zoning protected areas                                     |                  |
|                         | C3   | Prohibiting the use of destructive fishing methods (i.e., trawling, Taiwanese purse seine) in particular waters |                  |
|                         | C4   | Restricting the eligibility of renewal of licenses for fishing vessels that have had illegal records |                  |
|                         | C5   | Implementing and improving the suspension of fishing activities        |                  |
|                         | C6   | Fishing license buyback program                                         |                  |
|                         | C7   | Establishing an early-warning system for extreme weather events        |                  |
|                         | C8   | Establishing an immediate notification system for climatic disasters (e.g., typhoon) |                  |
|                         | C9   | Establishing a weather information station in fishing harbors           |                  |
|                         | C10  | Recording the logbooks and landings of every trip                       | [12,20,22,30,35,37–42]|
|                         | C11  | Setting the total allowable number of fishing vessels                  |                  |
|                         | C12  | Setting the time limit (e.g., closure season) for fishing               |                  |
|                         | C13  | Setting total allowable catches (TACs) for fishing activities           |                  |
|                         | C14  | Organizing fishery management and information seminars regularly for fishers |                  |
|                         | C15  | Implementing fish stock enhancement                                     |                  |
|                         | C16  | To assist fishers who have low willingness to fish in the transition to leisure fishing or other industries |                  |
|                         | C17  | Improving the current operations of fishers’ association               |                  |
|                         | C18  | Sailing at low speed to save on fuel consumption                       |                  |
|                         | C19  | Using advanced detection equipment to find fish                        |                  |
|                         | C20  | Organizing a production team or self-governance team to conduct fishery co-management |                  |
|                         | C21  | Cooperate with fishers who operate similar fishing methods to share information about fishing grounds and resources |                  |
3.3. Statistical Method

SPSS 20.0 statistical software was used for reliability and validity analysis, and factor analysis was performed to identify the sources of risk, production uncertainties, and the main factors of risk management. Principal component analysis (PCA) was used to select the main factors, followed by varimax method for rotation to extract key factors for establishing structural equations.

In terms of coefficient and effective, questionnaire consistency was tested using Cronbach’s alpha. If Cronbach’s alpha is <0.35, information from the questionnaire must not be used. If Cronbach’s alpha ranges between 0.35 and 0.7, information is moderately reliable and thus can be accepted for use. If Cronbach’s alpha is >0.7, information is highly reliable, suggesting that the questionnaire is well designed.

In factor analysis, the Kaiser–Meyer–Olkin (KMO) measurement of sampling adequacy for each dimension was calculated first. KMO test is a measure of how suited your data is for Factor Analysis. The test measures sampling adequacy for each variable in the model and for the complete model. Kaiser (1974) indicated that the KMO index must be greater than 0.6 in factor analysis [30].

Subsequently, LISREL 8.72 was employed for structural equation modeling to test the hypotheses and the relationship of each dimension. A structural equation model (SEM) presents the relationships between the analyzed variables by using multiple linear models [31] and can be used to verify theory-based causal relationships. Subsequently, maximum likelihood estimation (MLE) was performed. Then, this study adopted MLE to assess the goodness of fit of a model. Model estimates were revised according to the indices generated in the table. Information was entered by using a covariance matrix. After MLE, the goodness of fit of the model was first examined.

4. Empirical Results

4.1. Profile of Respondents

The questionnaires were completed by 273 respondents, of which 270 were men (98.9%). The respondents were mostly from Yilan County (44.7%), followed by New Taipei City (27.8%) and Keelung City (27.5%). Most of the respondents completed junior high school (30.8%), followed by senior high (vocational) school (30.0%) and elementary school or below (27.5%). Regarding age, the respondents were mostly 50–60 years old (30.04%), followed by 41–50 years old (24.5%) and 61–70 years old (20.2%). With respect to years of work experience, most of the respondents had 20 years or longer (43.6%), followed by 0–4 years (19.8%) and 15–19 years (15.6%). The respondents mostly used a single fishing method, specifically, 46.2% used pole and line, whereas 34.1% used fishing nets; and 19.8% used multiple fishing methods. In Taiwan, most fishers are male, elder and have many years of experience, so the samples collected are in line with expectations.

4.2. Coefficient and Effective

The three dimensions which include “the effects of climate change on the marine environment”, “fishery production uncertainties caused by climate change”, and “measures taken to adapt to and manage risks of climate change” in the 273 valid samples measured a Cronbach’s alpha of 0.843, 0.878, and 0.883, respectively. The Cronbach’s alpha of the questionnaire items as a whole was 0.926, which is higher than the recommended threshold of 0.7 [32]. Regarding validity analysis, if eigenvalue is >1 and the correlation coefficient between each variable and factor is >0.3 and can explain 40% or more of the variance in a given dataset, then factor analysis result is desirable. The results showed that all the dimensions of this study met this requirement [33].

4.3. Factor Analysis Results

The analysis results of our study revealed that the KMO index of each dimension was greater than 0.6 and the significance of the Bartlett’s test of sphericity was 0.00, meaning that factor analysis of the sample information can be performed. Regarding extracting and
naming of factors, we organized factors in a rotated component matrix and selected those with principal components having an eigenvalue >1 in factor analysis and those with factor loading >0.6 [34].

The dimension “the effects of climate change on the marine environment” comprised three factors that cumulatively explained 65.3% of the variance (Table 2). Factor 1 explained 39.1% of the variance; its eigenvalue was 4.3 and variables included spawning period, harvesting season, fishing water depth, and fishing areas. Given its characteristics, Factor 1 was named “impacts on habitats and behaviors of fishes”. Factor 2 (impacts on marine physical environment) explained 14.9% of the variance; its eigenvalue was 1.626 and variables included ocean current, ocean water turbidity, and intensity of upwelling. Factor 3 (extreme marine weather events) explained 11.4% of the variance; its eigenvalue was 1.2 and variables included torrential rain, cold-water intrusion, and typhoon.

| Table 2. Factor analysis. |
|---------------------------|

| Factor Source | Variable (Factor Loading) | Eigenvalue | Proportion |
|---------------|---------------------------|------------|------------|
| Risk Sources  |                           |            |            |
| Factor 1: Impacts on habitats and behaviors of fishes (HBF) | A1 (0.78); A2 (0.84); A3 (0.67); A4 (0.68); A5 (0.62) | 4.3 | 39.1 |
| Factor 2: Impacts on marine physical environments (MPE) | A9 (0.87); A10 (0.75); A11 (0.78) | 1.6 | 14.9 |
| Factor 3: Extreme weather events (EWE) | A6 (0.81); A7 (0.83); A8 (0.73) | 1.2 | 11.4 |
| Production Uncertainties |                           |            |            |
| Factor 1: Production expectations (PE) | B1 (0.68); B7 (0.69); B9 (0.84); B11 (0.75) | 3.7 | 46.0 |
| Factor 2: Production outcomes (PO) | B4 (0.84); B5 (0.84); B6 (0.68); B8 (0.63) | 1.3 | 15.6 |
| Management Measures |                           |            |            |
| Factor 1: Risk control (RC) | C2 (0.77); C3 (0.81); C4 (0.78); C12 (0.66) | 4.2 | 34.6 |
| Factor 2: Risk avoidance (RA) | C7 (0.76); C8 (0.83); C9 (0.73) | 1.7 | 14.1 |
| Factor 3: Resilience enhancement (RE) | C17 (0.71); C19 (0.76); C20 (0.75) | 1.1 | 9.3 |
| Factor 4: Input reduction (IR) | C6 (0.62); C18 (0.83) | 1.0 | 8.5 |

The dimension “fishery production uncertainties caused by climate change” comprised two factors that cumulatively explained 61.6% of the variance. Factor 1 (production expectations) explained 46.0% of the variance; its eigenvalue was 3.7. Factor 1 was primarily related to production expectations when catching fish in the sea, such as catch of target species, size and quantity of fish harvested, and fishing site conditions. Factor 2 (production outcomes) explained 15.6% of the variance; its eigenvalue was 1.3. Factor 2 was primarily related to uncertain matters at the end of a catch such as damage to fishing gear, bycatch, and species composition of harvests.

The dimension “measures taken to adapt to and manage risks of climate change” comprised four factors that cumulatively explained 66.4% of the variance. Factor 1 (risk control measures) explained 34.6% of the variance; its eigenvalue was 4.2. Factor 1 was primarily related to risk control measures in risk management, such as banning the use of destructive fishing gears and methods in specific waters, restricting fishing time, and placing restrictions on re-licensing fishing vessels that had broken the law or records of violations. Factor 2 (risk avoidance measures) explained 14.1% of the variance; its eigenvalue was 1.7. Factor 2 included early risk avoidance measures such as building disaster real-time reporting systems and extreme weather early warning systems. Factor 3 explained 9.3% of the variance; its eigenvalue was 1.1. Factor 3 (resilience enhancement) was primarily related to measures for stabilizing production value and output and included using advanced probing instruments and equipment to search for school of fish, setting up production and marketing training classes, and improving or changing current methods of operation.
Factor 4 (production input reduction) explained 8.5% of the variance; its eigenvalue was 1.0. Factor 4 primarily involved reducing production input to curb production activity, rather than adopting management interventions.

4.4. Factor Analysis Results
4.4.1. Model Specification and Goodness-of-Fit Criteria
The observed variables of each dimension were acquired from the factor analysis in the previous section, and the research hypotheses can be configured as shown in Table 3. In Table 3, the head of each factor can be found in Appendix A. The limits for the goodness-of-fit indices were acquired from several references [35–37]. The ratio of the Chi-square value to degrees of freedom ($X^2/df = 2.19$) is less than 3. Other fit indices, including adjusted goodness-of-fit index (AGFI) (0.81), goodness-of-fit (GFI) (0.86), normed fit index (NFI) (0.90), comparative fit index (CFI) (0.94) and root mean squares error of approximation (RMSEA) (0.066), indicate that the structural model has a reasonable explanation of the observed covariance among the constructs of interest. Thus, the proposed model fits well enough.

Table 3. Lists of research hypothesis.

| Hypothesis                              | Path   |
|-----------------------------------------|--------|
| Risk sources influence fishermen’s risk managerial measures | H1 HBF→PE |
|                                         | H2 HBF→PO |
|                                         | H3 MPE→PE |
|                                         | H4 MPE→PO |
|                                         | H5 EWE→PE |
|                                         | H6 EWE→PO |
|                                         | H7 PE→RC |
|                                         | H8 PE→AR |
|                                         | H9 PE→RE |
|                                         | H10 PE→IR |
|                                         | H11 PO→RC |
|                                         | H12 PO→AR |
|                                         | H13 PO→RE |
|                                         | H14 PO→IR |
| Risk sources lead to diversity production uncertainties          |
|                                         | H15 HBF→RC |
|                                         | H16 EWE→RC |
|                                         | H17 MPE→RC |
|                                         | H18 HBF→AR |
|                                         | H19 EWE→AR |
| Production uncertainties influence fishermen’s risk managerial measures | H20 MPE→AR |
|                                         | H21 HBF→RE |
|                                         | H22 EWE→RE |
|                                         | H23 MPE→RE |
|                                         | H24 HBF→IR |
|                                         | H25 EWE→IR |
|                                         | H26 MPE→IR |
4.4.2. Hypothesis Test

Based on the path coefficients between the latent variables, hypothesis testing was performed (Tables 4 and 5). The test results of direct and indirect effects revealed, that except for H9 and H15 which did not achieve a level of significance, the remaining hypotheses exhibited significant effect at 10%, 5% or 1% significance. Furthermore, we produced a path diagram of the effect of each path and hypothesis test results (Figure 2) to describe the effects between the latent variables.

Paths H1 to 6 were included in the hypothesis testing of the direct path of the causal relationship between the antecedent (the effects of climate change on the marine environment and resources) and mediating (fishery production uncertainties caused by climate change) variables. The antecedent variable (the effects of climate change on the marine environment and resources) comprised three latent variables, namely: impacts on habitats and behaviors of fishes (HBF), extreme weather events (EWE), and impacts on marine physical environments (MPE). The mediating variable comprised two latent variables, namely, productive expectations (PE) and productive outcomes (PO). The empirical results of H1–H6 showed that all of the hypotheses were positive and significant. The path coefficients ranged between 0.25 and 0.51; specifically, H3 and H5 were supported, with t values significant at 10%. H1, H2, H5, and H6 were also supported, with t values significant at 1%.

Paths H7 to 14 were included in the hypothesis testing of the direct path of the causal relationship between the mediating (fishery production uncertainties caused by climate change) and outcome or consequence (measures taken to adapt to and manage risks of climate change) variables. The mediating variable comprised two latent variables, namely, productive expectations (PE) and productive outcomes (PO). The outcome variable comprised four latent variables, namely, risk control (RC), risk avoidance (AR), resilience enhancement (RE), and input reduction (IR). According to the empirical results of H7–H14, the paths were all positive and significant, except for H9, which was not significant. The path coefficients ranged between 0.24 and 2.16; specifically, H10 was supported, with t values significant at 10%, and H11 and H14 were also supported, with t values significant at 5%. H7, H8, H12, and H13 were supported, with t values significant at 1%.

| Hypothesis | Path |
|------------|------|
| H27a       | HBF→PE→RC |
| H27b       | HBF→PO→RC |
| H28a       | HBF→PE→AR |
| H28b       | HBF→PO→AR |
| H29a       | HBF→PE→RE |
| H29b       | HBF→PO→RE |
| H30a       | HBF→PE→IR |
| H30b       | HBF→PO→IR |
| H31a       | EWE→PE→RC |
| H31b       | EWE→PO→RC |
| H32a       | EWE→PE→AR |
| H32b       | EWE→PO→AR |
| H33a       | EWE→PE→RE |
| H33b       | EWE→PO→RE |
| H34a       | EWE→PE→IR |
| H34b       | EWE→PO→IR |
| H35a       | MPE→PE→RC |
| H35b       | MPE→PO→RC |
| H36a       | MPE→PE→AR |
| H36b       | MPE→PO→AR |
| H37a       | MPE→PE→RE |
| H37b       | MPE→PO→RE |
| H38a       | MPE→PE→IR |
| H38b       | MPE→PO→IR |

Production uncertainty might enhance the effects of risk sources on risk managerial measures.
Paths H15 to 26 were included in the hypothesis testing of the direct path of the causal relationship between the antecedent (the effects of climate change on the marine environment and resources) and outcome or consequence (measures taken to adapt to and manage risks of climate change) variables. The empirical results of H15–H26 showed that all of the paths had a significant negative relationship with the antecedent variables except for H15. In the path of indirect effects (H27–H38), the antecedent variable forms a causal relationship with the outcome variable through the mediating variable. Our mediating variable comprised two latent variables, which were combined to form a total indirect effect. Empirical analysis for the path of indirect effects (H27–H38) revealed that all indirect effects were positive; thus, the mediating variable can be considered a key variable as a whole. In other words, production uncertainties influence the effects of risk sources on fishers’ decisions regarding management measures.

Table 4. Summary of direct effects and hypothesis tests.

| Path   | Estimate | t-Value | p-Value |
|--------|----------|---------|---------|
| H1     | 0.35     | 4.00    | ***     |
| H2     | 0.29     | 3.45    | ***     |
| H3     | 0.24     | 2.48    | *       |
| H4     | 0.51     | 5.25    | ***     |
| H5     | 0.23     | 2.55    | *       |
| H6     | 0.34     | 3.64    | ***     |
| H7     | 0.66     | 4.69    | ***     |
| H8     | 0.41     | 3.50    | ***     |
Table 4. Cont.

| Path          | Estimate | t-Value |
|---------------|----------|---------|
| H9 PE→RE     | 0.24     | 1.92    |
| H10 PE→IR    | 0.43     | 2.36    |
| H12 PO→AR    | 1.56     | 4.31    |
| H13 PO→RE    | 2.16     | 4.08    |
| H14 PO→IR    | 1.34     | 3.21    |
| H15 HBF→RC   | −0.06    | −0.52   |
| H16 EWE→RC   | −0.47    | −2.83   |
| H17 MPE→RC   | −0.30    | −2.32   |
| H18 HBF→AR   | −0.59    | −3.47   |
| H19 EWE→AR   | −0.72    | −3.04   |
| H20 MPE→AR   | −0.55    | −2.92   |
| H21 HBF→RE   | −0.71    | −3.07   |
| H22 EWE→RE   | −1.02    | −3.04   |
| H23 MPE→RE   | −0.59    | −2.32   |
| H24 HBF→IR   | −0.59    | −2.87   |
| H25 EWE→IR   | −0.61    | −2.18   |
| H26 MPE→IR   | −0.65    | −2.91   |

Note: * indicates significance at the 10% level. ** indicates significance at the 5% level. *** indicates significance at the 1% level.

Table 5. Summary of indirect effects, direct effects and total effects.

| Path          | Indirect Effect | Direct Effect | Total Effect |
|---------------|-----------------|---------------|--------------|
| H27a HBF→PE→RC | 0.23            | −0.06         | 0.31         |
| H27b HBF→PO→RC | 0.14            |               |              |
| H28a HBF→PE→AR | 0.14            | −0.59         | 0.01         |
| H28b HBF→PO→AR | 0.45            |               |              |
| H29a HBF→PE→RE | 0.08            | −0.71         | 0.01         |
| H29b HBF→PO→RE | 0.63            |               |              |
| H30a HBF→PE→IR | 0.15            | −0.59         | −0.05        |
| H30b HBF→PO→IR | 0.39            |               |              |
| H31a EWE→PE→RC | 0.16            | −0.47         | 0.05         |
| H31b EWE→PO→RC | 0.36            |               |              |
| H32a EWE→PE→AR | 0.10            | −0.72         | 0.17         |
| H32b EWE→PO→AR | 0.8             |               |              |
| H33a EWE→PE→RE | 0.06            | −1.02         | 0.15         |
| H33b EWE→PO→RE | 1.10            |               |              |
| H34a EWE→PE→IR | 0.10            | −0.61         | 0.18         |
| H34b EWE→PO→IR | 0.68            |               |              |
| H35a MPE→PE→RC | 0.15            | −0.30         | 0.09         |
| H35b MPE→PO→RC | 0.24            |               |              |
| H36a MPE→PE→AR | 0.09            | −0.55         | 0.07         |
| H36b MPE→PO→AR | 0.53            |               |              |
| H37a MPE→PE→RE | 0.06            | −0.59         | 0.20         |
| H37b MPE→PO→RE | 0.73            |               |              |
| H38a MPE→PE→IR | 0.10            | −0.65         | −0.10        |
| H38b MPE→PO→IR | 0.46            |               |              |
5. Discussion

The fishers’ risk perceptions of climate change originate primarily from changes in marine habitats and fish behaviors, and then from changes in the marine physical environment. Our empirical analysis revealed that among the direct effects of fishery production uncertainties, fish habitats and behaviors, marine physical environment, and frequency of extreme weather events significantly influenced pre-production expectations and post-production uncertainties. This finding is consistent with previous studies [5,38,39]. According to the fishers we interviewed, climate change increases the difficulty of calculating the probability of damage to fishing equipment, composition of harvests, expected harvests, and fishing duration. The results verified that the fishers are aware that pre-production expectations and post-production uncertainties are affected by sources of climate change-related risks.

Among the direct effects of the mediating variable on outcome variable, only pre-production expectations did not significantly influence industry resilience. This result suggests a nonsignificant causal relationship between uncertainties about pre-production expectation and strong industry resilience as perceived by the fishers. Predicting harvest situations, controlling fishing environment, and stabilizing production are difficult because of climate change. In addition, the size and quantity of fish harvested are not as expected, which results in unstable pricing and income generation. Therefore, fishers typically disagree with the concept that measures for strengthening industry resilience can facilitate a better grasp of harvest situations, and a direct relationship between the two cannot be established. The direct effects of the other mediating variables on the outcome variable were all positive and significant, suggesting that fishers agreed with the effectiveness of management measures despite having uncertainties about production, and they would take certain measures to control and adapt to risks, such as restricting fishing boat operation time and designating protected zones. These measures may reduce the probability of destroying vulnerable fishing areas, thereby stabilizing the species composition of harvests [9]. Moreover, the findings also support using early warning systems as adaption measures to avoid the potential risks of climate change [40]. Adopting measures that enhance the resilience of the fishery industry is an alternative management approach. For example, production uncertainties may lead to increased production cost, which lowers profits. Fishers can cut their spending on other aspects such as petroleum to compensate for the losses on damaged fishing gear and equipment. Alternatively, fishers can sell their fishing license to the government when times are tough (e.g., low fishing willingness or unfavorable business conditions) to adjust the overall scale of fishery operations. Hence, this study also found that different management measures must take into consideration the underlying economic benefits and industrial factors [41].

Finally, regarding measures taken to adapt to and manage risks of climate change, H15 was negative and nonsignificant, suggesting that fishers believe risk control measures have no causal relationship with changes in fish habitats and behaviors under climate change. In the relationship between the antecedent (the effects of climate change on the marine environment and resources) and outcome (measures taken to adapt to and manage risks of climate change) variables, the path coefficient and t value of each latent variable were negative and significant. Therefore, fishers agreed that the higher the risks of the impact of climate change, the more resistant they were against taking risk management measures. This result is probably because fishing communities in the northeastern part of Taiwan live on income from fishing activities, most fishers do not make income from other economic activities (e.g., farming). Increased frequency of extreme weather events not only reduces fishers’ chance of going out to sea but also changes the marine physical environment, which in turn affects the final harvests and also damages fishing gears and equipment [42,43]. Moreover, risk management measures restrict fishers’ fishing activities, which is why fishers oppose and strongly disagree with management measures that limit fishing activities. Generally speaking, fishers do not identify with management measures that emphasize only the impacts of climate change. We recommend improving the adaptive
capacity of fishing communities to enhance community resilience in response to the impacts of climate change on the families, the livelihood, and economy of fishing communities [44].

In the hypothesis testing of direct effect paths, all of the paths achieved statistical significance, except for H9. However, after the mediating variable was added to the indirect effect, the path through which the antecedent variables influence the outcome variable through the mediating variable achieved a significant level. This result suggests that the mediating variable generated a key effect. Among the paths of total effect, the path from the impacts on fish habitats and behaviors to the total effect of risk control and the path from the impacts on marine physical environment to the total effect of industry resilience were positive and significant, whereas the other paths were positive and nonsignificant. Although most of the total effect paths were not significant, the negative relationship caused by the direct path between the impacts of climate change and the risk management and adaptation measures adopted has been changed to positive effects. Therefore, before enforcing risk management measures in response to climate change, policy makers should consider the production uncertainties that fishers face. Specifically, policy makers can introduce fishery management approaches that reduce uncertainty, such as building weather or climate change early warning systems to lower uncertainties [35]. In addition, industry resilience to uncertainties can be enhanced by introducing marine resource management measures (e.g., designating marine protected zones or introducing closed fishing seasons) [9]. If the wrong management approach is used, not only is a problem unsolvable, but fishers might develop feelings of resentment along with distrust of management agencies. Because traditional fishers in Taiwan are pragmatic and hard-working, they are less accepting of measures that limit harvests and fishing times. In general, when fishers perceive the impacts of climate change on fish behaviors, they tend to take measures accordingly such as switching to other fishing practices in order to sustain their source of income [9]. Based on a case from Canada [45], community-level adaptation based on fishers’ knowledge and experience might be another potential solution for Taiwan’s marine fisheries.

6. Conclusions

This study explored how fishers manage the risks of climate change and how various uncertainties perceived by the fishers influence their decisions on the measures taken to manage the risks of climate change. Our empirical analysis revealed that the causal relationships hypothesized in this study were all verifiable. First, the effects of risk sources on the fishers’ risk management measures were negative and significant, suggesting that fishers opt to not take risk management measures when facing the risks of climate change. The second hypothesis was that risk sources lead to different production uncertainties; the effects in this path were positive and significant, meaning that the fishers agreed with this hypothesis. The third hypothesis was the effects of production uncertainties on fishers’ risk management measures, which were found to be also positive and significant, implying that the fishers agreed that production uncertainties affect their decision on risk management measures. Moreover, the empirical results showed that among the causal relationships in the path of indirect effect, the indirect effects were all positive and significant, indicating that production uncertainties influence the risk management measures taken by fishers in response to climate change. Therefore, the fourth hypothesis was determined in this empirical analysis. Based on the aforementioned empirical results, this study asserts that the various marine fishery management measures taken in response to climate change should be focused on the risks and uncertainties that fishers actually perceive. In doing so, the correct and more practical management tools can be selected to address the climate change-related risks and uncertainties that fishers encounter in real life.

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Appendix A

Table A1. Acronyms Used in the SEM Analysis.

| Dimension          | Factor                                      | Acronyms |
|--------------------|---------------------------------------------|----------|
| Risk Sources       | Impacts on habitats and behaviors of fishes (HBF) | HBF      |
|                    | Impacts on marine physical environments (MPE) | MPE      |
|                    | Extreme weather events (EWE)                | EWE      |
| Production Uncertainties | Production expectations (PE)              | PE       |
|                     | Production outcomes (PO)                   | PO       |
| Management Measures| Risk control (RC)                          | RC       |
|                     | Risk avoidance (RA)                        | RA       |
|                     | Resilience enhancement (RE)                | RE       |
|                     | Input reduction (IR)                       | IR       |

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