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Evaluating Producer Welfare Benefits of Whole-Farm Revenue Insurance

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Abstract: Agricultural insurance is by far the most popular risk management tool used in Iran. Despite many years of experience, Iran's current insurance policy has not managed to protect all producers in the sector. The basic principle of whole-farm insurance consists of pooling all the insurable risks of a farm into a single policy and overcoming most of the major impediments to existing policies. This study aimed to evaluate the benefits of whole-farm insurance (WFI) in Zanjan province of Iran. This study employed historical farm-level and county-level data from 1982 to 2021 to estimate yield and price density functions and predict future values. Parametric and non-parametric approaches were utilized to calculate farmers' expected compensation and guaranteed and simulated revenues. The premium rates were then calculated using the PQH simulation and Cholesky decomposition and compared under three scenarios: the single-crop, double-crop, and triple-crop options. Finally, farmers' welfare benefits were compared under the three scenarios with the no-insurance case. The results demonstrate that WFI provides lower loss ratios compared to yield insurance and crop-specific insurance. Furthermore, producer welfare can be improved when they insure at least one crop compared to no-insurance. For example, the welfare benefits of insuring wheat, barley, alfalfa, wheat–barley, wheat–alfalfa, barley–alfalfa, and barley–alfalfa in terms of cost reduction to producers at 75% coverage are 8.8, 1.8, 2.9, 1.2, 0.9, and 1.8, respectively. Therefore, we recommend that the Iranian Agricultural Insurance Fund adopts WFI as a new risk management tool. This policy has the potential to decrease insurance premiums and administrative costs while improving the certainty equivalents and benefits to farmers through crop insurance.

Keywords: whole-farm insurance; producer welfare; certainty equivalent; revenue risk; parametric method; non-parametric method; premium rate; Zanjan

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1. Introduction

The current agricultural insurance policy in Iran faces many problems owing to asymmetric information. Asymmetric information leads to problems such as adverse selection and moral hazards, two deep-rooted problems in the development of crop insurance due to hidden information and the unpredictability of insured farmers' behavior [1]. A moral hazard is a change in input use that deviates from the socially optimal level and occurs because the insured may take actions that affect the probability of loss without the insurer's awareness. Adverse selection occurs when, owing to asymmetric information, farmers at a higher risk of loss are more likely to insure their crops than the general population [2], which sets the average premium of all insurers for all farmers. Over time, low-risk farmers will no longer be insured, and vice versa, because the premium is high relative to risk. While these two issues harm all insurance markets, the impact is more significant for the agricultural sector because farms are geographically scattered, and gathering information, observing behavior, and diagnosing causes become more difficult. In addition, reducing the coverage level to address moral hazards decreases the number of people who buy insurance. Due to these issues, private agricultural insurance is not widely available. High administrative costs are another issue in Iran's current agricultural insurance system. Additionally, although the range of services provided by the Agricultural Insurance Fund has expanded in recent years, it remains far below the set targets. For example, over the past 20 years, the insured area has increased from 2.9 million to 3.5 million hectares for crops and from 92,000 to 690,000 for horticultural products [3]. At the same time, the number of contracts with beneficiaries increased from 715,000 to more than 1.51 million, insurance premiums increased from IRR 287 billion to IRR 1314.3 billion, and compensation paid to farmers increased from IRR 484 billion to IRR 1528.2 billion [3].

In Zanjan province, agricultural insurance adoption remains low among farmers, with significant fluctuations in the number of insured farmers and crops. The peak occurred in the 2010–2011 crop year, followed by a gradual decline. For the past two decades, farmers have received more compensation than they have paid in premiums [3]. Consequently, the loss ratio has exceeded 1 in most years, indicating inefficiency in the traditional farm insurance system and necessitating a shift towards new insurance programs. To address gaps in agricultural risk management, various policies have been proposed, including whole-farm insurance (WFI). The primary research question is whether WFI can be implemented in the agriculture sector of Zanjan province. In this study, we focused on Zanjan province as a pilot study subject because we needed historical crop yield data, particularly at the farm level for specific farmers to estimate yield and price density functions. These data were only available in this province. WFI is of particular interest for several reasons: it better captures farm-level risk by insuring against gross revenue loss; it may more accurately assess organic farming systems with integrated multi-crop and livestock programs; and it specifically targets the producers of multiple, currently uninsurable crops [4]. This study aimed to develop a WFI policy for Zanjan province's agricultural crops and evaluate its impact on farmers' welfare compared to existing programs. Farmers' income, dependent on crop prices and yields, decreases when one factor declines while the other remains constant. Due to the correlation between crop prices and yields in a region, their joint distributions must be considered when assessing farmers' income risk. WFI offers more comprehensive coverage than other insurance policies by addressing price and yield risks, their interrelationships, and crop income. In this program, the insurer and insured agree on random variables, with compensation paid when income falls below expectations. WFI covers multiple crops at a lower premium than single-crop programs by insuring combined farm income rather than individual crop income [5]. Zhu et al. [6] report that WFI premiums are 36% lower than crop-specific insurance. Hennessy et al. [7] argue that WFI is more cost-effective than other contracts for the same expected income, with the discount rate increasing as the correlation between products decreases. Kokot et al. [8] also contend that WFI is more suitable than crop-specific insurance and could be applied in Serbia.

Whole-farm insurance also increases producer welfare more than crop-specific insurance, because it concentrates probabilities more closely around the mean. WFI is a more effective policy if farmers have a similar level of risk aversion. The cost of administering this insurance is lower than those of other policies. Indeed, whole-farm insurance allows farmers who suffer losses to be compensated for by other products. Structurally, whole-farm insurance is similar to portfolio insurance, but the relationships and correlations between products may not be considered.

2. Background and Literature Review

In recent years, many agricultural economists have focused on new insurance policies, including WFI, and some researchers have evaluated the producer welfare of this insurance. For example, Hennessy et al. [7] investigated the financial and welfare effects of these insurance policies, determining that whole-farm insurance is advantageous to farmers in terms of expenses and risk coverage. They further contended that whole-farm insurance could provide higher coverage levels due to its diversity, which mitigates risk and reduces potential moral hazard issues associated with insurance programs. Meuwissen et al. [9] argued that whole-farm insurance is more attractive as it presents a viable option for optimizing farmers' welfare. Berg [10] utilized the variance expected value and Monte Carlo simulation to assess the farm-level impact of income and yield insurance, subsequently simulating insurance coverage. The findings indicated that farmers have sufficient motivation to acquire multi-risk insurance, as it considerably reduces income volatility and promotes specialization in production planning. Hart et al. [11] studied whole-farm insurance policy and discovered that for a coverage of 95% or less, fair premiums for cattle on various Iowa farms are notably lower than individual premiums for corn on the same farms. Bielza and Garrido [12] assessed the potential of whole-farm versus crop-specific insurance for plums, apricots, and grapes in Spain's Valencia community, concluding that whole-farm insurance was comparatively more favorable. Turvey [5] explored the impact of whole-farm income insurance on farm portfolio selection for a representative farm in Manitoba, Canada, employing a mean-variance model to minimize risk and a mean skewness model to maximize skewness. The study revealed that farmers significantly alter their farming strategies based on the type of insurance provided. Coble et al. [13] created a viable whole-farm insurance program, examining it under three scenarios: no-insurance, whole-farm insurance with 90% coverage, and a customizable whole-farm insurance (CAWFI) program with limitations on scope and coverage level. The results demonstrated that the optimal CAWFI program yields a comparable reliability equivalent to the alternative scenarios. However, they noted that imposing restrictions on the scope and level of coverage might diminish its effectiveness. The researchers proposed an adjustable whole-farm insurance program as an alternative policy to address some of the known shortcomings of existing designs. Chalise et al. [14] developed a model based on the customizable area-based whole-farm insurance (CAWFI) program and applied it to four US states: Kansas, North Dakota, Illinois, and Mississippi. Their research indicated that a constrained CAWFI design significantly reduced risk at a much lower cost compared to FWFI. Marković and Kokot [15] examined whole-farm revenue insurance by evaluating insurance for four crops in Serbia: spring wheat, corn, soybeans, and sunflowers. The program claimed to be able to protect businesses against natural and climatic risks and support market risks. Its premiums and administrative costs were low, and unlike conventional agricultural insurance, it avoided inconsistent choices and moral hazards. Luckstead and Devadoss [16] employed cumulative prospect theory to develop a theoretical model for agricultural price risk coverage and crops, focusing on supplemental coverage options for optimal return coverage decisions for risk-averse individuals. They investigated the impact of policies on wheat producers, utilizing a non-parametric approach to estimate bivariate yields and price distributions for wheat in Mitchell County, Kansas. The results showed that the farmer would be willing to bear greater losses due to a higher coverage level, but the coverage level could not be increased because the farmer has already chosen the maximum allowable revenue protection coverage level. Therefore, the farmer is willing to take on more basis risk by relying more on the county-level supplemental coverage option by decreasing the coverage level to reduce the average cost. Kokot et al. [8] explored the feasibility of implementing whole-farm income insurance in Serbia. They noted that due to drought in the study area, yields and expected incomes decreased, entitling farmers to USD 5697 in compensation. However, farmers were required to pay a USD 373 risk transfer fee to the insurance company. The study demonstrated that whole-farm income insurance could be applied in countries like Serbia. Biram et al. [17] examined the role of revenue insurance in mitigating yield and price risks for corn and soybeans across four regions in Kansas, USA. They utilized beta distribution to simulate yield and log-normal distribution to simulate price. The results revealed that for optimal risk management, producers should select their insurance coverage level with revenue coverage ideally falling within the 76–86 percent agricultural risk coverage range. Falsafian et al. [18] determined that area yield crop insurance provides positive welfare benefits and could serve as a viable alternative or supplement to existing crop insurance programs in Iran. Moreover, its success in other countries suggests that it could be an appropriate risk management program for developing nations such as Iran.

According to the context, whole-farm insurance is a new model which is designed to meet the needs of diversified farms that grow a variety of products and sell to local, regional, or specialized markets or directly. Modern risk management in agriculture is increasingly focusing on insuring farm revenues. The goal of this policy is to aggregate all of farm risks into a single contract while offering many advantages over traditional insurance. Unlike traditional insurance, whole-farm insurance is not subject to the problems of moral hazards and adverse selection. Whole-farm insurance provides more effective coverage than product-specific insurance under a single contract. In addition, whole-farm insurance benefits producers and improves the efficiency of government insurance subsidies. Considering the lack of research on whole-farm insurance and its welfare effects in Iran, there is a pressing need for modern insurance programs such as WFI in the country. Hence, this study can provide appropriate guidance on premium rate-making for policymakers while highlighting its welfare impacts to promote farmers' participation.

3. Materials and Methods

The modeling framework incorporates the evaluation of crop-specific insurance (CSI) and whole-farm insurance premiums for the number of purchased insurance policies and the number of crops insured. If the loss ratios of frequently insured farmers are lower with different insurance strategies in groups and crops, then a policy of whole-farm insurance that incorporates all policies into one program should be reasonable.

Suppose that a farmer grows N crops and each crop i has a yield probability distribution function of $f_i(x_i)$. Bielza and Garrido [12] showed that the actuarially fair premium for a multi-peril crop-specific insurance policy for each crop ($\mathrm{Pr_i}$) would be estimated by Equation (1).

$$\begin{gathered} \mathrm{Pr}_i = \underset{i}{E}[\widetilde{I}_i] \\ \widetilde{I}_i = \begin{cases} p_i \times \overline{X}_i \times \widetilde{\lambda}_i \times \widetilde{l}_i & if\ \widetilde{x}_i \prec \overline{X}_i \\ 0 & if\ \widetilde{x}_i \geq \overline{X}_i \end{cases} \end{gathered} \tag{1}$$

where $\widetilde{I}_i$ is the indemnity of crop i; $E[.]$ is the mathematical expectation operator; $\overline{X}_i$ is the guaranteed yield for crop i; $\widetilde{x}_i$ is the stochastic yield; p_i is the crop price at which crop losses are paid, which is assumed to be non-random; $\widetilde{l}_i$ is the random loss eligible for compensation (which does not always correspond to the farmer's loss); and $\widetilde{\lambda}_i$ indicates the probability of receiving compensation when the yield is below the insured level. Basically, the function of this variable is to capture the case where there are low returns for a reason that either leads ($\widetilde{\lambda}_i$ = 1) or does not lead ($\widetilde{\lambda}_i$ = 0) to compensation, as determined by the insurance policy. For a WFI policy, the fair premium would be the result of the following:

$$\mathrm{Pr} = E[\widetilde{I}]$$
$$\widetilde{I} = \begin{cases} min\left[\sum_i s_i \widetilde{I}_i, \left(R - \sum_i s_i p_i \widetilde{x}_i\right)\right] & if \sum_i s_i p_i \widetilde{x}_i \prec R \\ 0 & if \sum_i s_i p_i \widetilde{x}_i \geq R \end{cases} \tag{2}$$

where R is the insured revenue and farm-specific. It is equal to the expected revenue (when designing agricultural insurance, farmers' revenue is prioritized over profit to simplify premium calculations and minimize administrative costs, also improving the feasibility of the insurance program) that the farm would receive if all crops were subject to crop-specific policies, as shown in the following equation:

$$R = \sum_i s_i p_i \overline{X} \tag{3}$$

where Pr is specific to the farmer because the cropping patterns, S_i, are needed to calculate it. Furthermore, since the crops' yield functions are not independent in principle, calculating Pr and $\mathrm{Pr_i}$ numerically also requires correlations between random variables $\widetilde{I}_i$ and $\widetilde{x}_i$.

Savings in terms of insurance costs for the same expected revenue can be measured by Equation (4):

$$\Delta\mathrm{Pr} = \mathrm{Pr} - \sum_i s_i \mathrm{Pr}_i \tag{4}$$

Additionally, utility gains can be evaluated with Equation (5):

$$\Delta EU = EU(\widetilde{\pi}_{WFI}) - EU(\widetilde{\pi}_{CSI}) \tag{5}$$

where $\widetilde{\pi}$ is the farm's profits with different insurance policies; $U(\pi)$ is the DARA or CRRA utility function, such as $U(\pi) = \frac{\pi^{1-r}}{1-r}$; and r is the coefficient of relative risk aversion. Correspondingly, the difference of certainty equivalents was also calculated as follows:

$$\Delta CE = CE(\widetilde{\pi}_{WFI}) - CE(\widetilde{\pi}_{CSI}) \tag{6}$$

Note that, by all definitions of WFI, the difference in expected profits is as follows:

$$\Delta\pi^e = \pi^e_{WFI} - \pi^e_{CSI} = 0 \tag{7}$$

Because

$$\begin{aligned} \Pi^e_{WFI} &= E_{x_1,\ldots x_N}\left\{max\left[\sum_i s_i \times p_i \times \widetilde{x}_i, \min\left(R, \sum_i s_i \times (p_i \times \widetilde{x}_i + \widetilde{I}_i)\right)\right] - \sum_i C_i - \mathrm{Pr}\right\} \\ &= R - \sum_i C_i \end{aligned} \tag{8}$$

$$\begin{aligned} \pi^e_{CSI} &= E_{x_1,\ldots x_N}\left\{max\left[\sum_i s_i \times p_i \times \widetilde{x}_i, \sum_i s_i \times (p_i \times \widetilde{x}_i + \widetilde{I}_i)\right] - \sum_i C_i - \sum_i \mathrm{Pr}_i\right\} = \\ &\sum_i \left[s_i \times p_i \times \underset{x_i}{E}\left\{max\left[\widetilde{x}_i, \overline{X}_i \widetilde{\lambda}_i\right]\right\}\right] - C_i - Pr_i = R - \sum_i C_i \end{aligned} \tag{9}$$

where Ci is crop i's cost. Both results are equal to the implicit insured revenue (R) minus the production costs of the crops, because the premium was considered actuarially fair.

Let us observe the following in Equation (2): (i) when there is no loss, the final yield is $\widetilde{x}_i$; (ii) when there is an eligible loss ($\widetilde{\lambda}_i$ = 1), the final yield is the guaranteed yield $\overline{X}_i$; and

(iii) when the loss is not eligible for an indemnity ($\widetilde{\lambda}_i = 0$), yield is equal to $\widetilde{x}_i$ (with $\widetilde{x}_i < \overline{X}_i$). Also note that in Equation (2), variable $\widetilde{\lambda}_i$ only applies when $\widetilde{x}_i < \overline{X}_i$.

As mentioned earlier, there are particularly important factors in agricultural income insurance: first, the sum insured, which reflects the expected income and determines the compensation conditions, and second, the insurance premiums that reflect the amount of expected compensation and are paid based on the coverage level. Both of these factors depend on the distribution of yields, and therefore, the accuracy of their determination depends on the correct recognition of yield and price distribution for the product as well as the degree of correlation. Goodwin and Mahul [19] proposed that the probability density distributions for the yields and prices of products should be established to predict the probability distribution of farmers' revenue. Therefore, any premium rate-making procedure is associated with measuring revenue risk. The study utilized a joint probability distribution of the prices and yields.

3.1. Modeling Yield Distribution and Forecasting Approaches

Since WFI is intended to stabilize farmers' revenue, it is necessary to forecast the future values of yields and prices. Crop yields tend to increase over time due to technological advances, which implies that the data generation process is unstable. Therefore, it is not reasonable to compare the observed yields over different time periods. To address this issue, many methods have been proposed to detrend or normalize yield data. According to Zhu et al. [20], the commonly used method is a two-step estimation process. In this process, in the first step, yields are forecasted using parametric or non-parametric models. In the second stage, crop yields are detrended. Different regression models have been used in the literature, including linear [19,21,22], quadratic [22,23], and polynomial models [24]. In addition, Deng et al. [25] and Vedenov et al. [26] applied a log-linear model, while Adhikari et al. [22] and Harri et al. [27] applied bilinear spline and knot methods. Additionally, Ker [28], Goodwin and Ker [29], and Ker and Goodwin [30] used a stochastic model such as an autoregressive integrated moving average (ARIMA) to predict yields. There are two common approaches to detrending yields. These two approaches are based on the assumptions of constant and non-constant errors.

If a researcher assumes that the magnitude of the error is not influenced by the yield level, then they add all the residuals to the reference year (the last year of the observation period). However, if one believes that deviations from the trend are proportional to the level of yield, then they can consider constructing a normalized yield as follows:

$$y_t^{\text{det}} = \frac{y_t}{\hat{y}_t}\hat{y}_{\text{T}} \qquad \text{t} = 1, 2, \ldots., \text{T} \tag{10}$$

where $y_t{}^{\text{det}}$ is the detrended yield in year t; y_{t} and $\hat{y}_{\text{t}}$ are the observed and predicted values of yields, respectively; and $\hat{y}_{\text{T}}$ is the value forecasted for yield in the base year, which in this study is 2021. In this way, the potential problem of heteroskedasticity will also be corrected. In context, the methods used in yield distribution models fall into three wide groups: parametric, semi-parametric, and non-parametric methods [21]. After detrending and normalizing yields, the yield probability distribution was estimated using the parametric or non-parametric approach. A major advantage of using a parametric approach (beta, normal, log-normal, gamma, logistic, and Weibull) is the ease of estimation of the distribution of parameters, but in the rating of crop insurance products, these common parametric distributions often present problems such as not being able to model bimodality or multimodality; therefore, some researchers prefer the use of non-parametric methods, which define the shape of the distribution without a given prior specification. Kernel estimation is used as a non-parametric method for estimating the shape of the conditional price and the yield density and pricing of a crop insurance contract, which was used in this study too [18]. In this study, depending on the nature of the data and based on the literature, the second approach was used. In this method, the time series of the product yields are matched to the trend variable (in linear or logarithmic or quadratic form). Then, among these linear, logarithmic, and linear–logarithmic models, the fitting model is selected based on the goodness of fit criteria, including the transformation [31].

3.2. Modeling Price Distribution

In revenue insurance, the insurance company protects the policyholder against declines in crop yields and prices. Thus, revenue insurance involves predicting yields and prices at harvest time to build premium rates. Crop prices increase over time, especially in developing countries. In such cases, it is not reasonable to compare prices in different periods. In economic terms, the residuals are subject to heteroskedasticity. Thus, before modeling, the stochastic components of the price series should be separated. In this study, the nominal crop prices received by farmers during the period 1983–2018 were obtained from the website of the Ministrye of Agriculture. The price series were then converted into real data using the Producer Price Index (PPI) deflator published by the Central Bank of Iran. Since the deflated nominal data cannot account for the direct impact of changes in technology and market structure, it is necessary to detrend the data to separate the stochastic component from the price series. In this study, price series were detrended through linear, quadratic, polynomial, and log-linear regression models, as well as autoregressive integrated moving average (ARIMA) models. Then, the residuals were checked for normality and white noise properties. Finally, the best distribution for each price series was specified.

3.3. Measurement of Revenue Risk

As mentioned earlier, revenue risk is a combination of price and yield uncertainties. In general, revenue insurance policies protect producers against low prices and low crop yields. If income falls below the guaranteed level due to a combination of low yields and/or low prices, the insured farmer receives compensation equal to the difference between actual and guaranteed income. To measure revenue risk, it is required to determine the likelihood of price and profit occurrence. To achieve this, in the first step, yield and price risk must be accurately estimated. However, price and output densities are often not independent [11,32].

3.4. Measuring Farmers' Welfare

In this paper, the basic idea of evaluating the impact of whole-farm insurance (WFI) consists of comparing farmers' welfare under alternative scenarios. Two scenarios, including no crop insurance and whole-farm insurance (WFI), are hypothesized in this paper. The process to achieve this requires an estimate of farmers' welfare. In economic theory, the use of the expected utility model is the most general approach to comparing risky options and studying risky behavior under conditions of uncertainty. Therefore, a simulation model based on the expected utility function was developed in this paper to estimate farmers' welfare. Similar to previous studies [33–36], this paper applied the power utility function (Equation (11)) to compute farmers' utility [37].

$$U(W_0 + W) = \frac{1}{1-\theta}(W_0 + W)^{1-\theta} \tag{11}$$

where θ represents the constant relative risk aversion (CRRA) and is set to 2 to test the robustness of the analysis. Furthermore, W_0 represents the farmer's initial wealth, and W is the farmer's net income.

It is assumed that farmers seek to maximize the expected utility of their final wealth under uncertainty. The assessment of the expected utility of choosing insurance as a risk management tool depends on farmers' risk preferences and their subjective assessment of the risks they face. This analysis assumes that farmers are risk-averse and have risk preferences consistent with a CRRA function. The CRRA function implies that the individual's decision does not change in terms of budget share, or income elasticities are equal to 1. Mathematically, the utility function assuming CRRA is as follows:

$$U = \frac{W^{1-r}}{1-r} \tag{12}$$

In Equation (12), *W* is the net stochastic final wealth for choosing specific insurance, and r is the relative risk aversion coefficient (the Arrow–Pratt coefficient). The ending wealth (Equation (13)) includes the farmer's initial wealth, insurance premiums (net of subsidy), actual revenue, and indemnities.

$$\pi_i(\alpha) = BW + (p \times y) + I(\alpha) + \gamma - C \tag{13}$$

where π_i (α) is the final wealth, *BW* is the initial wealth, *p* is the product price, *y* is the product yield, $I(\alpha)$ is the indemnities received, γ is insurance premium, and *C* is the production costs.

The initial wealth and production costs are assumed to be constant for all insurance policies. The net insurance premium is paid by the farmer after the subsidy, which varies for each insurance policy and coverage level. The actual revenue is the product of n simulations of harvest prices and yields. Different risk management options were examined with the certainty equivalent (CE) of the net stochastic ending wealth (*W*). This analysis used a model that is consistent with [38–42], using a CRRA utility function. The expected utility is as follows:

$$E(U) = \sum_{i=1}^{n} \omega \frac{W^{1-r}}{1-r} \tag{14}$$

Here, *E* represents the expectation operator, and ω is the probability of the respective ending wealth. *r* was set at 2 to represent moderate risk aversion, which was used in several previous studies such as [38,39,41,42]. The guaranteed level of insurance was obtained from the product of the expected yield and the level of insurance coverage and the expected utility for different levels of coverage through Monte Carlo simulation.

In this study, the CE was calculated from the expected utility function, as shown in Equation (4). The CE is a measure of expected benefits that is calculated by taking into account all costs and subsidies associated with agricultural production, insurance costs, and the farmer's initial wealth. Benefits will be higher if the farmer chooses insurance with a higher CE. The results are expressed as net benefit per hectare for a more straightforward interpretation. This is calculated as the difference of two CEs presented in Equation (5): CE for insurance with a specific coverage level and CE_0 for no insurance [43]. This difference is divided by net hectares to represent the results in Rials per hectare, as shown in Equation (15).

$$CE = [(1-\alpha)E(U)]^{1-\alpha} \tag{15}$$

Therefore, the expected compensation can be calculated using Equation (16).

$$EI = LT - IS \tag{16}$$

where *EI* is expected compensation; *LT* is the guaranteed amount; and *IS* is the simulated revenue. The simulated revenue is determined based on appropriate distributions, such as the parametric distribution for yields and prices. In other words, the revenue of an individual farmer is modeled according to a probability distribution. For this, the simulated individual yield is multiplied by the simulated prices. Consequently, the net income can be calculated according to Equation (17).

$$U_i(\alpha) = -\pi_i(\alpha)^{1-R} \tag{17}$$

where R is greater than 1 and is the coefficient of relative risk aversion, and π_i is the guaranteed revenue per hectare. The insurance guarantee level is the product of the expected yield and coverage level. Assuming that a farmer chooses the insurance coverage level to maximize their expected utility, the farmer's decision problem is given by the following:

$$max\ EU_i(a) = max \int_x -\pi_i(a)^{1-R} df(-\pi_i \big| a) \tag{18}$$

The maximized expected utilities in Equation (18) are converted into associated certainty equivalents for each case using Equation (19):

$$CE = (-EU_i)^{\frac{1}{1-R}} \tag{19}$$

In this study, the certainty equivalent was estimated for a range of coverage levels under different scenarios. The farmer's welfare was then calculated based on the difference between the certainty equivalent per hectare for each case and the uninsured cases [22].

3.5. Study Site and Data

Iran is located in Northwest Asia, with an area of 1,648,195 km^2 and a population of about 85 million people. The capital of this country is Tehran. Zanjan province is in northwest Iran, with an area of 22,164 km^2 and a population of 1.1 million. The geographical location of Zanjan province in Iran is shown in Figure 1 [44].

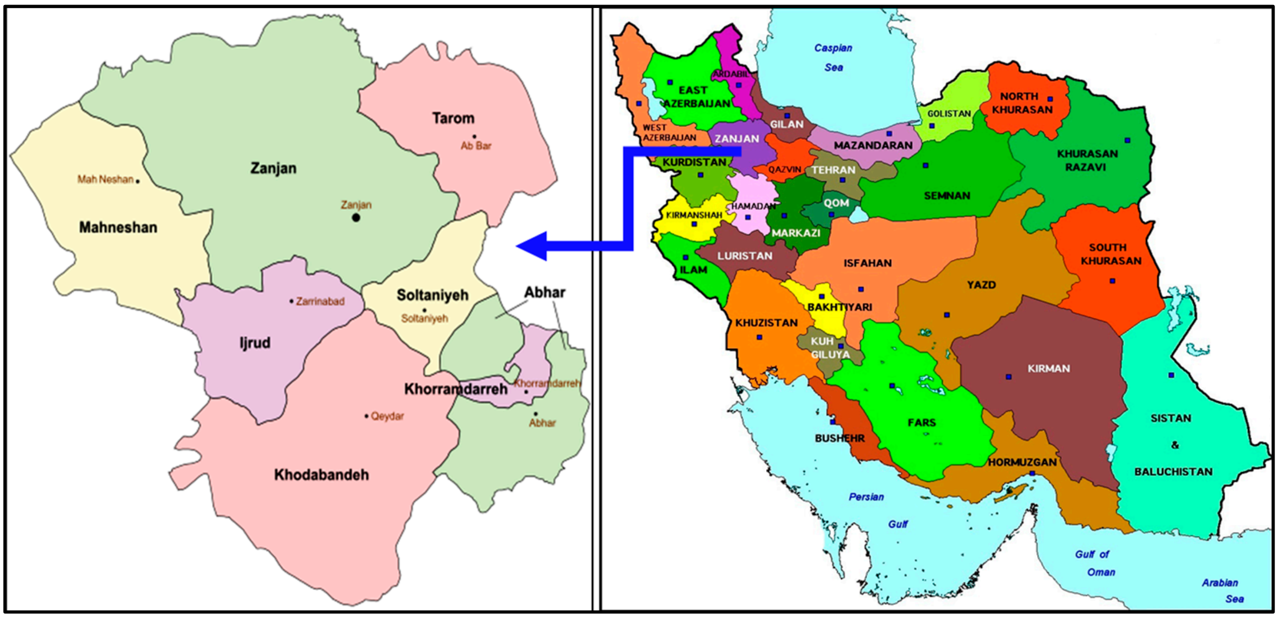

Figure 1. Location of Zanjan province in Iran. Source: [44].

In Zanjan province, the agricultural sector plays a crucial role in the economy. Wheat, barley, and alfalfa are the primary crops of the province, occupying roughly 65% of the total cultivated area [45]. This research utilizes historical yield data at both the farm and county levels, along with farm-gate prices, obtained from the provincial agricultural organization to estimate expected yields and prices. Farm-level yield data in Zanjan province span a 7-year period from 2015 to 2021, while county-level historical yields are available from 1981 to 2018. Prices are expressed in Iranian currency (IRR) per kilogram of produce [45]. In the crop year 2020–2021, Zanjan province farmers allocated about 445,000 hectares to agricultural production, yielding over 2.09 million tons of crops [46]. Concurrently, around 14,500 agricultural insurance policies have been issued, with 2,203 specifically for crops, encompassing 42,734 hectares of farmland in the region. In 2020–2021 crop year, the Provincial Agricultural Insurance Fund collected a total premium of IRR 253,011 million, including IRR 30,052 million from crops and IRR 10,897 million from farmers. However, during the 2018-19 crop year, the total compensation disbursed to Zanjan province's agricultural sub-sectors amounted to IRR 100,414 million, with IRR 12,000 million allocated for crops. This indicates loss ratios of 0.40 and 1.1 for the agricultural sector and crops, respectively, suggesting a deficit for the agricultural insurance fund. Furthermore, the existing agricultural insurance system fails to meet its additional objectives, such as guaranteeing farmers' economic security, boosting sector investment, and ensuring appropriate industry growth. Consequently, the need to explore the viability of new insurance policies becomes evident.

This research involved gathering time series data on cultivated area, yields, and prices for wheat, barley, and alfalfa crops from the 1982–83 to 2020–21 crop years. Additionally, yield data for individual farmers during the 2008–2009 and 2020–2021 crop years were obtained from the provincial Agricultural Jihad Organization. The average yield over a 10-year period was determined for 30 chosen farmers. Subsequently, three scenarios were developed for a whole-farm income insurance policy.

1. Single income crop insurance for separate wheat, barley, and alfalfa crops
2. Whole-farm income insurance for two crops: wheat–barley, wheat–alfalfa, and barley–alfalfa.
3. Whole-farm income insurance in the case of three crops at the same time (wheat, barley, and alfalfa).

Simetar 5.0 and Stata 15.1 MP packages were used to estimate econometric models by estimating the probability density and cumulative distribution functions and simulating yields and prices.

4. Results

4.1. Testing for Stationarity

In this study, the DF-GLS unit root and KPSS tests were used to check for the stationarity of the yields and prices of crops, and the results are presented in Table 1. Considering that the critical values of the DF-GLS test in the model, including the intercepts at 1% and 5%, are -2.64 and -1.95, respectively, and that those for the models including the intercept at the origin and trend are -3.77 and -3.19, respectively, we understand that the logarithms of wheat and barley yields have no unit root and are stationary at the data level. Meanwhile, alfalfa yields were non-stationary. Additionally, the critical values for the KPSS test in the model including the intercepts at 1% and 5% are 0.74 and 0.46, respectively, and for the models including the intercepts at the origin and trend, they are 0.22 and 0.15, respectively. The KPSS test results also confirm the stationarity of yields and prices and lead us to use a trend regression model to detrend yields and an ARIMA model to detrend prices. To determine the type of distribution of the variables, detrended values were used. Linear and quadratic regression models were used to detrend the yields, and ARIMA models were applied to detrend prices. The Box–Cox transformation test [31] was applied to select the appropriate model among the linear, quadratic, and logarithmic models. Table 2 presents descriptive statistics of historical prices and yields for wheat, barley, and alfalfa after detrending the data.

Table 1. Results of KPSS and DF-GLS tests for yields and prices.

Variable	Crop	Intercept		Intercept and Trend	
		DF-GLS Statistic	KPSS Statistic	DF-GLS Statistic	KPSS Statistic
Log of yield	Wheat	−1.46	0.69	−3.86	0.13
	Barley	−3.12	0.62	−4.51	0.08
	Alfalfa	−0.99	0.27	−1.46	0.17
Log of price	Wheat	1.51	0.76	−3.99	0.10
	Barley	1.25	0.75	−3.66	0.07
	Alfalfa	1.05	0.75	−3.33	0.09
Log of first-differenced yield	Wheat	−0.94	0.48	−4.44	0.33
	Barley	−3.05	0.26	−4.30	0.24
	Alfalfa	−0.77	0.27	−1.30	0.15
Log of first-differenced price	Wheat	1.64	0.75	1.51	0.10
	Barley	−0.31	0.75	−3.16	0.07
	Alfalfa	0.79	0.50	−1.59	0.50

Source: authors' elaborations.

Table 2. Summary of statistics for detrended yields and prices.

Variable	Mean	STDV	CV	Max	Min	Skewness	Kurtosis
Wheat Yield	3828	530.2	13.9	4702	3006	−0.156	−1.294
Barley Yield	2802	403.8	14.4	3767	1993	−0.101	0.095
Alfalfa Yield	6137	538.5	8.8	7194	5312	0.368	−0.910
Wheat Price	8966	1264.1	14.1	11181	6415	−0.093	−0.779
Barley Price	9043	1513.9	16.7	15254	6689	2.092	7.752
Alfalfa Price	6841	991.4	14.5	9150	4947	0.245	0.088

Source: authors' elaborations.

An examination of the coefficient of variation (CV) in Table 2 shows that alfalfa yields are less variable than those of wheat and barley. Wheat price movements are less dispersed than those of barley and alfalfa, which is expected and reasonable given the guaranteed price of the product. Wheat and barley yields and wheat prices are left-skewed. A left-skewed distribution has a long tail on its left side and implies that the tails are thicker to the right with yields and prices close to the maximum value observed more frequently than meager yields and prices. At the same time, alfalfa yields and prices and barley prices tend to be right-skewed. A right-skewed distribution is longer on the right side of its peak than on its left. In addition, the kurtosis coefficients for wheat yield, alfalfa yield, and wheat price are negative, while they are positive for barley yield, barley price, and alfalfa price.

4.2. Forecasting Future Prices and Yields

Estimating future yields and prices for each product is necessary to calculate the guaranteed income. Various methods were employed for this purpose, including parametric approaches such as trend regression and ARIMA modeling, as well as the non-parametric technique of exponential smoothing. The predicted values for yields and prices obtained through each method are presented in Table 3.

Table 3. Forecasted future values for yields and prices obtained using different methods (kg/ha).

Variable	ARIMA Model	Trend Regression	Exponential Smoothing
Wheat Yield	-	4400	4094
Barley Yield	-	2723	2727
Alfalfa Yield	-	6752	6703
Wheat Price	12,410	-	11,054
Barley Price	9507	-	8703
Alfalfa Price	7837	-	7616

Source: authors' elaborations.

As shown in Table 3, different methods provide different predictions of yields and prices. Brosch–Godfrey and Q-stat tests were used to examine the white noise characteristics of the disturbance term of the model as an indicator of the adequacy of the ARIMA models. The Q-statistic for the first difference of the residual terms is insignificant, and the residuals are within the range. Furthermore, the LM statistic of the Brosch–Godfrey test is not significant in testing the serial autocorrelation of the disturbance terms, which confirms the adequacy of the selected model.

4.3. Calculating the Aggregate Limit of Indemnity and Premium Rates

To determine the best parametric distribution for yields and prices, Cumulative Density Function Deviations (CDFDEVs) were utilized. CDFDEVs indicate the deviation of the distribution from the empirical distribution. Therefore, the lower the CDFDEV, the more suitable the CDF is for describing the density distribution. The results of different distributions for the detrended yields and prices of wheat, barley, and alfalfa are presented in Table 4. As the data in Table 4 show, the beta distribution function is the best choice for describing the yields of wheat, barley, and alfalfa in addition to wheat and alfalfa prices, while log-log distribution is the best option for describing the price of barley.

Table 4. CDFDEV values obtained from different distributions for crops' yields and prices.

Var./Dist.	Beta	Gamma	Logistic	Log-Log	Log-Normal	Normal	Weibull
Wheat Yield	2620.0	293,684.2	862,223.7	1,262,060	371,825.0	246,035.6	272,327.2
Barley Yield	11,003.9	42390.6	142,034	318,178.9	58,532.6	38,254.2	80,449.6
Alfalfa Yield	2815.7	125,296.9	447,428.8	361,655.9	126,677.9	140,215.4	430,977.9
Wheat Price	50,382.2	726,859.6	2,159,977.2	3,527,013.6	920,337.0	630,479.2	894,549.4
Barley Price	974,859.3	537,686.8	1,521,433	299,645.3	372,705.9	1,185,918	3,243,836
Alfalfa Price	51,044.5	255,639.5	940,606.5	1,471,864	317,808.8	283,967.6	650,343.2

Source: authors' elaborations.

After selecting the most appropriate probability density function, guaranteed crop revenues were estimated using the joint distribution of yields and prices at different coverage levels. In the next step, the expected compensation from the insurance company was calculated based on the simulated and guaranteed income. Finally, the premium rates were calculated for the one-product, two-product, and three-product scenarios according to three coverage levels from 65 to 90%, as presented in Table 5. The figures in Table 5 show that in the case of growing only one crop, the expected compensation for wheat is the highest, and that for barley is the lowest. In the case of two crops, the highest expected compensation was for wheat–alfalfa and the lowest for barley–alfalfa. The expected indemnity for three crops is lower than that for two-crop wheat–barley and wheat–alfalfa and higher than that for combined barley and alfalfa insurance. Table 5 also shows that the income risk of wheat is higher than that of the other products. Alfalfa had the lowest income risk compared with wheat and barley. Additionally, the probability of compensation under the single-crop program was the highest for wheat compared to other crops and the lowest for alfalfa. For the two crops, the probability of compensation was the lowest in the barley–alfalfa case and the highest in the wheat–barley case.

Table 5. Expected indemnities and premium rates for crops calculated using parametric methods.

Scenario	Crops	Coverage Level	65%	70%	75%	80%	85%	90%
Single crop	Wheat	Expected Indemnity	3695	5546	7713	10,139	12,726	15,402
		Indemnity Probability	61.9	73.6	84.4	92.7	96.5	98.8
		Actuarial Fair Premium	10.4	14.5	18.8	23.2	27.4	31.3
		Real Fair Premium	11.6	16.1	20.9	25.8	30.5	34.8
	Barley	Expected Indemnity	8.4	25.5	86.2	221.7	447.2	767.2
		Indemnity Probability	14.6	27.4	41.7	55.1	69.6	78.5
		Actuarial Fair Premium	0.1	0.1	0.4	1.1	2.0	3.3
		Real Fair Premium	0.1	0.2	0.5	1.2	2.3	3.7
	Alfalfa	Expected Indemnity	328	874	1793	3051	4685	6666
		Indemnity Probability	1	2.3	2.7	14.1	21.1	28.5
		Actuarial Fair Premium	0.95	2.36	4.52	7.21	10.42	14.0
		Real Fair Premium	1.06	2.62	5.02	8.01	11.57	15.55
Double crop	Wheat–Barley	Expected Indemnity	901	2019	3655	5804	8562	11,754
		Indemnity Probability	26.0	50.1	72.9	89.0	97.2	99.4
		Actuarial Fair Premium	1.72	3.58	6.05	9.01	12.51	16.23
		Real Fair Premium	1.91	3.98	6.73	10.01	13.90	18.03
	Wheat–Alfalfa	Expected Indemnity	1128	3142	6465	10,875	15,883	21,183
		Indemnity Probability	20.8	34.4	45.6	60.8	74.7	83.4
		Actuarial Fair Premium	1.6	4.2	8.0	12.6	17.4	21.9
		Real Fair Premium	1.8	4.6	8.9	14.0	19.3	24.3
	Barley–Alfalfa	Expected Indemnity	28	166	574	1421	2820	4753
		Indemnity Probability	1.5	6.1	15.9	27.4	42.4	55.4
		Actuarial Fair Premium	0.05	0.30	0.97	2.52	4.21	6.70
		Real Fair Premium	0.06	0.33	1.08	2.50	4.68	7.45
Multi-crop	Wheat–Barley–Alfalfa	Expected Indemnity	308	1249	3296	6729	1140	17,026
		Indemnity Probability	7.8	21.7	40.9	61.2	77.7	89.6
		Actuarial Fair Premium	0.36	1.34	3.29	6.30	10.04	14.18
		Real Fair Premium	0.39	1.49	3.66	7.01	11.16	15.76

Source: authors' elaborations. Values are in percent and Rials.

As shown in Table 5, the compensation probabilities for the three crops are lower than those for wheat and barley and for the two crops wheat–barley and wheat–alfalfa, implying that WFI, while insuring yields and prices, reduces the risk of damages and compensation. Based on Table 5, the highest real premium rate in the single-crop program is for wheat, and the lowest is for barley. In the double-crop case, the highest real premium is for wheat–alfalfa, and the lowest is for the barley–alfalfa program. Additionally, the actual premium rates for the three crops are lower than the separate real premium rates for wheat and alfalfa and higher than the actual premium rates for barley. In addition, the real premium rates of these three crops are lower than the actual premium rates of wheat–barley and wheat–alfalfa and higher than the combined premium rates of barley and alfalfa. Therefore, it can be concluded that with an increase in the number of insured crops, the actual and actuarial premium rates decrease, which shows the superiority and high efficiency of the WFI policy compared to insuring crops individually.

To select the best method for estimating expected compensation, the probability of payment, and actuarial and actual premium rates in the whole-farm income insurance program, a non-parametric approach was also used, and the results are presented in Table 6. The results in Table 6 show that in the case of a single crop, the expected compensation of wheat is the highest, and that of barley is the lowest, which is consistent with the results of the parametric methods. In the case of the two crops, the highest expected compensation belongs to wheat–alfalfa and the lowest to barley–alfalfa insurance, consistent with the results of the parametric methods. Furthermore, the table shows that the expected compensation in the case of three crops is higher than that of two crops of barley–alfalfa but lower than that of wheat–barley and wheat–alfalfa. Additionally, the expected compensation for three-crop insurance is higher than that for individual insurance for barley but lower than that for individual insurance for wheat and alfalfa, which confirms the results of the parametric approaches. In general, comparing the estimates of the probability and cumulative density functions of yields and prices with histograms and empirical values shows that non-parametric estimates are more efficient than parametric estimates. Therefore, this method will be used in the next steps.

Table 6. Expected indemnities and premium rates for crops calculated using non-parametric methods.

Scenario	Crops	Coverage Level	65%	70%	75%	80%	85%	90%
One crop	Wheat	Expected Indemnity	951	1713	2796	4144	5727	7526
		Indemnity Probability	27.9	40.6	54.1	64.6	75.1	83.7
		Actuarial Fair Premium	3.2	5.4	8.2	11.4	14.9	18.5
		Real Fair Premium	3.6	6	9.2	12.7	16.5	20.5
	Barley	Expected Indemnity	0.3	6.3	19.4	59.9	155.2	324.4
		Indemnity Probability	0.1	1	1.4	5.3	11	17.2
		Actuarial Fair Premium	0	0	0.1	0.3	0.8	1.5
		Real Fair Premium	0	0	0.1	0.4	0.9	1.7
	Alfalfa	Expected Indemnity	178	560	1262	2297	3663	5382
		Indemnity Probability	9.6	20.4	34.3	46.4	60.1	73.9
		Actuarial Fair Premium	0.53	1.57	3.30	5.62	8.44	11.71
		Real Fair Premium	0.59	1.74	3.66	6.25	9.38	13.01
Two crops	Wheat–Barley	Expected Indemnity	82	301	789	1641	2896	4498
		Indemnity Probability	3.7	9.3	18.8	31.4	41.7	52.3
		Actuarial Fair Premium	0.18	0.62	1.52	2.97	4.94	7.24
		Real Fair Premium	0.20	0.69	1.69	3.30	5.49	8.05
	Wheat and Alfalfa	Expected Indemnity	130	615	1841	4101	7383	11,466
		Indemnity Probability	5.3	16.7	35.1	58.2	77.9	90
		Actuarial Fair Premium	0.2	0.9	2.5	5.3	9	13.2
		Real Fair Premium	0.2	1	2.8	5.9	10	14.7
	Barley–Alfalfa	Expected Indemnity	4	46	229	697	1572	2958
		Indemnity Probability	0.4	2	7.8	18.4	30.2	43.4
		Actuarial Fair Premium	0.01	0.09	0.41	1.17	2.47	4.40
		Real Fair Premium	0.01	0.10	0.45	1.30	2.75	4.88
Three crops	Wheat, Barley, and Alfalfa	Expected Indemnity	12	140	667	1914	4171	7556
		Indemnity Probability	0.4	4.8	13.7	29.1	47.4	64.8
		Actuarial Fair Premium	0.02	0.17	0.74	1.99	4.09	6.99
		Real Fair Premium	0.02	0.18	0.82	2.21	4.54	7.77

Source: authors' elaborations. Values are in percent and Rials.

4.4. Calculating the Changes in Farmers' Welfare

The impact of insurance on producers' welfare can be assessed by comparing certainty equivalent differences with and without coverage. To evaluate the effects of participating in the whole-farm insurance program on farmers' well-being, their welfare was computed and compared to the scenario without insurance. In Iran, the government covers most insurance premiums, so farmers' net income must be calculated by determining their portion of the paid premium. The Agricultural Insurance Fund of Zanjan province reported that farmer insurance premium rates for wheat, barley, and alfalfa were 22%, 21%, and 25%, respectively. The bivariate kernel function-derived insurance premium rates were utilized to simulate crop yields and prices for calculating farmers' revenue. Table 7 summarizes the results of comparing welfare changes under the whole-farm insurance program. It demonstrates that producers' welfare increased when participating in the program compared to being uninsured. For instance, at 75% coverage, a farmer insuring only wheat gains IRR 4,496,261, only barley IRR 418,990, only alfalfa IRR 1,548,318, wheat and barley IRR 900,964, and wheat and alfalfa IRR 948,330. Insuring two crops (barley and alfalfa) would increase welfare by IRR 915,054 per hectare, while insuring all three crops simultaneously would result in an increase of IRR 963,155 per hectare.

Table 7. Farmers' welfare changes in the whole-farm income insurance program.

Coverage Level	Wheat	Barley	Alfalfa	Wheat and Barley
Welfare without Insurance	5,080,6540	23,733,081	52,915,424	74,529,621
Welfare with Insurance				
65%	53,492,439	23,944,271	53,536,867	74,680,332
70%	54,348,406	24,046,293	53,929,468	74,929,784
75%	55,302,801	24,152,071	54,463,742	75,440,585
80%	56,304,663	24,288,124	55,147,026	76,379,423
85%	574,140,618	24,452,453	55,997,361	77,873,647
90%	58,690,953	24,657,033	57,011,527	79,960,930
Coverage Level	Wheat and Alfalfa	Barley and Alfalfa	Wheat, Barley, and Alfalfa	
Welfare without Insurance	109,798,764	82,725,305	127,455,045	
Welfare with Insurance				
65%	109,945,383	82,867,485	127,603,489	
70%	110,207,557	83,121,027	127,869,636	
75%	110,747,094	83,640,359	128,418,200	
80%	111,739,301	84,595,017	129,427,225	
85%	113,316,297	86,113,789	131,030,293	
90%	115,511,229	88,233,047	133,259,050	

Source: authors' elaborations.

5. Discussions

The results of the DF-GLS unit root test and the KPSS test are expected and consistent with the literature, which states that the yield series follows the Trend Stationary Process (TSP), and the price series follows the Differences Stationary Process (DSP). Therefore, the linear and quadratic regression models were used to detrend the yield series, and ARIMA models were applied to detrend the price series. Falsafian et al. [18] also found that the wheat and barley yield in Iran follows the TSP. The shape of the distribution functions indicates that wheat and alfalfa yields are mostly scattered to the left of the county average, while barley yields are mostly scattered to the right of the county average. As a result, wheat and barley yields are mostly lower, and alfalfa yields are higher than the regional average. In addition, the kurtosis coefficients imply that wheat and alfalfa yields and wheat prices have a flat distribution, while barley yield and barley and alfalfa prices show a peaked distribution. Similar to the findings of Goodwin and Ker [29] in the United States, Yonar et al. [47] in China and Bangladesh, and Kumar et al. [48] in India, the yields showed negative skewness in most of the cases, although positive skewness was reported by Chen and Miranda [49].

Our findings show that the beta distribution function is proper for describing the yields of wheat, barley, and alfalfa, as well as the prices of wheat and alfalfa, whereas the log-log distribution best describes barley prices. These findings are consistent with those of Hennessy et al. [7] and Zhu et al. [20]. In the next step, the shapes of the probability density function and the cumulative probability function of the data were examined to ensure the correct selection of PDFs to describe yields and prices. According to [46], the plots of the functions were compared with empirical PDFs to check their consistency with actual yields and prices. From the comparison, it appears that the PDF histogram of the beta distribution corresponds better with the empirical PDFs than the other functions, and thus, the beta distribution is best suited to describe wheat yield. In this study, the probability and cumulative density functions of yields and prices were compared with histograms and empirical values, and we found that the non-parametric estimates are more efficient than parametric ones. Consequently, this method was employed to calculate the producer's welfare. These results are consistent with those of Ozaki et al. [21] for calculating premium rates for corn, soybean, and wheat in Brazil and Falsafian et al. [18] for wheat and barley in East Azerbaijan counties of Iran. The results of the parametric method showed that the highest real premium rate in the one-crop program was for wheat and the lowest for barley. For the two crops, the highest real premium was for wheat–alfalfa insurance and the lowest for barley–alfalfa insurance. Additionally, the real premium rates for three crops differed from the real premium rates for wheat, alfalfa, and barley. The actual insurance premium rates for the three crops were lower than the actual insurance premium rates for wheat–barley and wheat–alfalfa and higher than the combined premium rates for barley and alfalfa. In the non-parametric approach, the probability density and cumulative density functions of the variables were plotted using the kernel function and compared with the empirical cumulative density function. The results showed that the highest real premium rates were for single-crop wheat and double-crop wheat–alfalfa insurance. Furthermore, as the number of insured crops increases, the premium rate decreases, which indicates the high efficiency of whole-farm insurance over individual crop insurance. In other words, whole-farm insurance contracts have lower premiums than individual crop insurance contracts; therefore, farmers must pay less.

Evaluating the changes in producer welfare reveals that the WFI policy is superior to and more efficient than individual crop insurance. Specifically, insuring all three crops simultaneously would lead to an increase of IRR 963,155 in gains per hectare. These findings align with Deng et al. [25] and Falsafian et al. [18], suggesting that whole-farm insurance program participation enhances farmers' welfare. They also concur with Adhikari et al. [22], who demonstrated that the proper management of crop insurance programs can improve the certainty equivalent. Moreover, these outcomes are comparable to those reported by Serfilippi et al. [50] for cotton farmers in Burkina Faso, Ye et al. [51] regarding Chinese wheat producers' welfare, Gallenstein and Dougherty [52] in Ghana, Wang et al. [37] in China, and Chattha [53] in Arkansas county of the United States. Additionally, this enhancement in producer welfare illustrates the economic benefits associated with the WFI policy and the strategic alignment it creates in managing risk across diverse agricultural outputs. By integrating the insurance of multiple crops into a cohesive framework, farmers can effectively mitigate the financial uncertainties that arise from adverse weather conditions, disease outbreaks, and market fluctuations. This collective approach fosters an environment where producers are encouraged to invest in more sustainable farming practices, knowing their livelihoods are safeguarded against potential losses. Moreover, the efficiency of the WFI policy translates into lower administrative costs and streamlined processes compared to managing separate insurance policies for individual crops. Such simplification reduces the bureaucratic burden on farmers, enabling them to focus more on enhancing productivity rather than navigating complex insurance claims. The substantial increase of IRR 963,155 per hectare not only boosts immediate income but also contributes to the overall resilience of the agricultural sector, ensuring that farmers are well equipped to respond to future challenges.

6. Conclusions

This study had two objectives: first, to determine the premium rate of whole-farm income insurance and then to calculate the welfare benefits of WFI for producers. Parametric and non-parametric approaches, as well as methods incorporating individual and regional data, were utilized to evaluate the whole-farm income insurance program. In the parametric approach, detrended yields and detrended real prices were used to model the yield and price distributions, respectively. Beta, gamma, normal, log-normal, log-log, logistic, and Weibull distribution functions were utilized to model yields and prices. The calculation of the CDDFEV for the above distributions showed that the beta distribution function is the best description for the yields of wheat, barley, and alfalfa and the prices of wheat and alfalfa, and the log-log function was found to be appropriate for describing barley prices.

In this study, the yields of representative farms were analyzed by taking advantage of the relationship between individual farmer yields and regional yields. For this purpose, deviations between the farmers' yields and the regional average yields were calculated, and then the probability distribution function of the individual yield was estimated using the bivariate kernel function. The results obtained for insurance premium rates from the simulation of representative farms differed from those of the parametric and non-parametric methods. This method also confirmed that the values of the insurance premium rates and loss probability in the two-product insurance program were lower than those in the single-product and three-product programs. In other words, the whole-farm insurance program becomes more efficient when the number of insured crops increases. For example, with 75% coverage, the probabilities of loss for wheat, barley, and alfalfa are 63%, 14%, and 38%, respectively. Meanwhile, insuring wheat and barley together reduces the probability of loss by 39%, insuring wheat and alfalfa reduces it by 35%, and insuring barley and alfalfa decreases it by 7%. In the case of insurance for all three products, this figure dropped to 18%.

In general, it can be concluded that whole-farm income insurance using the bivariate kernel probability distribution method will produce more reasonable premiums. Therefore, we recommend that this method be applied to estimate insurance premiums. The experience of developed countries in agricultural insurance, including the United States and India, shows that the conversion of yield insurance to index insurance has addressed most of the issues and minimized the risk of loss for farmers and the agricultural sector in general. Therefore, based on this issue and the current research results, it is recommended that the Agricultural Insurance Fund apply this policy instead of the traditional insurance program. The important point in this context is that, in agricultural insurance, it is also necessary to consider the needs of insured farmers. As whole-farm insurance has lower premiums, it can encourage farmers to participate in agricultural insurance programs. Therefore, this insurance program should be included in the agenda of the Agricultural Insurance Fund.

In this study, to evaluate the change in the economic well-being of farmers after they participated in the whole-farm insurance program, the certainty equivalent was used by calculating the expected utility function and risk aversion coefficients of the farmers. The results showed that, in general, applying whole-farm insurance at different levels increases the welfare of producers, and by increasing the level of coverage, the rate of increase in farmers' welfare also increases. In other words, the economic welfare of a farmer increases when they use an insurance program for at least one product, compared to the case of not insuring. It is clear that whole-farm insurance can complement existing agricultural risk management tools, and because of its advantages, it will have a positive impact on the development of insured farms in Iran, as well as strengthening the trust between farmers and the Agricultural Insurance Fund. Future studies should focus on including production costs in premium calculations.

It should be noted that this study had three limitations. First, farm-level yield data were not available over longer time periods, which may have led to bias in measuring the correlation between county-level and farm-level yields. Second, farm-level yield data were only available for a few regions, which led us to focus on Zanjan province. Third, this study focused solely on farm revenue, excluding production costs. Future studies incorporating production costs should consider farms' net revenue.

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