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Weather-Based Index Insurance Pricing- Canonical Vine Copula Function Approach

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ABSTRACT

Gardening products, like apple, are exposed to a variety of risks caused by unfavorable weather conditions. This kind of risk is unavoidable, but manageable. Agricultural insurance is an effective scheme in weather risk management. Nevertheless, current insurance schemes have challenges, such as high transaction costs, and problems caused by asymmetric information, i.e. adverse selection and moral hazard. Therefore, this study aimed to present an appropriate insurance scheme for apple production in Damavand, the so-called "weather-based index insurance". In this regard, the information on apple yield and weather variables was collected between 1987-2016, from Iranian Agriculture Jihad Organization and the local meteorological station. The dependency structure between apple yield and weather variables was investigated by *C-Vine* Copula as a joint distribution to compute the expected loss. Then, according to the expected loss, weather-based index insurance premium was measured. The premium amount was equal to Thousand Rials 32,546.11 in the crop year 2016-17, which is different from the current insurance premium. This difference is because of the distinct nature of the two insurance schemes and the imperative and official mode of current insurance scheme.

Keywords: Adverse weather, Apple, Bayesian method, Damavand**,** Expected loss.

INTRODUCTION

Apple is one of the main products in gardening sub-sector that is ranked the first among the gardening crops, contributing 18 percent of the total production of this sub-sector (Ministry of Agriculture Jihad, 2015). Damavand County in Iran, with a 223 thousand tons production of apple, is ranked the first producer among the counties of Tehran, and is considered as a hub in apple production in the country, which by itself accounts for 6.4 percent of the total production of the country (Damavand Agriculture Jihad Office, 2015). Like other crops, apple production is affected by bad weather conditions such as hail, cold, and frost. Hence, its production is a risky activity. In recent years, the amount of apple damages caused by weather change in the country and Damavand has become significant. In the past decade, the damage to apple fruits was equal to 10 percent of the total damages of gardening products. In Damavand, frostbite is the most important cause of damages to apple such that 70 percent of damages are because of frost and cold (Agricultural Insurance Fund, 2013). Consequently, it can be claimed that most of the apple damages is due to adverse weather conditions and climate change. Hence, considering the importance and position of this product, it is necessary to adopt appropriate policies to manage weather risks. One of these policies is agricultural insurance.

Agricultural insurance helps to stabilize farmers' income over time and reduces the

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cost of weather risk. In Iran, like other countries, apple insurance was applied for this purpose. The current insurance plan insures this crop against the hail, flood, cold and frost, earthquake, and untimely and continued rains. The number of apple growers insured in the country was 89,490. The total earned premium, the farmer's share of premium, and paid indemnity for apple were Million Rials 727,170, 170,565, and 967,570, respectively. In other words, in the current apple insurance, the paid indemnity is 1.33 times of the earned premium. The government pays, on average, 65.60 percent of premium. This system has an administrative and circular mode. In order to reduce moral hazard, loss evaluation is made twice, leading to a high administration cost. The indemnity payment has a long suspension period such that only 31.54 percent of apple gardens are insured (Agricultural Insurance Fund, 2013). In addition, insurance adoption studies showed that the participation rate of farmers is low in the current insurance plan, and this plan is not efficient. For example, Faraji and Mirdamadi (2006) pointed that the consent of the current insurance was 40 percent in Damavand. Falsafian and Vaezi (2010) investigated the effect of insurance on technical principles in Damavand apple gardens, and showed that insurance was not efficient. Ghiyasi and Davari (2015) stated that 61.3 percent of the farmers had a negative and relatively negative attitude towards the agricultural insurance. Ghelich (2016) showed that the farmers' attitude level toward the current agricultural insurance was negative. Furthermore, the current insurance plan suffers from problems caused by asymmetric information i.e. adverse selection and moral hazard. Adverse selection means that the distinction of high-risk insured from the low-risk ones is difficult or costly; consequently, after a while, the insurer faces with a large number of high-risk insured, as well as an indemnity over the expected indemnity. Moral hazard also occurs when the insured changes his behavior after purchasing insurance or deliberately causes damage (Wenner and Arias, 2003). Such challenges will lead to increase in premium rate, indemnity and more accurate damage assessment; therefore, the insurer will be obliged to accept additional cost to assess the damages (Ofoghi *et al.*, 2011).

Regarding the current agricultural insurance problems, it is immediate to provide an appropriate insurance system that can minimize these difficulties and transaction costs, also stabilize producer's income (Jie *et al.*, 2013). In recent years, a variety of mechanisms have been developed to deal with this issue, one of which is weather-based index insurance. Weather-based index insurance is a form of insurance in which the payment of indemnity is based on some observable weather variables, such as temperature and rainfall that can be measured by external independent organization with a high public confidence. Indemnity is paid in the case that index becomes lower or upper than the predetermined trigger value, i.e. it depends on the construction of index indemnity payment. Therefore, indemnity payment does not depend on the crop survival or failure. Consequently, farmers do their best to maintain the crops. Reliance on the factors beyond the control of farmers decreases the problems of adverse selection and moral hazard. Moreover, unlike traditional plans in paying indemnity, insurance companies do not have to visit the farms to determine the loss. A further advantage of weather-based index insurance is that indemnity payment can be done faster, together with the fact that insurance contracts are clearer and transaction costs are lower. More importantly, historical data for weather variables is available in many countries, even those with low income (Ofoghi *et al.*, 2011).

Despite the numerous benefits of weather-based index insurance, the implementation of this insurance has challenges including high implementation cost to cover the marketing, educational and Pilot preparation cost, the lack of access to reliable weather

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data, the basis risk and the complex design of the index contract. The basis risk occurs when the weather index as measured at the station differs from the weather index at the farmer's plot. For example, a farmer with index insurance could lose his crop at a micro location, but not receive an indemnity if the index at the region's weather station does not reach the trigger value (Aziznasiri, 2011). Although the basis risk is a big problem for this insurance, it can be controlled by selecting the homogeneous regions in terms of weather conditions, paying indemnity based on the phenological stages and using the appropriate method for measuring the dependency structure of weather indices and yield.

Regarding the numerous benefits of weather-based index insurance, in most countries, this insurance has been used as a new and efficient tool in risk management. In this regard, Conradt *et al.* (2015) investigated the flexibility of weather-based index insurance in Kazakhstan. They believed that using the index insurance in agriculture sector was more effective than current insurance. Bokusheva (2010) studied the relationship between weather indices, including, cumulative rainfall index, Selyaninov drought index, and rainfall deficit index, and wheat yield in Kazakhstan over the period from 1961 to 2003. She emphasized that the designing of weather-based index insurance is strongly based on an implicit assumption about the dependency structure, so, she showed that the Copula functions were better than regression analysis. In addition, she suggested that researchers use indices that have the strongest dependency with yield. Pishbahar *et al.* (2015) computed the weather-based index insurance premium for wheat. They measured the dependency using the *D-Vine* Copula. They showed that index insurance for crops that have a strong relationship with weather condition was better than the other tools. Khajehpour and Keykha (2014) acknowledged that weather-based index insurance compared to current insurance has advantages such as faster compensation of losses, lower transaction costs, adverse selection, and moral hazard. Aziznasiri (2011) suggested that weather-based index insurance plan is an efficient tool in agricultural risk management. Considering the benefits of weather-based index insurance, and the fact that the main damage factor for agricultural products and apple is adverse weather conditions, it seems necessary to apply this insurance system. Therefore, to reduce insurer transaction costs, to encourage farmers, and to preserve apple production in Damavand and the whole country, we aimed to design a weather-based index insurance for Damavand apple and use a new approach to measure the dependency structure to accurately determine the expected loss and premium.

MATERIALS AND METHODS

In general, methods for computing the premium fall into two categories. The first method is the expected utility that all risky behaviors of producers should be taken into consideration in the decision-making process. The second method is the determination of the premium using expected loss-based actuarial method and secondary data (Robison and Barry, 1987). In this study, due to the limitations of the first method in the reflection of all risky behaviors, the second method was used, in which we must determine the expected loss of the apple yield with respect to weather variables. In other words, the dependency structure between weather variables and yield should be determined. The classical methods, like simple regression and linear correlation, have major drawbacks, the most important of which is considering the unilateral or mutual relationship of the variables, and they are based on the normal distribution (Schulte and Berg, 2011). Therefore, it seems that investigation of multivariate flexible distribution in dependency structure can provide results that are more reliable. In this regard, the use

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of Copula functions as an efficient statistical tool became popular (Chen *et al.*, 2013). In fact, "Copula" is a function that connects a group of marginal distributions together and forms a multivariate joint distribution.

Vine Copula

Although simple Copula functions are more effective compared to other methods, they are limited in the large number of variables, because multivariate data often have a complex dependency pattern (Brechmann and Schepsmeier, 2012). Many efforts are made by researchers to create more flexibility and the Vine Copula is among such efforts (Czado *et al.*, 2014). This type of Copula provides a flexible graphical model to describe the construction of the multivariate distribution using bivariate Copulas called Pair-Copula Construction (PCC). Joint density function of multivariate Vine Copula is decomposed to pair Copula functions in a chained manner. Joint probability density function with *d*-variable is shown as follows (Brechmann and Schepsmeier, 2012):

$$f(x_1, x_2, ..., x_d) = f_1(x_1).f(x_2 \mid x_1). f(x_3 \mid x_1, x_2)....f(x_d \mid x_1, ..., x_{d-1}) \quad (1)$$

Where $f(X_1,X_2,\ldots,X_d)$ is joint probability density function, $f_1(X_1)$ is marginal density function for X_1 and $f(X_2| X_1)$, $f(X_3| X_1, X_2)$ … $f(X_d| X_1, \ldots X_{d-1})$ are conditional density functions.

By employing *Sklar's* theorem, each of the components of the above equation can be decomposed into Copula functions. The first conditional density function is decomposed as:

$$f(x_2 \mid x_1) = \frac{f(x_1, x_2)}{f_1(x_1)} = \frac{c_{12}(F_1(x_1), F_2(x_2)).f_1(x_1).f_2(x_2)}{f_1(x_1)} = c_{12}(F_1(x_1), F_2(x_2)).f_2(x_2) \quad (2)$$

Where, c_{12} is the bivariate Copula density function of (x_1, x_2), and f_i is the density function. Similarly, the second conditional density function can be decomposed as follows:

$$f(x_3 \mid x_1, x_2) = \frac{f(x_2, x_3 \mid x_1)}{f(x_2 \mid x_1)} = c_{23|1}(F(x_2 \mid x_1), F(x_3 \mid x_1)).f(x_3 \mid x_1) \quad (3)$$

Also, according to the Equation (2), Equation (3) can be written as Equation (4):

$$f(x_3 \mid x_1, x_2) = c_{23|1}(F(x_2 \mid x_1), F(x_3 \mid x_1))c_{13}(F_1(x_1), F_3(x_3)).f_3(x_3) \quad (4)$$

Finally, the *trivariate* joint density, after decomposition, becomes a function of the marginal density and the unconditional and conditional pair Copula, and is obtained as:

$$f(x_1, x_2, x_3) = f_1(x_1).f_2(x_2).f_3(x_3).c_{12}(F_1(x_1), F_2(x_2)).c_{13}(F_1(x_1), F_3(x_3)).c_{23|1}(F(x_2 \mid x_1), F(x_3 \mid x_1)) \quad (5)$$

In general, conditional distribution function or h-function is calculated using Equation (6), which is used in the simulation and making input for the next trees.

$$h(x \mid \upsilon, \theta) = F(x \mid \upsilon) = \frac{\partial C_{x\upsilon_j|\upsilon_{-j}}(F(x \mid \upsilon_{-j}), F(\upsilon_j \mid \upsilon_{-j}) \mid \theta)}{\partial F(\upsilon_j \mid \upsilon_{-j})} \quad (6)$$

Where, υ is a *d*- dimensional vector, υ_j is an arbitrary component of υ and υ_{-j} shows the (*d-1*)-variable vector.

Decomposition of Vine Copula is not particular, and a large number of pair copula structures can be selected. For their classification, Bedford and Cooke (2001 and 2002) introduced graphic patterns or "Regular Vine Copula" (*R-Vine*) (Brechmann and Schepsmeier, 2012). In this model, the joint distribution function is shown in a nested set of trees $\{T_1,\ldots,T_{d-1}\}$ (In the theory of graphs, the tree is in fact an acyclic connected graph. A graph is a set of nodes and edges. One node can be considered per each variable and these nodes are connected by an edge.).

In other words, a Regular Vine Copula with *d*-variable is a set of (*d-1*)-trees, where edges of the tree *j* are the nodes of tree *j+1*. Here, the proximity condition should be dominating.

C-Vine (Canonical Vine) and *D-Vine* (Drawable Vine) are the two famous types of *R-Vine* that are frequently applied in the literature. A *D-Vine* is a *R-Vine* that has a

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direct structure (path), while a *C-Vine* has a star-like structure. Choosing these two most widely used types of *R-Vine* makes the process easy (Czado *et al.*, 2014).

Estimation of Parameters for Copula Functions

In a specified *R-Vine* tree structure, ν, and the bivariate Copula, B, the main problem is estimation of parameters, θ, for a vector of x. In order to estimate the *R-Vine* parameters, θ, the likelihood function, $L(\nu, B, \theta)$, can be expressed as a product of densities function, $f_{1:d}$, that is shown in Equation (7).

$$L(\nu, B, \theta) = \prod_{k=1}^{N} f_{1:d}(x_k \mid \nu, B, \theta) \tag{7}$$

Due to the fact that observations for agricultural yields have short length, the application of maximum likelihood method in parameter estimation is not valid. Therefore, in order to solve this problem, as Bokusheva (2010) pointed out, we can use the *Bayesian* approach. In Bayesian methodology, each parameter is treated as random variable and described by two types of distribution: prior and posterior one. The prior one expresses our prior information (or lack of information) about the variable–and here is denoted by $\pi(\theta)$. Then, this distribution is revised with respect to the information contained in the observations *x*, and a new distribution is obtained for θ, known as the posterior distribution, $P(\theta) = p(\theta \mid x)$. The posterior distribution can be displayed as the multiplication of the likelihood function, $L(\theta \mid x)$, and prior density function, $\pi(\theta)$, as follows (Czado *et al.*, 2014):

$$p(\theta \mid x) = \frac{L(\theta \mid x) \cdot \pi(\theta)}{f(x)} \propto L(\theta \mid x) \cdot \pi(\theta) \tag{8}$$

The point estimation of the unknown parameter, θ, is as follows (Czado *et al.*, 2014):

$$\hat{\theta}_B = \int \theta p(\theta \mid x) d\theta = \int \theta \, \pi(\theta) \, L(\theta \mid x) d\theta \tag{9}$$

The calculation of $\hat{\theta}_B$ will not be easy. Therefore, the entire distribution of parameter as an approximation of $\hat{\theta}_B$ can be used. The logical solution is using Markov Chain Monte Carlo (MCMC) method to approximate the parameter's posterior distribution. It should be noted that here the sequential or tree to tree procedure can be followed, in which the likelihood function for the pair Copula *c* is expressed as follows:

$$L(u_1, u_2 \mid \theta) = \prod c(F_{u_1}(u_1 \mid \theta), F_{u_2}(u_2 \mid \theta)) \cdot f_{u_1}(u_1 \mid \theta) \cdot f_{u_2}(u_2 \mid \theta) \tag{10}$$

Choosing a Bivariate Copula Family

Since the simultaneous selection of the Copula is difficult due to the multiplicity of the possible states, tree to tree method is used (Czado *et al.*, 2014). The selection of Copula is based on the value of information criteria, such as Akaike (*AIC*), Schwarz (*SBC*), and Vuong and Clarke. Here, we used *AIC* and *SBS*.

Choosing the Tree's Structure

The conventional method is sequential, which follows a tree to tree sequential procedure with regard to the Proximity Condition at each stage (Czado *et al.*, 2014). In the sequential procedure, the decision-making is based on the maximum sum of absolute *Kendall's* tau.

Copula Data

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Since the Copula function needs to be grounded to satisfy the feature of joint distribution function, the data set should have uniform margins in [0,1], the so-called Copula data. While empirical evidence shows that the data of the real world are seldom in this interval, we must transform our real data to Copula data. For this purpose, the Empirical Cumulative Distribution Function was applied (Brechmann and Schepsmeier, 2012)

Simulation

When we make the Copula data, we can apply the Vine Copula to determine the joint distribution function. Then, according to the joint distribution, we simulate the *CDF* of yield with respect to the weather variable to measure the expected loss. Conditional method is one of the common methods of simulation in the Copula functions, where, initially as per the dimensions of each variable, an observation is sampled, then, by reversing the conditional distribution function in the sampled variable, the next observations are created, thus, adequate number of random observations is created.

Determining the Marginal Distribution of Variables.

When we simulate the *CDF* of yield by Vine Copula as a joint distribution, the generated data are in [0, 1] as well. In order to bring them back to their standard form, we can use the inverse cumulative distribution function. For this purpose, it is necessary to determine the marginal distribution of variables. Therefore, we can use statistical test, such as "*Kolmogorov-Smirnov*", "*Anderson-Darling*" and "*Pearson*". Here, we used the *EasyFit* software to compare a number of theoretical distributions to determine the yield distribution. This software measures the statistic of the mentioned test for 65 distributions and, finally, considering the minimum value of these statistical tests, we determined the appropriate distribution. In addition, according to Pishbahar *et al*. (2015), the most common used distributions for yield are *Weibull* and *Wakeby*.

Contract Premium.

After determining the joint distribution function and generating the simulated data, using the forecasted value of yield by ARIMA process, the critical value of yield in three coverage levels including 50%, 70%, and 100% were calculated as the multiplication of the forecasted yield and the coverage levels, i.e. $y_C = y_{fore} \cdot COV$, where y_c is critical yield, y_{fore} is the forecasted yield, and *COV* is the coverage level (Ofoghi *et al*., 2011). Finally, simulated observations of yield were compared with the critical value. Paying indemnity also occurs when the amount of yield is less than the amount considered for the critical yield. The amount of expected loss is equal to the average deviation of the critical value of yield and the simulated values or average of $[Max(y_c - y,0)]$. Therefore, the fair premium is equal to $Ave[Max(y_c - y,0)] \cdot P$, where Ave is the average operator, $[Max(y_c - y,0)]$ is the difference of critical yield and simulated yield that $y_C > y$, and P is the guaranteed price by Agricultural Insurance Fund (Skees *et al*., 1999).

Weather variables used in this study consisted of temperature, cumulative rainfall index, relative humidity in different phenological stages (crop growth season) and fasten wind speed at harvest time. The phenological stages can be classified in five stages: hibernation, germination, flowering, growing fruit, ripening. These variables are modified for

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every crop year as the weighted mean. The apple yield data and weather variables were collected during the years 1987-2016 from the Office of Iranian Agricultural Organization, and the meteorological station in Damavand.

RESULTS AND DISCUSSION

To determine the dependency structure of apple yield with weather variables, we used a *C-Vine* pattern and the selection of the tree structure was based on the *Kendall's* tau. In order to simplify the calculations, a number was assigned to the standardized variables by Empirical Cumulative Distribution Function, including $Y_{ECDF}= 1$, $U_{ECDF}= 2$, $T_{ECDF}= 3$, $CRI_{ECDF}= 4$, $RH_{ECDF}= 5$. Therefore, the variable 1 is (yield), 2 (fasten wind speed), 3 (temperature), 4 (cumulative rainfall index), and 5 (relative humidity). The five named variables constitute the set of nodes ($N1$= {1,2,3,4,5}) in the first tree. The central node (root node) in each tree is determined in a *C-Vine* structure. *Kendall's* tau of all pair variables must be calculated for the central node and eventually a node with the highest sum of the absolute value of the *Kendall's* tau will be chosen as the central node. The results of the first tree are reported in Table 1. According to *Kendall's* tau yield and fasten wind speed are poorly correlated. This variable affects yield indirectly through other variables, in other words, in other tree structure it makes a conditional dependency with other weather variables. In addition, the empirical evidence showed that this variable in harvest time can cause a strong damage to apple. Therefore, we kept this variable in our analysis. Furthermore, it should be noted that *Kendall's* tau is just measured to determine the tree structure and it is not necessary to interpret its coefficient. Thus, we did not determine their *p-value*.

The sum of the absolute value of *Kendall's* tau is reported in the last row of Table 1. Given that the greatest number obtained is related to variable 5, this variable was selected as the central node in the first tree. Thus, in the first tree, the set of edges is as E_1= {(5,1), (5,2), (5,3), (5,4)}. Selected edges in the first tree, will be nodes in the second tree, so, the set of nodes for the second tree is as N_2= {(5,1), (5,2), (5,3), (5,4)} and there are four representatives for the central node in the second tree. *Kendall's*

Table 1. The *Kendall's* tau in the first tree.

Standardized variables	1	2	3	4	5
1	-	-0.07	0.54	0.30	0.36
2	-0.07	-	-0.04	0.15	0.13
3	0.54	-0.04	-	0.35	0.46
4	0.30	0.15	0.35	-	0.45
5	0.36	0.13	0.46	0.45	-
Sum	1.27	0.39	1.39	1.25	1.40

Table 2. The *Kendall's* tau in the second tree.

Standardized variables	5,1	5,2	5,3	5,4
5,1	-	-0.15	0.39	0.21
5,2	-0.15	-	-0.14	0.02
5,3	0.39	-0.14	-	0.20
5,4	0.21	0.02	0.20	-
Sum	0.75	0.31	0.73	0.43

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tau was calculated with new entries created. The results are reported in Table 2.

With regard to the maximum sum of the absolute value of the *Kendall's* tau, the central node in the second tree is node (5,1). The set of edges in the second tree is as E_2= {(1,2 | 5), (1,3 | 5), (1,4 | 5)}. The input for the third tree again must be determined. Likewise, the third and fourth trees were also created. Considering the third and fourth trees, the results for the *Kendall's* tau are reported in Tables 3 and 4. The reported results in Table 3 show that the central node is (1,2 | 5) in the third tree.

According to the results of the tables, the ranking of the variables in a *C-Vine* modeling is as follows: the variable 5, 1, 2, 3, and 4. Of course, the order of variables does not reflect their relative importance and cannot be interpreted.

Selecting Pair Copula and Estimating Their Parameters in *C-Vine.*

The results of the pair Copula selection by *AIC* and *SBC* and estimation of the parameters using Bayesian approach are reported in Table 5. The estimated parameters in Table 5 cannot be interpreted, and merely contain *C-Vine* tree structure components. This *C-Vine* tree, which is the output of the software *R* and package *CDVine*, is shown in the Figure 1. The parameters posterior distribution diagrams are displayed in Appendix.

It should be noted that in the tree structure, the first phrase represents the Copula family, the second phrase is the *Kendall's* tau, and the last phrase is the estimated parameter. The joint density distribution function of yield and weather variables is the tree structure of the obtained *C-Vine* model.

Determining the Suitable Marginal Distribution for Yield Variable to Simulate Its CDF.

Table 3. The *Kendall's* tau in the third tree.

Standardized variables	1,2|5	1,3|5	1,4|5
1,2|5	-	-0.06	0.07
1,3|5	-0.06	-	0.05
1,4|5	0.07	0.05	-
Sum	0.13	0.11	0.12

Table 4. The *Kendall's* tau in the fourth tree.

Standardized variables	2,3|5,1	2,4|5,1
2,3|5,1	-	0.04
2,4|5,1	0.04	-
Sum	0.04	0.04

Table 5. Pair Copulas selection and their parameters estimation using Bayesian approach.

Tree Number	Parameter	Selected family	θ	Standard error
First	$P_{5,1}$	Clayton	0.907	0.342
	$P_{5,2}$	Gaussian	0.220	0.096
	$P_{5,3}$	Joe -180 degrees	2.812	0.503
	$P_{5,4}$	Frank	4.729	1.335
Second	$P_{1,2\|5}$	Gaussian	-0.138	0.096
	$P_{1,3\|5}$	Frank	4.839	1.337
	$P_{1,4\|5}$	Frank	1.984	1.131
Third	$P_{2,3\|5,1}$	Frank	-0.805	1.081
	$P_{2,4\|5,1}$	Gaussian	0.030	0.103
Fourth	$P_{3,4\|5,1,2}$	Gaussian	0.120	0.097

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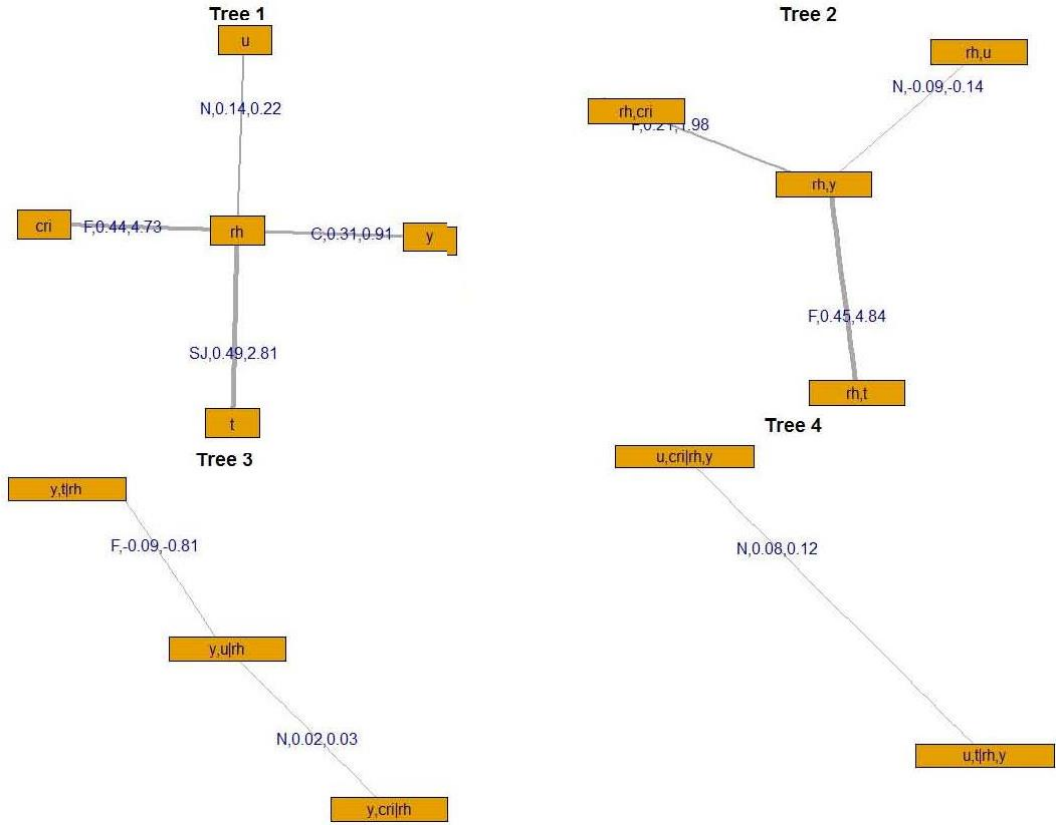

Figure 1. Estimated *C-Vine* trees for apple yield and weather variables; each node shows the variable and each edge shows the selected Copula i.e., C or Clayton, N or Gaussian, SJ or Survival Joe or Joe -180 degrees, F or Frank.

After estimation of joint distribution by *C-Vine* Copula, we simulated the *CDF* of yield which is in [0,1]. To convert this variable to standard form, the most appropriate theoretical marginal distribution for apple yield was selected, and by its inverse cumulative distribution the simulated Copula data was transformed. As mentioned above, 65 theoretical distributions were assumed for apple yield. The null hypothesis of each test was that the theoretical distribution was fit for yield. Finally, based on the minimized value of the above three tests, the *Wakeby* distribution for the apple yield was selected, as reported in Table (6).

Specifications of Wakeby distribution is as follows:

$$yield \sim \text{WAK}(\xi = 8.7243, \alpha = 18.598, \beta = 0.5220, \gamma = 0, \delta = 0) \quad (11)$$

Where, ξ is the location parameter , α and β are scale parameters, and δ and γ are shape parameters.

Computation of the Premium Contract

Using the ARIMA(0,1,2) process, the forecasted amount of yield becomes 29.243 (ton hec^{-1}), then, by this amount the critical values of yield are calculated in three coverage levels, including, 50, 70 and 100%. It should be noted that these levels are selected according to the coverage levels of the current insurance for apple in the Damavand County. In this study, the price of apple was considered as 3500 Rials, which is equal to the price stated by Agricultural Insurance Fund for apples in the premium calculation. In Table 7, the computed

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Table 6. Selection of suitable marginal distribution for the apple yield.

Suitable distribution		Kolmogorov-Smirnov	Anderson-Darling	*Chi*-Squared
Wakeby	Statistic	0.088	0.374	0.999
	P-value	0.957	-	0.801
	Critical value (α= %5)	0.241	2.501	7.814

premium amount for weather-based index insurance plan was reported for coverage levels of 50, 70, and 100%.

The total premium amount that is determined by Agricultural Insurance Fund for apple, the so-called current insurance plan, from 2014-15 to 2016-17 is presented in Table 8 at 100 percent coverage level. As can be seen, the apple premium in the current plan of Agricultural Insurance Fund is administrative and circular, such that, during the crop years mentioned, it had a severe decreasing trend (Agricultural Insurance Fund, 2016).

According to the results in Tables 7 and 8, the computed premium in the weather based index insurance, (valued Thousand Rials 32,546.11) is less than the current plan in the crop year 2014-2015 in the 100 percent coverage level. Also, it is greater than the current plan in the crop years 2015-16 and 2016-17.

To pay indemnity, we must determine the weather variable that has the strongest dependency with yield at a special phenological stage of apple and, considering its effect on yield, we can pay for the damages. In fact, it needs an accurate examination in the field to determine the effect of weather variable on yield. This can be the subject of further research.

CONCLUSIONS

Current agricultural insurance lack a desirable efficiency due to problems such as adverse selection, moral hazard, and high transaction costs. Therefore, like other countries, this study designed a new tool, i.e. weather-based index insurance, for Damavand apple. For this purpose, we determined the dependency structure between yield and weather variables. In order to estimate the joint distribution function, *C-Vine* Copula was used, which has had high flexibility in recent years due to the possibility of modeling the high number of variables. According to the estimated *C-Vine* Copula for apple yield and weather variables as a joint distribution, the expected loss at the coverage level of 100 percent was obtained as 9.298 tons per hectare. This expected loss is similar to the Agricultural Insurance Fund report (2016) that says the expected loss of Damavand apple caused by adverse weather situation is about 30 percent of apple yield. In the crop year 2016-17, the weather-based index insurance premium was calculated as

Table 7. Computed premium amounts in weather-based index insurance plan for apple.

Coverage level	Critical values (ton hec^{-1})	Ave[max(yc-y),0]	Fair premium (Thousand Rials)
100	29.243	9.298	32546.11
70	20.470	3.344	11704.95
50	14.621	0.890	3118.467

Table 8. The total amount of premium in the current apple insurance plan.

Crop year	2014-2015	2015-2016	2016-2017
Current insurance premium amount (Thousand Rials)	39170	27700	13900

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Thousand Rials 32546.11, which is different from the current premium, like Aziznasiri *et al.* (2012) results. This difference is because of the distinct nature of the two insurance systems and the imperative and official mode of the current insurance system. In the current plan, premium is based on the cost of production, but in the weather-based index insurance plan, the premium is calculated based on the production or yield value; in addition, weather variables are not considered in the current apple insurance plan. According to Faraji and Mirdamadi (2006), Falsafian and Vaezi (2010), Fazelbeigi and Yavari (2010), and Ghelich (2016), the administrative and circular form of the current insurance is one of the most important reasons for farmers' disinclination to Agricultural Insurance.

Based on the results of this study, the policy makers in this field are provided with the following recommendations:

Since the apple premium is determined in the administrative and circular form in the current plan of Agricultural Insurance Fund and, sometimes, the indemnity amounts that are determined will change with the change of government and other effective factors and there is no special norm, it is recommended to use weather-based index insurance premium as an appropriate solution.

For the success of weather-based index insurance plan, it is necessary to evaluate the expected loss more accurately. Therefore, in the simulation of the joint distribution function, to the extent possible, all weather parameters affecting crop yield should be identified and considered, so that the calculated damages get close to the reality and the farmers show adequate inclination to participate in insurance plan.

Weather conditions in a region experience major changes over time and vary from one region to another, therefore, in order to reduce basis risk, it is recommended that these studies be repeated for a region, and homogeneous regions in terms of weather conditions be included in this plan.

If there is not sufficient weather station in the region and it leads to basis risk, according to Bokusheva (2010) and Pishbahar *et al*. (2015), it is better to put Pilot in each field and record daily weather data, yield growth rate, and their dependency to increase the accuracy of the expected loss estimation and to reduce the basis risk. The fields that are selected for this goal should have the highest level of efficiency and their loss is almost entirely caused by adverse weather conditions. Although the operation of this insurance system costs a lot initially, it has long-term benefits for the society. In addition, since this system has a transparent contract, it will increase the farmers' tendency to this insurance. Therefore, weather-based index insurance can provide a safe business environment for agricultural products and, by controlling the risk, it can increase the investment and production in agricultural sector and, consequently, can improve the marketing.

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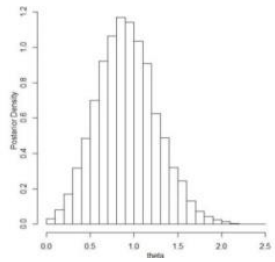
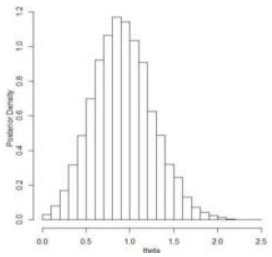
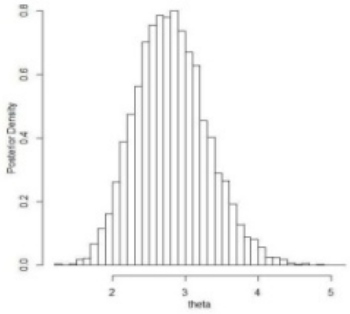


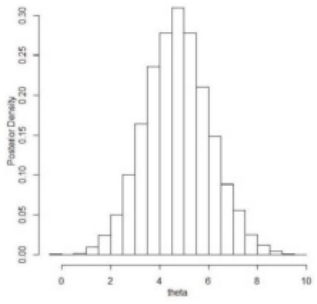
Clayton parameter ($P_{5,1}$)



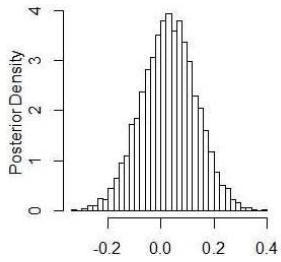
Gaussian parameter ($P_{5,2}$)



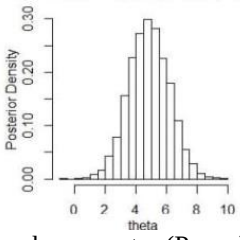
Joe -180 ° parameter ($P_{5,3}$)



Frank parameter ($P_{5,4}$)



Gaussian parameter ($P_{1,2|5}$)



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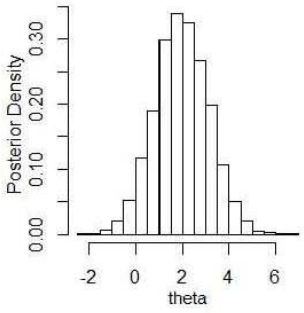

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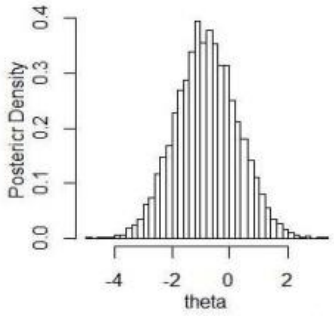
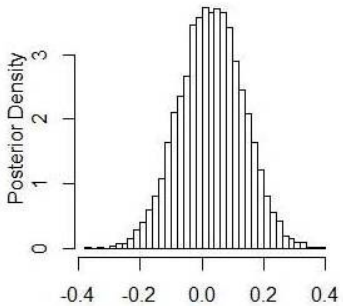


Frank parameter ($P_{2,3|5,1}$)



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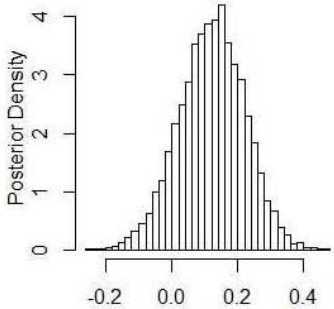

Gaussian parameter ($P_{3,4|5,1,2}$)

Appendix: Diagrams of posterior distribution of pair Copulas parameters in Bayesian approach

[DOR: 20.1001.1.16807073.2019.21.1.7.6]

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نرخ‌گذاری بیمه شاخص آب و هوایی- رهیافت تابع مفصل مویرگی کانونی

س. ترابی، ا. دوراندیش، م. دانشور، ع. کیانی راد، و ح. محمدی

چکیده

تولیدات باغی مانند تولید سیب، در معرض انواع ریسک‌های ناشی از شرایط نامساعد آب و هوایی قرار دارند. این نوع ریسک‌ها عنصری گریزناپذیر ولی قابل مدیریت هستند. بیمه کشاورزی از جمله برنامه‌های موثر در مدیریت ریسک آب و هوایی است. اما طرح‌های فعلی بیمه چالش‌هایی نظیر هزینه مبادله بالا و مسائل ناشی از اطلاعات نامتقارن یعنی انتخاب نامناسب و مخاطرات اخلاقی را دارند بنابراین مطالعه حاضر یک برنامه بیمه‌ای مناسب برای تولید سیب دماوند را ارائه می‌دهد که معروف به بیمه شاخص آب و هوایی است. در این راستا، اطلاعات مربوط به عملکرد سیب و متغیرهای آب و هوایی طی سال‌های۱۳۹۵-۱۳۶۶ از سازمان جهادکشاورزی و ایستگاه هواشناسی جمع‌آوری گردید. ساختار وابستگی بین متغیرهای عملکرد محصول سیب و متغیرهای آب و هوایی با استفاده از مفصل مویرگی کانونی به عنوان توزیع توام برای تعیین خسارت مورد انتظار بررسی شد. سپس با استفاده از خسارت مورد انتظار حق بیمه بیمه شاخص آب و هوایی اندازه‌گیری شد. مقدار حق بیمه در سال زراعی ۹۶-۱۳۹۵ برابر ۳۲۵۴۶/۱۱ هزار ریال به دست آمد، که از مقدار حق بیمه بیمه فعلی متفاوت است. این اختلاف به دلیل ماهیت متفاوت دو نوع بیمه و حالت دستوری و اداری بودن طرح فعلی بیمه است.

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