Economic Modelling 44 (2015) 80–85

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/ecmod

Risk paradigm and risk evaluation of farmers cooperatives' technology innovation

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ARTICLE INFO

Article history:
Accepted 14 October 2014
Available online 28 October 2014

Keywords:
Farmers cooperatives
Agricultural technology innovation
Risk paradigm
Risk evaluation

ABSTRACT

Technology innovation has become one of the most important factors for cooperatives to gain competitive advantage and to improve farmers' income. However, cooperatives must face huge risks of technology innovation. This paper discusses the risk paradigm of cooperatives' technology innovation from three dimensions of cooperatives' internal factors, technology factors and external environment factors. Then it determines the weight of each risk index with the integration of rough set and information entropy, and determines the risk coefficient with fuzzy comprehensive evaluation method. Lastly it conducts risk evaluation for a specific innovation project by numerical examples.

1. Introduction

China is keen to accelerate technology innovation and scientific research in agriculture, a move to boost the country's modern agricultural development. However, there are many obstacles in the implementation process of agricultural technology innovation, such as the technology gap between supply and demand, the slow diffusion of agricultural technology, and the uneven distribution of innovation income among farmers, customers and providers of agricultural resources. Therefore, there must be an organization standing for farmers' benefits to address the above issues. Farmers cooperatives play important roles in the agricultural technology innovation system.

In recent years, farmers cooperatives in China have developed very rapidly and become one of the key pillars in China's agricultural economy. Farmers cooperatives have been serving farmers with fertilizers, feeds, farm supplies, market information and agricultural technology, etc. Farmers cooperatives partly settle the docking problem between farmers' scattered small-scale production and large market, by offering many services such as the supply of agricultural materials, market information, agricultural technology, etc. However, cooperatives' participation in technology innovation has related risks and uncertainties which may result in innovation failure. Consequently, it is imperative to conduct careful risk evaluation to avoid pitfalls and attempt to identify successful alternatives. Such evaluations will support the healthy functioning of Chinese cooperatives and continuing development of agricultural technology innovation systems.

Many researchers have focused on the technology innovation risk in different fields. Gulcin et al. examined software development project risks and proposed an integrated multi-criteria evaluation methodology based on a two-additive Choquet integral for modeling various effects of importance and interactions among risks (Büyüközkan and Ruan, 2010). Hoecht and Trott investigated the innovation-related risks in strategic outsourcing and adopted a trust, collaboration and network-perspective for their analysis (Hoecht and Trott, 2006). Ghadim et al. studied risks in crop innovation and developed empirical models based on a theoretical framework which conceptualizes adoption as a dynamic decision process involving information acquisition and learning-by-doing by growers who vary in their managerial abilities, risk preferences, and their perceptions of the profitability and riskiness of the innovation (Ghadim et al., 2005). Borchers explored risk and decision uncertainty in management of wildfires, forest resource values, and new technology (Borchers, 2005).

Technology innovation risk is the possibility of technology innovation failure caused by technology uncertainty, market conditions, finance, policies, laws, etc. (Faith, 2003). Cooper (Cooper, 1999) outlines seven critical factors in product innovation as the new product development "Blockers" to avoid repeating the same mistakes. Wang (Wang and Fan, 2009) divided technology innovation risk into technology risk, market risk, organizing risk and environmental risk. Balachandra (Balachandra and Friar, 1997) proposed a contingency framework for the new product and R&D project models in which technology innovation risk includes market risk, technology risk, environment risk and organization risk. Li et al. divide the technology innovation risk of the Chinese oil and gas industry into technology risk, management risk and external risk. There are also several existing approaches for technology innovation risk evaluation, such as a method based on the mean square deviation and the expected lost sales, probabilistic methods (Dosi, 1982), a grey hierarchy evaluation model combining grey system theory and AHP method (Lixin and Fan, 2009).

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http://dx.doi.org/10.1016/j.econmod.2014.10.024
0264-9993/

Many researchers have been focusing on the risk paradigm and risk evaluation. However, cooperatives behave differently from profit-maximizing firms (Luo, 2013). There is a great difference in the income distribution, mode of employment and organization structure between cooperatives and traditional firms (Luo, 2012). Enterprise characteristic of cooperatives determines the uniqueness of risk management in technology innovation. Therefore, according to the features of cooperatives' technology innovation, we build a risk paradigm of cooperatives' technology innovation from three dimensions, namely, cooperatives' internal factor, technology factor and external environment factor. Then we develop a risk evaluation method to determine the risk degree. Such a method allocates weight coefficient of the risk factor indexes with rough set and information entropy, which overcomes the subjective factor of the traditional method in determining the weight.

2. Risk paradigm of farmers cooperatives' technology innovation

Despite the fact that farmers cooperatives participating in technology innovation can gain competitive advantage and improve farmers income, they will take huge risks. In order to build a risk paradigm of cooperatives' technology innovation, we investigate 106 sci-tech farmers cooperatives in Jiangsu province of China. The survey showed that the 106 sci-tech cooperatives take three factors of risk, namely, cooperatives' internal factor, technology factor and external environment factor (See Fig. 1).

2.1. Cooperatives' internal factor

Cooperatives' internal factor of risk refers to the risk factor arising from innovation project's activities within the cooperatives. As shown in Fig. 1, cooperatives' internal factor of risk includes capital risk, production risk, management risk and talents risk.

2.1.1. Capital risk

Farmers cooperatives must take more capital risk than traditional profit-maximizing firms. On one hand, in the early stage of development, because of irreversibility of investment and uncertainty of profit in participating in agricultural technology innovation, cooperatives take more risks in financing channels and financing costs for the lack of funds, which will affect the healthy capital operation. On the other hand, as a labor-managed firm, farmers cooperatives face difficulty in getting innovation fund from financing institution or venture capital firms for the adverse selection and moral risk. Financing institutions are unwilling to lend money to cooperatives because of unclearly defined property rights and little early capital accumulation within the cooperatives. The problem of adverse selection arises as financing institutions do not know the inherent riskiness of borrowers (Armendáriz and Morduch, 2010). Moral risk refers to a situation in which the cooperatives will try to use non-contractual behavior to impose cost on the capitalists as lenders after signing the loan contract. For instance, farmer cooperatives tend to invest high-risk innovation project with high-returns after getting risk fund. Therefore, farmers cooperatives will benefit from the success of high-risk innovation project and financing institutions must bear the failure.

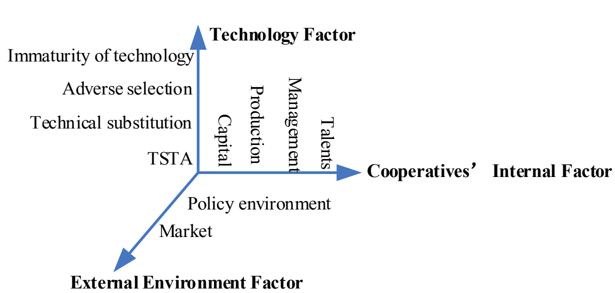

Fig. 1. Risk paradigm of cooperatives participating technology innovation.

2.1.2. Production risk

By technical training and standard production, farmers cooperatives can partly reduce production risk. However, cooperatives can hardly control each farmer's production process, since they still maintain separate production. Consequently, the innovative products probably can't meet the market demand in delivery time and qualification.

2.1.3. Management risk

Compared to profit-maximization firms, farmers cooperatives take more management risks for their organization system design and development in an early stage. On one hand, most cooperatives have not set up a special technical department to manage technology introduction, experiment and demonstration, and technology transfer. On the other hand, it is difficult for cooperatives to control the problems in the technical implementation and production because the internal members of cooperatives in the technical implementation and production maintain relative independence.

2.1.4. Talents risk

In China, farmers' cooperatives are short of scientific and technological talents in the early stage of development. Technical talents of most cooperatives come from colleges and universities, scientific institution, as the form of rural sci-tech special commissioner. Rural sci-tech commissioner might bring risk to cooperatives when they help cooperatives get involved in technology innovation. For instance, the commissioner may cause termination of the innovation projects when their original institutes require them to return. Moreover, external commissioner will increase risk of technology spillover.

2.2. Technology factor

Agricultural technology innovation is difficult and advanced with high technical barriers. Therefore, cooperatives will take more risks and uncertainty when participating in technology innovation. As shown in Fig. 1, technology factor of risk originates from the risk of technology immaturity, adverse selection, technology substitution and technology transform.

2.2.1. Risk of technology immaturity

Many agricultural projects contain unstable and immature technology, which impose the cooperatives with more risks. Immaturity of agricultural technology includes agricultural technology itself and the extent to which members of cooperatives grasp the agricultural technology. Consequently, agricultural technology implementation largely depends on the maturity of technology.

2.2.2. Risk of adverse selection

Cooperatives participating in agricultural technology innovation will be restricted by technique information, namely incomplete information and asymmetric information. Consequently, a moral hazard may occur since farmers cannot correctly estimate cost-benefit of new technologies. The adverse selection problem will occur when high-tech are replaced by low-tech. In China, most production technology farmers applied is conventional technique and the ratio of high-tech is too small. As a consequence, the inferiority of agricultural production is the restrictive factor on the development of rural innovation system. The inferiority of agricultural production also leads to the great similarity of agricultural production structure in different areas.

2.2.3. Risk of technology substitution

Due to the long production cycle, the process of agricultural technology innovation will continue for a longer period of time, from R&D, experiments and demonstration, technology extension to sales. When cooperatives developed a new technology, a more advanced technology may appear to replace the original technology in the process of technology transfer, even if the original technology is advanced at present. The risk of technology substitution will cause the cooperative unable to recover the cost of technology innovation.

2.2.4. Risk of technology transform

The industry-university-research collaborations have disconnection in agricultural technology innovation system. A new technology maybe perfect in theory and academy. However, if it cannot be commercialized, technology innovation will also be a failure. Farmers cooperatives will suffer vast losses from the failure of technology transform, though the rate of technology transform has been improved when farmers cooperatives are participating in technology innovation.

2.3. External environment factor

2.3.1. Market risk

Market risk is brought by the uncertainty of the market size and scale, customers' demand, competitive advantage of new products, the time of market acceptance, the product life, market development and so on. In the technology innovation process, the risks from technology development, experiments and demonstration, to technology extension, will defer and erupt in the phase of market. The seasonality and vulnerability (or perishability) of agricultural products will cause the problem of asset specificity, and the hold-up problem in transaction, which increase the market risk.

2.3.2. Policy risk

Policy risk refers to the probability of innovation failure resulting from the adverse effect of the change of the internal and external circumstance (political, economic and technological circumstance) on innovative programs, including the policies failing to meet the national industrial policy, the change of domestic macro-economy (Day et al., 2004), and the limits on intellectual property protection. For instance, the changes in the quality of the pesticide residues of vegetables or the hormone levels of the animal feed will cause the innovation technology of cooperatives being eliminated. Currently, the cooperatives depend on the federal policy support in technology innovation. Therefore, the changes of the federal policy will exercise a great influence on the cooperatives' technology innovation.

3. Risk evaluation of cooperatives' technology innovation

This study mainly focuses on the evaluation phase of the technology innovation risk management process. The technology innovation risk management process is the process of assessing the impact and likelihood of identified risks. As the risks of technology innovation are multidimensional, they should be evaluated in accordance with more than one criterion to get more accurate and reliable results. In most of the risk evaluation methods, the weight of the risk factor is determined by subjective experience with subjectivity and ambiguity. However, we apply the method combining rough set with information entropy to determine the weight of risk factor, and use fuzzy comprehensive evaluation method to measure the overall risk of cooperatives' technology innovation, which makes the evaluation more objective, scientific and practical.

Based on the risk paradigm of cooperatives' technology innovation analyzed above, we have established evaluation index system (see Table 1), including weights symbols of risk evaluation index (see Table 2).

Table 1
Risk evaluation index system of cooperatives' technology innovation.

The first-grade index	The second-grade index
Technology factor C_1	Immaturity of technology C_{11}
	Adverse selection C_{12}
	Technology substitution C_{13}
	Technology transform C_{14}
Internal factor C_2	Capital risk C_{21}
	Production risk C_{22}
	Management risk C_{23}
	Talents risk C_{24}
External environment factor C_3	Policy risk C_{31}
	Market risk C_{32}

3.1. Weight determination of the risk index

In the risk evaluation, the weight of the indexes may affect the accuracy and the validity of the results directly. Therefore, the determination of the weight of indexes is a key point and also a difficult point in risk valuation. There are methods, the subjective judgment method and the objective analytic method. The subjective judgment method is based on the experts' judgment and marking. The drawback of this method is the calculated result depending more on the subjective factors. However, the objective analytic method is to carry on analysis of the objective information contained by the statistical data, including analytic hierarchy process, similarity evaluation, principal component analysis, superiority chart and conjoint analysis. Among the objective analytic methods, rough set theory doesn't need the priori knowledge of data such as probability distribution in statistics, which can process inexact, incomplete or vague knowledge in the real world data. However, rough set theory considers that the weight of redundant attributes equals to 0. Conversely, information entropy theory will make the weight of redundant attributes greater than the original value. To overcome the positive or negative deviation of the weight of the attributes, we design a method integrating rough set and information entropy to determine the index's weight of risk factors.

3.1.1. Weight determination based on rough set

Rough set theory was developed by Pawlak in the early 1980's. It is a mathematical tool for approximate reasoning in decision support. Rough set theory is particularly well suited for feature selection, feature extraction etc.

An information system (attribute-value table) is defined as a pair (U, A), where U is a non-empty finite set of finite objects, $A = C \cup D$ is a non-empty finite set of attributes, C denotes as the set of condition attributes and D denotes as the set of decision attributes, $C \cup D \neq \emptyset$. There are attributes in the information system which are more important to the knowledge represented in the equivalence class structure than other attributes. There is a subset of attributes which can, by itself, fully characterize the knowledge in the database. Such an attribute set is called a reduct.

U/D represents the classification of U according to the decision attributes D, namely $U/D = \{(U_i, \ldots, U_j), \ldots, (U_k, \ldots, U_l)\}$, $i, j, k, l = 1, 2, \ldots, n$, and $i \neq j \neq k \neq l$. Similarly, U/C represents the classification of U according to the decision attributes C. And the importance of attributes C can be expressed as

$$r_C(D) = \text{card}\,(\text{pos}_C(D))/\text{card}\,(U). \tag{1}$$

If an attribute C_i is removed, and the important rating of attributes $(C\text{-}C_i)$ is defined as:

$$r_{(C-Ci)}(D) = \text{card}\left(\text{pos}_{(C-Ci)}(D)\right)/\text{card}\,(U) \tag{2}$$

Table 2
The first-grade index and weights symbols.

Item number	C_1	C_2	C_3	Decision attributes D
U_1	V_{11}	V_{12}	V_{13}	d_1
…	…	…	…	…
U_n	V_{n1}	V_{n2}	V_{n3}	d_n

wherein $\mathrm{card}(\mathrm{pos}_C(D))$ represents cardinality of the set $\mathrm{pos}_C(D)$. The importance of C_i according to D can be expressed as

$$k_i = r_C(D) - r_{(C-Ci)}(D) \tag{3}$$

k_i can be normalized as

$$w_i = k_i \Big/ \sum_{i=1}^{n} k_i. \tag{4}$$

3.1.2. Weight determination based on information entropy

Suppose C and D are the condition attribute set and decision attribute set respectively. $X = U / \mathrm{IND}(C) = \{X1, X2, \ldots, Xn\}$ and $Y = U / \mathrm{IND}(D) = \{Y1, Y2, \ldots, Ym\}$ represent the division of U exported by the equivalence relation $\mathrm{IND}(C)$ and $\mathrm{IND}(D)$ respectively. Therefore, $(p(X_1), p(X_2), \ldots, p(X_n))$ and $(p(Y_1), p(Y_2), \ldots, p(Y_m))$ represent the finite probability distribution of C in X and D in Y respectively. Consequently, the information entropy of attribute set C is

$$H(C) = -\sum_{i=1}^{n} p(X_i) \ln p(X_i). \tag{5}$$

The entropy of attribute set D conditioned on attribute set C is

$$H(D|C) = \sum_{i=1}^{n} p(X_i) H(Y|X_i) \tag{6}$$

where

$$H(Y|X_i) = -\sum_{j=1}^{m} p\left(Y_j|X_i\right) \ln p\left(Y_j|X_i\right),\ p\left(Y_j|X_i\right) = \left|Y_j \cap X_i\right| / |X_i|. \tag{7}$$

The mutual information of C_i and D can be defined as $I(C_i, D) = H(D) - H(D|C_i)$.

Consequently, the weight of condition attribute C_i based on information entroy can be defined as:

$$\beta_i = \frac{I(C_i, D)}{\sum_j I\left(C_j, D\right)}. \tag{8}$$

3.2. Fuzzy comprehensive evaluation in project risk

Fuzzy comprehensive evaluation adopts the principle of fuzzy relationship synthesis, comprehensively judges the membership grade status of the things to be judged from many factors. Because the issue of fuzzy factors, one of the characteristics of human thinking which regards evaluation objectives as a fuzzy set (named the factor set U) composed of a variety of factors with different evaluation levels is considered because of the issue of fuzzy factors. Another fuzzy set named the evaluation set V is employed to calculate the membership degree of each individual factor in the evaluation set to establish a fuzzy matrix. The quantitative evaluation value of each factor is finally determined by calculating the weight distribution of each factor in the evaluation goal. Fuzzy comprehensive evaluation model involves four elements, namely factor set C, evaluation set V, fuzzy relationship matrix R_i and weight distribution vector W. Fuzzy comprehensive evaluation method includes four steps.

I Establish the comprehensive evaluation factor set. The factor set of technology innovation is an ordinary set, which is composed of the elements of various factors, usually expressed by C, that is $C = \{C_1, C_2, \ldots, C_m\}$. Where the element C_i ($i = 1, 2, \ldots, m$) represents the i-factor affecting evaluation project. These factors usually have different degrees of fuzziness. In the risk evaluation of cooperatives' technology innovation project, as mentioned above, the factor set $C = \{C_1, C_2, C_3\}$ = {Technology Factor, Internal Factor, External Environment Factor}, where $C_1 = \{C_{11}, C_{12}, C_{13}, C_{14}\}$ = {Immaturity of Technology, Adverse Selection, Technology Substitution, Technology Transform}, $C_2 = \{C_{21}, C_{22}, C_{23}, C_{24}\}$ = {Capital Risk, Production Risk, Management Risk, Talents Risk}, and $C_3 = \{C_{31}, C_{32}\}$ = {Policy Risk, Market Risk}.

II Set up evaluation set V. The evaluation set $V = \{v_1, v_2, \ldots, v_n\}$ is a set composed of n kinds of evaluation standards by the judgment results of evaluation objects. Where v_i stands for several possible judgment results, and v_i may be expressed by grades, comments or numerals according to the actual situation needs. For the technology innovation project, the risk is divided into five grades, namely $V_i = \{1, 2, 3, 4, 5\}$ = {low risk, lower risk, medium risk, higher risk, high risk}.

III Carry on fuzzy evaluation for single factor and then obtain the evaluation matrix R. R is a fuzzy relationship matrix composed of evaluation factor set C and the evaluation set V, which is composed of m single factors evaluation vector R_i, namely $R = (R_1, R_2, \ldots, R_m)$. $R_i = (r_{i1}, r_{i2}, \ldots, r_{in})$, where $r_{ij} = u_R(C_i, \nu_j)$ $(0 \le r_{ij} \le 1)$ represents the degree of membership on C_i to ν_j, namely the degree of C_i belonging to ν_j.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}. \tag{9}$$

IV Set up a comprehensive evaluation model. The weight vector W of evaluation factors is determined by the method combined by rough set and information entropy, namely $W = (w_1, w_2, \ldots w_m)$. The results of comprehensive evaluation can be obtained by doing complex operations calculation between factor weight vector W and fuzzy relationship matrix R, which is $B = W \cdot R$.

The method of fuzzy comprehensive evaluation can make a more scientific and pragmatic quantitative evaluation by accurate mathematical treatment for the fuzzy evaluation objects. Moreover, the evaluation result is present with the vector, but not the point value. The vector includes a wealth of information, which can not only provide a precise analysis, but also offer reference information by further treatment of the information. However, the method of fuzzy comprehensive evaluation has some shortcomings yet. When there are too many influencing factors in factor set, the weight of relative membership degree is smaller than normal since the sum of the weight is 1. The evaluation result may be fuzzier for mismatching between the weight vector W and the evaluation matrix R, which will lead to an error evaluation.

4. Numerical example

Suppose one farmers cooperative will implement eight alternative technology innovation projects, the scores in items of every project have been labeled in Table 3.

Table 3
The first-grade of index of the risk factors and their scores.

	Technology factor C_1	Internal factor C_2	External factor C_3	Decision attribute D
1	3	4	4	1
2	5	4	4	2
3	5	5	5	2
4	4	4	4	1
5	4	5	4	2
6	4	3	4	1
7	5	5	3	2
8	5	5	4	1

Remark: $V_i = \{1, 2, 3, 4, 5\}$ = {low risk, lower risk, medium risk, higher risk, high risk}. Decision attribute set $D = \{1, 2\}$ = {Affordable, unaffordable}.

4.1. Determine the index weight of risk

4.1.1. Weight determination based on rough set

From Table 3, the indiscernibility relation IND (D) divides U into $U / D = \{(1, 4, 6, 8), (2, 3, 5, 7)\}$. The partition for U divided by condition attributes $C = \{C_1, C_2, C_3\}$ is $U / C = \{1, 2, 3, 4, 5, 6, 7, 8\}$.

Respectively, the weights of C_1, C_2, C_3 are

$$\begin{aligned} d_1 &= d_{(C-C1)}(\mathrm{D}) = 1-r_{(C-C1)}(\mathrm{D}) / r_C(\mathrm{D}) \\ &= 1-\frac{card(POS_{(C-C_1)}(D)/card(U)}{card(POS_C(D)/card(U)} = 1-3/8 = 5/8. \\ d_2 &= d_{(C-C2)}(\mathrm{D}) = 1-r_{(C-C2)}(\mathrm{D}) / r_C(\mathrm{D}) = 1/2; \\ d_3 &= d_{(C-C2)}(\mathrm{D}) = 1-r_{(C-C3)}(\mathrm{D}) / r_C(\mathrm{D}) = 1/2. \end{aligned}$$

After normalizing, $\alpha_1 = 5/13, \alpha_2 = 4/13, \alpha_3 = 4/13$.

4.1.2. Weight calculation method based on information entropy

The partition for U divided by condition attributes D is $Y = U / D = \{(1, 4, 6, 8), (2, 3, 5, 7)\}$. And the information entropy of D is

$$\begin{aligned} H(D) &= -[p(Y_1) \cdot \ln p(Y_1) + p(Y_2) \cdot \ln p(Y_1)] \\ &= -(4/8 \cdot \ln 4/8 + 4/8 \cdot \ln 4/8) = 1. \end{aligned}$$

The partition for U divided by condition attributes C_1 is $U / \{C_1\} = \{1, (2,3,7,8), (4,5,6)\}$. Consequently, the conditional entropy of D given C_1 is defined as

$$\begin{aligned} H(D|C_1) &= -\left[\frac{1}{8}\cdot 0+\frac{4}{8}\left(\frac{1}{4}\cdot \ln\frac{1}{4}+\frac{3}{4}\cdot \ln\frac{3}{4}\right)+\frac{3}{8}\left(\frac{2}{3}\cdot \ln\frac{2}{3}+\frac{1}{3}\cdot \ln\frac{1}{3}\right)\right] \\ &= \frac{3}{4}\ln 2 = 0.52. \end{aligned}$$

Similarly,

$$H(D|C_2) = 0.52, H(D|C_3) = 0.477.$$

The mutual information of C_1 and D can be defined as $I\,(C_1, D) = H\,(D) - H\,(D|\{C_1\}) = 1 - 0.52 = 0.48$. $I(C_2, D) = H\,(D) - H\,(D|C_2) = 1 - 0.52 = 0.48$; $I\,(C_3, D) = H(D) - H(D|C_3) = 1 - 0.477 = 0.523$.

Respectively, the weights of C_1, C_2, C_3 can be defined as $\beta_1, \beta_2, \beta_3$, as follows.

$$\begin{aligned} \beta_1 &= I(C_1,D) / [I(C_1,D) + I(C_2,D) + I(C_3,D)] = 0.48/1.483 \\ &= 0.324 \end{aligned}$$

$$\beta_2 = 0.324, \beta_3 = 0.353$$

4.1.3. Determine the factors' weight with combined methods

Suppose $\alpha = (\alpha_1, \alpha_2, \alpha_3)$ and $\beta = (\beta_1, \beta_2, \beta_3)$ are the factors' weights derived from rough set and information entropy. Given $\varepsilon = 0.7$, then the comprehensive weight of the first index (C_1, C_2, C_3) can be defined as

$$w = (w_1, w_2, w_3) = 0.7\alpha + 0.3\beta = (0.3664,\ 0.3126,\ 0.3213).$$

Similarly, we obtain attributes' weights of the second index (See Table 4).

4.2. Fuzzy comprehensive evaluation

Suppose evaluation set $V = \{V_1, V_2, V_3, V_4, V_5\} = \{1, 2, 3, 4, 5\} = \{$low risk, lower risk, medium risk, higher risk, high risk$\}$. For a project of agricultural technology innovation, the fuzzy evaluation of risk factors in cooperatives' technology innovation can be obtained in Table 5. For instance, with regard to the second-grade index C_{11}, its single factor evaluation vector is gained by the expert scoring $C_{11} = (0, 0, 0.2, 0.3, 0.5)$. It means that 50% of the experts regard the project as high risk, 30% as higher risk, and 20% as medium risk.

Table 4
The weights of risk factors.

First-grade index	Weight	Second-grade index	Weight
C_1	0.3664	C_{11}	3/10
		C_{12}	2/5
		C_{13}	1/10
		C_{14}	1/5
C_2	0.3126	C_{21}	3/8
		C_{22}	1/8
		C_{23}	1/8
		C_{24}	3/8
C_3	0.3213	C_{31}	2/5
		C_{32}	3/5

Using the single-factor evaluation matrix of the second-grade index. We can obtain the single-factor evaluation matrix R_1 of the first-grade index C_1 as the following.

$$\begin{aligned} R_1 = (w_{11}, w_{12}, w_{13}, w_{14})r_1 &= \left(\frac{3}{10},\frac{2}{5},\frac{1}{10},\frac{1}{5}\right)\begin{bmatrix} 0 & 0 & 0.2 & 0.3 & 0.5 \\ 0.8 & 0.1 & 0.1 & 0 & 0 \\ 0 & 0.2 & 0.7 & 0.1 & 0 \\ 0.2 & 0.6 & 0.2 & 0 & 0 \end{bmatrix} \\ &= \left(\frac{9}{25},\frac{9}{50},\frac{21}{100},\frac{1}{10},\frac{3}{20}\right) \end{aligned}$$

Similarly, the single-factor evaluation matrix R_2 (or R_3) of the first-grade index C_2 (or C_3) can be obtained as the following.

$$R_2 = (w_{21}, w_{22}, w_{23}, w_{24})r_2 = \left(\frac{3}{40},\frac{19}{40},\frac{11}{40},\frac{7}{80},\frac{7}{80}\right)$$

$$R_3 = (w_{31}, w_{32})r_3 = \left(\frac{3}{50},\frac{8}{50},\frac{31}{50},\frac{5}{50},\frac{3}{50}\right)$$

Consequently, we can get the comprehensive evaluation result of B from the factor set $C = \{C_1, C_2, C_3\}$ as the following.

$$B = WR = (w_1, w_2, w_3)(R_1, R_2, R_3)^T = (0.175, 0.266, 0.362, 0.096, 0.102)$$

According to the maximum membership degree principle, 0.362 is the biggest size of membership degree which is corresponding to the medium danger class.

5. Conclusions

Agriculture is undergoing a technology revolution as evidenced by the processes of industrialization, product differentiation, and increased vertical integration in agriculture. Risk paradigm and risk evaluation of technology innovation as described in this paper, have been developed in the empirical setting of a limited number of projects and cooperatives. It becomes clear that the method is so far perceived as being a

Table 5
Fuzzy evaluation of risk factors.

Factors	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}
V_1	0	0.8	0	0.2	0.1	0	0	0.1	0	0.1
V_2	0	0.1	0.2	0.6	0.8	0	0.2	0.4	0.1	0.2
V_3	0.2	0.1	0.7	0.2	0.1	0.1	0.6	0.4	0.8	0.5
V_4	0.3	0	0.1	0	0	0.2	0.2	0.1	0.1	0.1
V_5	0.5	0	0	0	0	0.7	0	0	0	0.1

valuable tool to detect the key risks in cooperatives' technology innovation through a numerical example with risk paradigm and risk evaluation. Our researches have great theoretical significance in identifying and evaluating risks for farmer cooperatives participating in technology innovation. Moreover, the researches on the risk paradigm and the risk evaluation have great practical significance for farmers cooperatives to select technology innovation projectors, and reduce risks of technology innovation.

Firstly, the risk paradigm has been developed for the risk index of cooperatives participating in technology innovation. Considering the income distribution, mode of employment and organization structure of cooperatives, we have built a risk paradigm of cooperatives' technology innovation from three dimensions, namely, cooperatives' internal factor, technology factor and external environment factor. Compared to traditional profit-maximizing firms, our research shows that farmer cooperatives will take more risks in agricultural technology innovation.

Secondly, the risk evaluation method has been built to determine the risk of cooperatives participating in technology innovation. Our risk evaluation method determines the weight of each risk index with integration of rough set and information entropy, rather than traditional qualitative approach, to reduce the influence of the subjective factor in the certain degree. Moreover, this method overcomes the shortcoming of the single quantitative approach. Our risk evaluation method determines the risk coefficient with fuzzy comprehensive evaluation method. The fuzzy comprehensive evaluation method can reflect the fuzziness of evaluation factors and evaluation process, quantify various risk factors, and reduce the defects caused by individual subjective judgment, making the risk evaluation of cooperatives' technology innovation more scientific and reasonable.

Acknowledgments

We acknowledge the National Natural Science Foundation of China under Grant 71203161, the China Postdoctoral Science Foundation under Grant 2013 M530287, the Zhejiang Postdoctoral Science Foundation under Grant BSH1302095, and the Humanity and Social Science Youth foundation of Ministry of Education of China under Grant 11YJCZH121.

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