Incentive Mechanism of Innovation Failure Knowledge Sharing of Virtual Research Organization

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JDIM
Journal of Digital Information Management

ABSTRACT: Purpose
Innovation failure knowledge sharing plays an important role in reducing the probability of repeated failure of subsequent innovation and improving innovation ability of virtual research organization. However, it is very difficult for members to actively share the innovation failure knowledge without incentives. This study aims to establish the incentive mechanism of innovation failure knowledge sharing, and promote the sharing behavior of innovation failure knowledge in virtual research organization.

Design/methodology/approach
By using game theory, considering the risk aversion degree of organization members and the negative effect of innovation fault-tolerance environment, the incentive model of innovation failure knowledge sharing of virtual research organization was constructed, and the incentive relationship of innovation failure knowledge sharing between organization and its members under the influence of different states was analyzed.

Findings
Without considering the negative effect of innovation fault-tolerant environment, the optimal incentive coefficient of innovation failure knowledge sharing is positively related to the sharing rate of innovation failure knowledge and the transformation ability of innovation failure knowledge of organization members, and negatively related to the sharing cost and risk aversion degree of organization members. Considering the negative effect of innovation fault-tolerant environment, virtual research organization should make a corresponding modification of sharing incentive intensity according to the estimation of tolerance degree to innovation fault-tolerant environment by itself and its members, so as to reduce the knowledge input of organization.

Originality/value
This study proposes an incentive mechanism of innovation failure knowledge sharing considering the negative effect of innovation fault-tolerant environment, which provides a novel idea and method for the design of incentive mechanism of innovation failure knowledge sharing in virtual research organization.

Subject Categories and Descriptors:
[I.2.4 Knowledge Representation Formalisms and Methods]: [I.2.6 Learning]: Knowledge acquisition; **[H.5.3 Group and Organization Interfaces]**

General Terms: Research Organizations, Knowledge Transfer, Innovation

Keywords: Virtual Research Organization, Innovation Failure Knowledge, Knowledge Sharing, Incentive Mechanism

Received: 13 January 2020, Revised 29 May 2020, Accepted 20 June 2020

Review Metrics: Review Scale: 0/6, Review Score: 4.95, Inter-reviewer consistency: 81%

DOI: 10.6025/jdim/2020/18/5-6/184-194

1. Introduction

In the era of knowledge economy, innovation subjects can effectively improve their innovation ability through knowledge sharing in the process of innovation. However, the process of knowledge sharing is affected by

many factors such as knowledge-sharing subject and object, knowledge-sharing environment and knowledge-sharing medium (Ghobadi, 2015), which makes knowledge sharing become one of the problems faced by knowledge management of innovative organizations. Especially in the increasingly fierce and complex competitive environment, more and more innovation subjects strengthen their agility of market opportunity response, core competence of enterprises and speed of collaborative innovation through the organizational form of alliance network (Dickson and Weaver, 2011), which further increases the difficulty of knowledge sharing among innovation subjects. The virtual research organization, which represents the development trend of innovative organization in the future, also faces the uncertainty, dispersion and complexity of internal knowledge, which makes the knowledge sharing of virtual research organization difficult.

Virtual research organization is a cooperative R & D organization established by multiple independent R & D subjects centering on the common goal, using highly developed modern information, communication and transportation technology, breaking the time and regional restrictions, and realizing the complementarity and sharing of resources such as equipment, capital, technology and talents under the network innovation paradigm characterized by the integration of technological resources and organizations (Dai and Hu, 2011). Theory and practice found that through the integration and sharing of knowledge resources among member enterprises, virtual research organization improved the efficiency of R&D resources utilization and knowledge value efficiency (Davenport and Daellenbach, 2011), became the endogenous factor of its innovation ability improvement, and was the foundation of sustainable innovation of virtual research organization. However, due to an anti-failure bias (McGrath, 1999), failed innovation has not attracted widespread attention in traditional innovation research and practice. In particular, knowledge resources contained in innovation failure have not become the focus of knowledge sharing in virtual research organization. In the process of innovation, failure events are inevitable and objective. By analyzing and identifying failure events, learning from failure experience can acquire more knowledge than learning from success experience (Desai, 2015). It can be seen that failure knowledge is an important resource in organizational learning, which can help enterprises reduce the probability of repeated failure and further improve enterprise performance (Shepherd, 2003). Therefore, within the virtual research organization, the knowledge sharing of innovation failure among different members plays an important role in the collaborative development of members and the improvement of innovation ability of the organization.

However, because the knowledge of innovation failure is the learning and transformation of members' previous experience of innovation failure, the differences in learning ability and knowledge transformation ability of mem bers may lead to the difficulty in expressing the knowledge of innovation failure and the high cost of transformation and sharing (Wang, 2017). In addition, under the influence of anti-failure bias, the knowledge sharing of innovation failure by organization members will also cause organizations and other members to question their innovation ability, and thus receive different treatment in the position and resource allocation of virtual research organization (Xiong *et al.*, 2019).

2. Literature Review

B Theorists and practitioners are increasingly aware of the important resources contained in innovation failure events. The innovation organization can reduce the probability of similar failure in the future and improve the organization's innovation performance by exploring and learning the failure experience and adjusting the way of behavior in subsequent innovation. Carmeli and Dothan (2017) found that moderate failure can stimulate enterprises to find solutions to problems. According to the findings of Deichmann and Ende (2013) and Yu and Pu (2018), learning from failure can transfer knowledge and generate new knowledge, which has a positive effect on innovation performance. It is not hard to see that failure knowledge refers to some potential knowledge and skills to improve organizational performance acquired by innovative organizations in the exploration and learning from failure experience. It is learned from three parts: failure identification, failure analysis and failure handling (Cannon and Edmondson, 2001). Amankwah Amoah *et al.* (2018) believed that the accumulation of failure resources by innovation organizations can improve and enrich the skills and knowledge extremely useful for subsequent innovation activities. Kim and Miner (2007) found that in order to adapt to the changes and innovation of the external environment. Failure knowledge plays an important role. In innovation research, everyone prefers to learn from successful enterprises, thus neglecting the experience learning and knowledge transformation of failure (Chen *et al.* 2017). But when enterprises absorb new knowledge and expect future outcomes, Lin *et al.* (2019) believed that learning from failure is as important and effective as learning from success. Rhaiem and Amara (2019) also pointed out that failure learning is an important help for innovation organizations to cope with current and future crises. Especially with the increasing intensity of market competition, it is difficult for enterprises to maintain their own sustainable competitive advantage by independently carrying out innovation activities. By using dynamic organizational forms such as virtual research organization and supply chain alliance, resource sharing among innovative enterprises can be realized, and then knowledge collaborative innovation of enterprises can be promoted (Connell *et al.*, 2014). Compared with the knowledge innovation of a single enterprise, knowledge innovation between enterprises connected in the form of dynamic organization can provide more and more valuable knowledge resources.

However, due to the non-coding and complexity of knowledge and many inherent obstacles in the process of knowledge sharing (Razmerita *et al.*, 2016), the phenomenon of active knowledge sharing by member enterprises without incentives seldom occurs. In addition, knowledge itself is difficult to measure its external characteristics (Ma and Chan, 2014), which makes it difficult to accurately monitor the level of knowledge sharing efforts. Member enterprises are prone to free riding in knowledge sharing activities, which affect the overall operational efficiency of the organization and undermine the coordination of the organization (Yu, 2018). Therefore, how to design incentive mechanism to promote knowledge sharing of member enterprises under the condition of asymmetric information has attracted attention. At present, scholars have carried out extensive research on knowledge sharing incentive. Siemsen *et al.* (2007) believed that incentive can increase knowledge sharing behavior of teams. Zhang and Zhang (2014) pointed out that material incentives can promote knowledge sharing. Choi *et al.* (2008) believed that salary incentive can promote knowledge sharing more than technical support. Xie and Liu (2014) constructed and tested the theoretical framework of knowledge sharing incentive mechanism based on multi theory and multi factor perspective by integrating economic, social and psychological theories. Nan (2008) classified knowledge according to its intangibility, and constructed an incentive model for sharing different types of knowledge under the condition of asymmetric information. Yang and Liu (2012) used principal-agent theory to explore the incentive problem of invisible knowledge sharing of enterprises, and pointed out that the level of invisible knowledge sharing efforts of enterprises can achieve Pareto optimality under symmetric information, but not under asymmetric information. Wang and Shao (2012) considered the complementarity of knowledge, and designed incentive contracts of agent risk neutral and risk averse under the framework of principal-agent theory. Liu *et al.* (2015) proposed a knowledge sharing incentive model of e-commerce service supply chain from the perspective of knowledge complementarity and knowledge integration ability.

Through the review of the above literature, it can be found that the failure knowledge management has attracted attention, and the incentive mechanism of knowledge sharing among member enterprises in different forms of alliance organization has been discussed in detail, and some research findings have been achieved. But research on the incentive mechanism of knowledge sharing for innovation failure of virtual research organization is not in-depth. In the context of innovation failure, innovation fault tolerance environment may be an important factor that affects knowledge sharing of innovation failure (Zhang, 2019). The incentive mechanism based on principal-agent theory often ignores the negative effect of innovation fault-tolerant environment, and the incentive mechanism of knowledge sharing of innovation failure of virtual research organization may have its own uniqueness. Therefore, virtual research organization is took as the research object, the incentive model of innovation failure knowledge sharing is constructed, and the incentive mechanism forms under the situation of negative utility influence and no influence of fault-tolerant environment are compared, so as to provide theoretical reference for the design of incentive mechanism of knowledge sharing of innovation failure of virtual research organization.

3. Modelling

Learning and sharing knowledge of innovation failure can effectively improve the innovation ability of virtual research organization. The quantity and quality of knowledge sharing of innovation failure depend on each member's ability of knowledge transformation, the willingness of knowledge sharing, and the incentive level of knowledge sharing of innovation failure in virtual research organization. Thus, a game relationship about knowledge sharing of innovation failure is formed between virtual research organization and its members. Further, it is assumed that a member of virtual research organization has failed innovation. Its innovation failure knowledge transformation ability level is x, the effort level of knowledge sharing of innovation failure is Δe, the knowledge sharing cost of innovation failure is $C(\Delta e)$, and the knowledge sharing benefit of innovation failure among members of the organization to virtual research organization is $R(\Delta e, x)$. To encourage members to share the knowledge of innovation failure, virtual research organization will reward the members of innovation failure knowledge sharing by incentive fee S. At this time, the game strategies of knowledge sharing of innovation failure between virtual research organization and its members are: virtual research organization = {incentive, no incentive}, organization member = {sharing, no sharing}. It can be seen that the income matrix of the game relationship between the virtual research organization and its members is shown in Table 1.

Virtual research organization	**Organization member**	
	Sharing	**No sharing**
Incentive	$R(\Delta e, x) - S$, $S - C(\Delta e)$	$-S$, S
No incentive	$R(\Delta e, x)$, $-C(\Delta e)$	0, 0

Source: Created by the authors.

Table 1. The income matrix of the game relationship

From the results in Table 1, it can be seen that the optimal strategy of virtual research organization is not to encourage the failure knowledge sharing behavior of its members, while the optimal strategy of its members is not to share the failure knowledge. The implementation of the above-mentioned game strategies often leads to the problem of adverse selection between virtual research organization and members, weakens the communication and information sharing among members of virtual

research organization, to a certain extent, affects the flow of failure knowledge among members, and reduces the overall innovation output and innovation ability improvement of virtual research organization. Therefore, virtual research organization needs effective incentive mechanism to promote the failure knowledge sharing among organization members. Through learning of innovation failure knowledge by organization members, the innovation ability of virtual research organization can be improved and the probability of innovation failure can be reduced.

Further, when a member of virtual research organization has a certain amount of innovation failure knowledge, but because the innovation failure knowledge is the transformation of previous failure experience, there is a certain degree of private ownership of innovation failure knowledge for members, and organization members do not share all the knowledge of innovation failure, q $(0 \leq q \leq 1)$ is the shareable rate of innovation failure knowledge of organization members. The higher the shareable rate q is, the more innovation failure knowledge that organization member can share, the easier it is to share. Innovation failure knowledge stock $K(x)$ owned by organization members is a function of their own innovation failure knowledge transformation ability x. According to the expression of Cobb-Douglas production function, the growth mode of innovation failure knowledge stock of virtual research organization members is as follows:

$$K = xM^a \tag{1}$$

Where, K is the innovation failure knowledge stock of virtual research organization members. M is the loss of innovation failure of organization members. a is the output elasticity coefficient of innovation failure knowledge. In addition, b $(0 \leq b \leq 1)$ is the sharing cost coefficient of innovation failure knowledge of organization members. $S(R)$ is the optimal incentive contract that virtual research organization gives to its members, and R is the benefit that failure knowledge sharing brings to virtual research organization. Specifically, the income function $R(\Delta e, x)$ of failure knowledge sharing is a linear function of the sharing effort level Δe and the transformation ability of failure knowledge x, namely:

$$R(\Delta e, x, \varepsilon) = q(xM^a)\,\Delta e + \varepsilon \tag{2}$$

Where, ε is an exogenous random variable, and $\varepsilon \square N(\mu, \sigma^2)$.

The sharing cost function of innovation failure knowledge of organization members is as follows:

$$C(\Delta e) = b\Delta e^2/2 \tag{3}$$

It is assumed that the optimal incentive contract of virtual research organization includes two parts: one is the basic income of organization members; the other is the incentive income of organization members, which is related to the sharing income of innovation failure knowledge of virtual research organization. β is the sharing incentive coefficient of innovation failure knowledge. Therefore, the optimal incentive contract $S(R)$ given to organization members by virtual research organization can be expressed as:

$$S(R) = \alpha + \beta R\,(\Delta e, x, \varepsilon) \tag{4}$$

In addition, according to the findings of Xiong *et al.* (2019), the previous failure experience of innovation subjects often has a negative impact on their subsequent innovation decisions, which makes innovation failure subjects excessively enlarge the risk perception of re-innovation. Therefore, in the context of innovation failure knowledge sharing among members of virtual research organization, it is further assumed that organization members are risk averse, and its utility function is expressed as follows:

$$U(W_A) = -e^{-\rho W_A} \tag{5}$$

Where, ρ is the absolute risk aversion coefficient. At the same time, the risk cost of organizational members is $\rho var(s)/2 = \rho\beta^2\alpha^2/2$, which indicates that organizational members are willing to pay $\rho\beta^2\alpha^2/2$ in return for the deterministic utility. Assuming that the virtual research organization is risk neutral, the expected utility of the virtual research organization is equal to the expected income. At this time, the expected income and expected utility of virtual research organization are as follows:

$$Wvro = R(\Delta e, x, \varepsilon) - S(R) = -\alpha + (1-\beta)\,(qxM^a\Delta e + \varepsilon) \tag{6}$$

$$U(Wvro) = -\alpha + (1-\beta)\,(qxM^a\Delta e + \mu) \tag{7}$$

The expected income and expected utility of organization members are as follows:

$$W_A = S(R) - C(\Delta e) = \alpha + \beta\,(qxM^a\Delta e + \varepsilon) - b\Delta e^2/2 \tag{8}$$

$$U(W_A) = \alpha + \beta\,(qxM^a\Delta e + \mu) - b\Delta e^2/2 - \rho\beta^2\sigma^2/2 \tag{9}$$

From the perspective of virtual research organization, it hopes that more organization members can share the innovation failure knowledge, so as to improve the innovation ability of the organization and reduce the probability of innovation failure, and yet the organization members will pay more attention to the maximization of their own utility. Therefore, when considering the conditions of participation constraint (PC) and incentive constraint (IC), the incentive model of innovation failure knowledge sharing is as follows:

$$\max_{\alpha,\,\beta,\,x,\,\Delta e} U(Wvro) = -\alpha + (1-\beta)\,(qxM^a\Delta e + \mu) \tag{10}$$

In virtual research organization, information asymmetry

is often found between the organization and members. Under the condition of incomplete information, it is difficult for virtual research organization to accurately observe the level of innovation failure knowledge sharing efforts of organization members, but it can measure the level of transformation ability of innovation failure knowledge by judging the level of innovation ability of organization members, and it can also observe the output income of innovation failure knowledge sharing. The output income is determined by the level of innovation failure knowledge sharing efforts of organization members and exogenous random variables.

$$s.t\begin{cases}(PC)\ \alpha+\beta\,(qxM^a\Delta e+\mu)-b\Delta e^2/2-\rho\beta^2\sigma^2/2\geq\overline{u}\\(IC)\ \Delta e^*\in argmax\,[\alpha+\beta\,(qxM^a\Delta e+\mu)-b\Delta e^2/2-\rho\beta^2\sigma^2/2]\end{cases}\tag{11}$$

Therefore, when the model parameters x, α and β are determined, the incentive constraint (IC) of innovation failure knowledge sharing can be expressed as:

$$\max_{\Delta e}U(W_A)=\max_{\Delta e}\,[\alpha+\beta\,(qxM^a\Delta e+\mu)-b\Delta e^2/2-\rho\beta^2\sigma^2/2]\tag{12}$$

The first derivative of parameter Δe is obtained from formula (12), which is equivalent to the maximization of the deterministic income of innovation failure knowledge sharing of organization members.

$$(IC)\ \Delta e=\beta qxM^a/b\tag{13}$$

On above basis, the conditions of participation constraint (PC) and incentive constraint (IC) are introduced into the objective function, and the following results are obtained:

$$\max_{\beta}U(Wvro)=-\overline{u}-\beta^2q^2x^2M^{2a}/2b+\beta\,q^2x^2M^{2a}/b-\rho\beta^2\sigma^2/2+\mu\tag{14}$$

In the above objective function, the first derivative of β is calculated, namely:

$$\partial U(Wvro)/\partial\beta=-\beta q^2x^2M^{2a}/b+q^2x^2M^{2a}/b-\rho\beta\sigma^2=0\tag{15}$$

Obtain:

$$\beta^*=q^2\,x^2\,M^{2a}/\,(b\rho\sigma^2+q^2x^2M^{2a})\tag{16}$$

$$\Delta e^*=q^3\,x^3\,M^{3a}/\,(b^2\rho\sigma^2+bq^2x^2M^{2a})\tag{17}$$

According to the findings of Zhang *et al.* (2019), the fault-tolerant environment for innovation failure will affect the innovation subjects' correct understanding of previous innovation failure, and negatively affect their subsequent innovation decisions. Therefore, fault-tolerant environment may also be an important exogenous factor that affects the innovation failure knowledge sharing of virtual research organization. In fact, the tolerance degree of fault-tolerant environment in virtual research organization is often difficult to observe, which can only be described by the prior probability of subjective attitude of virtual research organization and its members. That is to say, when the members of virtual research organization are at the same level of innovation failure knowledge sharing efforts, the more tolerant the organization's internal fault-tolerant environment is, the more able the organization members can correctly understand each other's previous innovation failure, actively learn from the failure experience, and will not question the innovation ability level of the partners and affect each other's innovation collaboration because of the previous innovation failure, so that the innovation failure knowledge sharing of virtual research organization has a better effect. However, if there is a negative fault-tolerant environment in the virtual research organization, it will have a more obvious negative effect on the innovation failure knowledge sharing efforts of organization members. In the above analysis process, the exogenous random variables including innovation fault-tolerant environment are assumed to be observable. It is necessary to consider the impact of fault-tolerant environment on the level of innovation failure knowledge sharing efforts of organization members, and further assume that the sharing cost function of innovation failure knowledge of organization members is as follows:

$$C=b(\Delta e-r\varepsilon)^2/2\tag{18}$$

Where, r is the impact degree of innovation fault-tolerant environment in virtual research organization, and $0<r<1$. If $r=0$, it is the sharing cost of organization members under the ideal condition without considering the negative effect of fault-tolerant environment. Furthermore, due to the information asymmetry between organization and member, there are also differences between the organization and members in their perception of innovation fault-tolerant environment (Wang, 2017). Therefore, we assume ε_{vro} is the tolerance degree of virtual research organization to innovation fault-tolerant environment, and ε_A is the tolerance degree of organization members to innovation fault-tolerant environment, To some extent, ε_{vro} and ε_A reflect the estimation of difficulties that virtual research organization and members may encounter in the process of innovation failure knowledge sharing. According to findings of Xu and Qiu (1999), the higher the value of and is, the higher the tolerance degree of organization and its members to innovation fault-tolerant environment. At this time, the expected utility of virtual research organization is:

$$U(Wvro)=-\alpha+(1-\beta)\,(qxM^a\Delta e+\varepsilon_{vro})\tag{19}$$

The deterministic equivalent income of organization members is:

$$\begin{aligned}W_A&=\alpha+\beta\,(qxM^a\Delta e+\varepsilon_A)-b(\Delta e-r\varepsilon_A)^2/2-\rho\beta^2\sigma^2/2\\&=\alpha+\beta qxM^a\Delta e+(\beta+br\Delta e)\varepsilon_A-b\Delta e^2/2-br^2\varepsilon_A^2/2-\rho\beta^2\sigma^2/2\end{aligned}\tag{20}$$

Thus, the incentive constraint can be expressed as:

$$\alpha + \beta qxM^a\Delta e + (\beta + br\Delta e)\varepsilon_A - b\Delta e^2/2 - br^2\varepsilon_A^2/2 - \rho\beta^2\sigma^2/2 \geq \overline{W_A} \quad (21)$$

Furthermore, it can be transformed into the following form:

$$(IC)\ \Delta e = \beta qxM^a/b + r\ \varepsilon_A \quad (22)$$

The optimal incentive model of innovation failure knowledge sharing can be changed into the following forms:

$$\max_{\alpha,\ \beta,\ x,\ \Delta e} U(Wvro) = -\alpha + (1-\beta)\ (qxM^a\Delta e + \varepsilon_{vro}) \quad (23)$$

$$s.t \begin{cases} (PC)\ \alpha + \beta qxM^a\Delta e + (\beta + br\Delta e)\varepsilon_A - b\Delta e^2/2 - br^2\varepsilon_A^2/2 - \rho\beta^2\sigma^2/2 \geq \overline{W_A} \\ (IC)\ \Delta e = \beta qxM^a / b + r\varepsilon_A \end{cases} \quad (24)$$

Take formula (22) into formula (23) and obtain:

$$\max_{\beta} U(Wvro) = \beta\ (\varepsilon_A - \varepsilon_{vro}) + \varepsilon_{vro} + qxM^a r\varepsilon_A - \rho\beta^2\sigma^2/2 - \overline{W_A} - \beta^2q^2x^2M^{2a}/2b + \beta q^2x^2M^{2a}/b \quad (25)$$

Calculating the first derivative of β with respect to formula (25) and obtain:

$$(\varepsilon_A - \varepsilon_{vro}) - \rho\beta\sigma^2 - \beta q^2x^2M^{2a}/b + q^2x^2M^{2a}/b = 0 \quad (26)$$

The optimal incentive coefficient β^{**} is:

$$\beta^{**} = [b(\varepsilon_A - \varepsilon_{vro}) + q^2x^2M^{2a}]/(b\rho\sigma^2 + q^2x^2M^{2a}) \quad (27)$$

Furthermore, the following result is obtained:

$$\Delta e^{**} = [q^3x^3M^{3a} + b(\varepsilon_A - \varepsilon_{vro}) + qxM^a]\ /\ (b\rho\sigma^2 + q^2x^2M^{2a}) + r\varepsilon_A \quad (28)$$

4. Result Analysis and Discussion

4.1 Without Considering the Negative Effect of Innovation Fault-tolerance Environment

According to the calculation results of formula (16), the first derivative of the parameters q, b, $\rho\sigma^2$ and x is calculated for formula (16) respectively, and the following results are obtained:

$$\partial\beta^*/\partial q = 2qx^2M^{2a}b\rho\sigma^2\ /\ (b\rho\sigma^2 + q^2x^2M^{2a})^2 > 0 \quad (29)$$

$$\partial\beta^*/\partial q = -\rho\sigma^2q^2x^2M^{2a}\ /\ (b\rho\sigma^2 + q^2x^2M^{2a})^2 < 0 \quad (30)$$

$$\partial\beta^*/\partial\rho\sigma^2 = -bq^2x^2M^{2a}\ /\ (b\rho\sigma^2 + q^2x^2M^{2a})^2 < 0 \quad (31)$$

$$\partial\beta^*/\partial x = 2xq^2M^{2a}b\rho\sigma^2\ /\ (b\rho\sigma^2 + q^2x^2M^{2a})^2 > 0 \quad (32)$$

According to formulas (29) and (32), β^* is an increasing function of parameters q and x. According to the results of formulas (30) and (31), β^* is a decreasing function of parameters b and $\rho\sigma^2$. Therefore, it can be concluded as follows:

Theorem 1. Without considering the negative effect of innovation fault-tolerant environment, the optimal incentive coefficient of virtual research organization for innovation failure knowledge sharing will increase with the improvement of the sharing rate of innovation failure knowledge and the transformation ability of innovation failure knowledge of organization members, and decrease with the increase of sharing cost coefficient of innovation failure knowledge and risk aversion degree of organization members.

Specifically, when the members of virtual research organization have more shareable innovation failure knowledge, the organization should give more incentive intensity to the members. Innovation failure knowledge is an important source to enhance an organization's innovation ability. Through learning of innovation failure knowledge, organization members can effectively reduce the probability of failure in the innovation process, so as to improve the overall innovation income of virtual research organization. The higher knowledge transformation ability of virtual research organization members is, the more they can transform their innovation failure experience into the knowledge form that can be stored, spread and shared. Optimal incentive coefficient of innovation failure knowledge sharing is also affected by the sharing cost. The higher the sharing cost, the lower the sharing incentive intensity. The reason is that the high sharing cost of innovation failure knowledge means that virtual research organization needs to invest too much incentive investment to realize innovation failure knowledge sharing, but the organization pursues economic benefits, and the high sharing cost will further inhibit organization's incentive. The greater the risk aversion degree of organization members is, the lower members' willingness to share innovation failure knowledge, which leads to the lack of incentive willingness of organizations. The possible reasons are: on the one hand, the existence of sharing cost will make members pay attention to their own interests. On the other hand, more importantly, organization members choose risk aversion because they are not willing to show their own innovation failure results to the organization and other members, resulting in others' question their own innovation ability, thus affecting their position in the virtual research organization and the allocation of R & D resources.

4.2 Considering the Negative Effect of Innovation Fault-tolerance Environment

According to the calculation results of formula (27), the first derivatives of parameters ε_{vro} and ε_A are calculated for formula (27), and the following results are obtained:

$$\partial\beta^{**}/\partial\varepsilon_A = b\ /\ (b\rho\sigma^2 + q^2x^2M^{2a}) > 0 \quad (33)$$

$$\partial\beta^{**}/\partial\varepsilon_{vro} = -b / (b\rho\sigma^2 + q^2x^2M^{2a}) < 0 \qquad (34)$$

It can be seen from formulas (33) and (34) that β^{**} is an increasing function of parameter ε_A and a decreasing function of parameter ε_{vro}. Therefore, it can be concluded as follows:

Theorem 2. Considering the negative effect of innovation fault-tolerant environment, the optimal incentive coefficient of virtual research organization for innovation failure knowledge sharing of organizational members will decrease with the improvement of the organization's estimation of tolerance degree to fault-tolerant environment. The organization thinks that the better the fault-tolerant environment is, the smaller the optimal incentive coefficient is. When the organization members' estimation of tolerance degree to fault-tolerant environment is increased, the better the fault-tolerant environment is, the higher the optimal incentive coefficient is.

Specifically, when the organization's estimation of tolerance to fault-tolerant environment ε_{vro} is large, it indicates that the organization believes that there is a good innovation fault-tolerant environment within the virtual research organization. Organization members can positively examine the innovation failure results, through the transformation and sharing of innovation failure knowledge, and then improve the overall innovation ability of virtual research organization. The increment of innovation income will be considered by the organization as a result of a good fault-tolerant environment, not determined by the level of innovation failure knowledge sharing efforts of the organization members themselves. Therefore, the virtual research organization will reduce the incentive of innovation failure knowledge sharing. When the value of ε_{vro} is small, the organization will think that there is a poor fault-tolerant environment within the current organization, the increment of innovation income generated by innovation failure knowledge sharing is more from the level of innovation failure knowledge sharing efforts of organization members. Therefore, virtual research organization will further stimulate members' willingness to knowledge sharing and improve the level of knowledge sharing efforts by enhancing the incentive intensity of innovation failure knowledge sharing.

When the organization members' estimation of tolerance to fault-tolerant environment ε_A is large, it means that organization members think that there is a good fault-tolerant environment for innovation within the virtual research organization. Organization members' will not be questioned by the organization and other members about their innovation ability because of innovation failure knowledge transformation and sharing of their own experience, but also get more innovation incomes and sharing rewards from the organization due to the innovation failure knowledge sharing. Therefore, organization members will pay more innovation failure knowledge and higher level of sharing efforts, and organization will pay more incentives of innovation failure knowledge sharing. When the value of ε_A is small, organization members may be more worried about the threat of their position and R & D resource allocation in virtual research organization due to the innovation failure knowledge sharing, which will reduce their efforts of knowledge sharing, and thus reduce the incentive intensity of the organization.

According to the results of formulas (16) and (27), ignoring the negative effect of innovation fault-tolerant environment, the optimal incentive coefficient of innovation failure knowledge sharing is $\beta^* = q^2x^2M^{2a}/(b\rho\sigma^2 + q^2x^2M^{2a})$. Considering the negative effect of innovation fault-tolerance environment, the optimal incentive coefficient is $\beta^{**} = [b(\varepsilon_A - \varepsilon_{vro}) + q^2x^2M^{2a}]/(b\rho\sigma^2 + q^2x^2M^{2a})$. The difference lies in whether virtual research organization's and its members' estimation of tolerance to fault-tolerant environment is equally. When $\varepsilon_A \neq \varepsilon_{vro}$, because of the difference about estimation of tolerance to fault-tolerant environment between organization and members, it is necessary to readjust the incentive intensity to further promote the innovation failure knowledge sharing among members in virtual research organization. According to the findings of Theorem 2, the optimal incentive coefficient is negatively related to organization's estimation of tolerance to fault-tolerant environment, and positively related to organization members' estimation of tolerance to fault-tolerant environment. Specifically, when ε_{vro} is determined, the better organization members' estimation of tolerance to fault-tolerant environment, and the larger ε_A is, the more incentive intensity of innovation failure knowledge sharing should be increased, and more innovation failure experiences of organization members should be transformed and shared. On the contrary, the smaller ε_A is, organization members think that there is a certain risk in the process of innovation failure knowledge sharing, and they are not willing to share more innovation failure knowledge. At this time, the organization's incentive means have no obvious influence on the member's knowledge sharing effort, so the organization should reduce the incentive.

4.3 Data Simulation

To more intuitively reflect the difference of the optimal incentive level of virtual research organization and the level of innovation failure knowledge sharing efforts of organization members, the data simulation of the model analysis results is carried out. Assume that the initial value of the model parameters is: $b = 0.4$. $q = 0.6$, $xM^a = 1$, $\rho\sigma^2 = 1$. Taking the initial value of the above parameters into formula (27), the optimal incentive coefficient β of virtual research organization is obtained, that is:

$$\beta^{**} = 0.526 \times (\varepsilon_A - \varepsilon_{vro}) + 0.474 \qquad (35)$$

Using Matlab R2015b software to simulate the data, the change of the optimal incentive coefficient β of virtual research organization is obtained under the two situations of whether the impact of innovation fault-tolerant environment is considered or not.

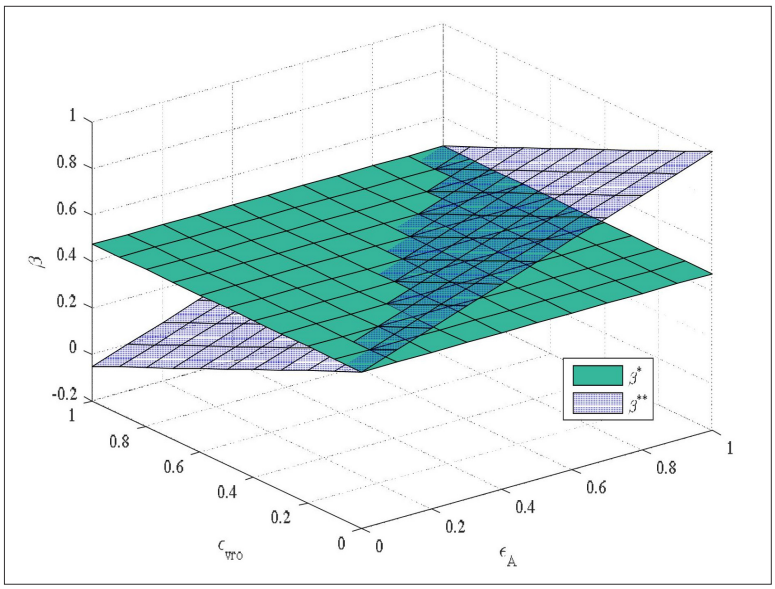

Figure 1. The change of the optimal incentive coefficient of virtual research organization

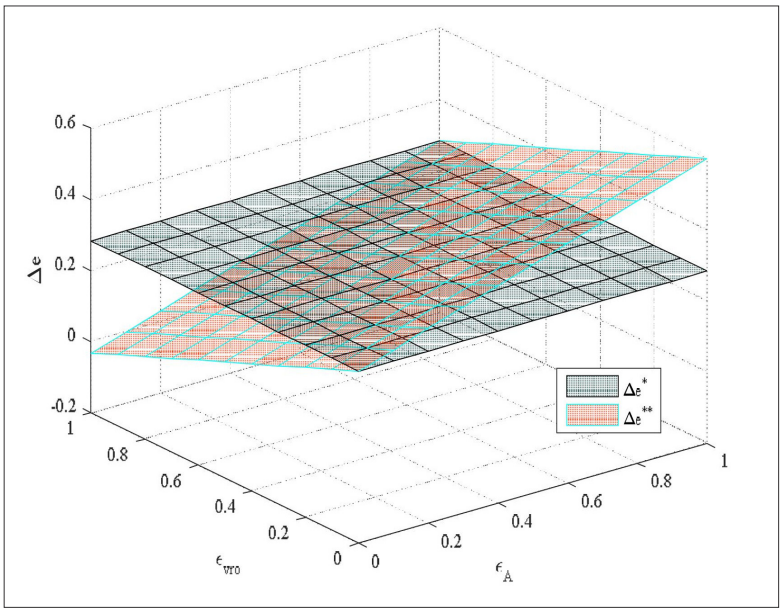

Figure 2. The change of innovation failure knowledge sharing efforts of virtual research organization

It can be seen from Figure 1 that when considering the negative effect of innovation fault-tolerant environment, the incentive level of innovation failure knowledge sharing decreases with the increase of the organization's estimation of tolerance degree to innovation fault-tolerant environment, and increases with the increase of members' estimation of tolerance degree to innovation fault-tolerant environment, which further verifies Theorem 2. Furthermore, when $\varepsilon A > \varepsilon vro$, the incentive level of innovation failure knowledge sharing will gradually increase. When $\varepsilon A = \varepsilon vro$, virtual research organization and its members have the same estimation of tolerance degree to innovation fault-tolerance environment, and the incentive level will remain unchanged.

The initial value of model parameter is brought into formula (29), and the following relation function is obtained:

$$\Delta e^{**} = 0.316 \times (\varepsilon A - \varepsilon vro) + 0.284 + r\varepsilon A \quad (36)$$

It can be seen that the level of innovation failure knowledge sharing efforts Δe is positively related to the member's estimate of tolerance degree to innovation fault tolerance environment εA, The better members perceive the tolerance degree of innovation fault-tolerant environment, the better they can promote their own innovation failure knowledge sharing efforts. When the impact of innovation fault-tolerant environment on level of innovation failure knowledge sharing efforts $r = 0$, the change of innovation failure knowledge sharing efforts Δe is shown in Figure 2.

It can be seen from Figure 2 that the change of sharing efforts level Δe of organization members is similar to the change of optimal incentive coefficient β, that is to say, the knowledge sharing efforts level of organization members decreases with the increase of the organization's estimate of tolerance degree to innovation fault-tolerant environment, and increases with the increase of the member's estimate of tolerance degree to innovation fault-tolerant environment.

When $r \neq 0$, r is independent of the organization's incentive level. However, there is a positive correlation between the knowledge sharing efforts of organization members and the organization's incentive level. The negative effect of innovation fault-tolerant environment will further affect the observation of members' knowledge sharing efforts. When $\varepsilon_A > \varepsilon_{vro}$, the level of knowledge sharing efforts of organization members is higher, they will actively share innovation failure knowledge and are willing to bear the corresponding risk of knowledge sharing, so the organization should increase its incentive compensation. When $\varepsilon_A < \varepsilon_{vro}$, the sharing effort level of organization members without considering the negative effect of innovation fault-tolerant environment is higher than that with considering the negative effect of innovation fault-tolerant environment. At this time, the sharing incentive of virtual research organization cannot promote the level of members' knowledge sharing effort, so the organization should reduce the incentive.

It should be noted that, If ε_{vro} is too large, the organization will reduce the incentive level of knowledge sharing of innovation failure, if a member of virtual research organization finds out this situation, it may have social loafing effect (Vveinhardt and Banikonytė, 2017), and is not conducive to the innovation failure knowledge sharing of the whole virtual research organization. Therefore, on the one hand, virtual research organization should timely adjust the incentive intensity according to the estimation of tolerance degree to innovation fault-tolerant environment of itself and its members; on the other hand, it should also strengthen the correct understanding of innovation fault-tolerant environment of itself and its members.

5. Conclusions

In view of the process of innovation failure knowledge sharing among the members of virtual research organization, considering the risk aversion degree of the organization members and the negative effect of innovation fault-tolerant environment, this study constructs the incentive model of innovation failure knowledge sharing of virtual research organization. Through the analysis and data simulation of the incentive model, the following conclusions were drawn: (1) the optimal incentive coefficient of virtual research organization for innovation failure knowledge sharing will increase with the improvement of the members' sharing rate of innovation failure knowledge and the members' transformation ability of innovation failure knowledge, and decrease with the increase of members' sharing cost coefficient and members' risk aversion degree. (2) Considering the negative effect of innovation fault-tolerant environment, the optimal incentive coefficient of virtual research organization for innovation failure knowledge sharing will decrease with the increase of tolerance degree of organization to fault-tolerant environment, and increase with the increase of tolerance degree of organization members to fault-tolerant environment. (3) The virtual research organization should make the corresponding revision of the sharing incentive intensity according to the information it has, in order to further reduce the risk of knowledge sharing incentive and improve the overall innovation income of the organization.

In addition, this study focuses on the impact of the negative effort of innovation fault-tolerant environment on the incentive of innovation failure knowledge sharing in virtual research organization. However, in the case of previous innovation failure, the incentive of innovation failure knowledge sharing is not only closely related to external environment conditions, but also closely related to the individual characteristics of organization members, such as the cost of innovation failure of members, the position of members in virtual research organization and other factors. Therefore, in the follow-up study, we can further consider the influence of individual characteristics of members in virtual research organization on the incentive intensity of knowledge innovation failure sharing.

6. Acknowledgement

This study was supported by the National Social Science Fund of China (Grant No. 18CJL006), Science and Technology Innovation Talent Support Plan in Colleges and Universities of Henan, China, in 2020 (Humanities and Social Sciences) (Grant No. 2020-cx-019).

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