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Resource sharing analysis of technology alliance based on evolutionary game

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ABSTRACT

Technology alliance is the main organizational form for enterprise technology innovation, which can facilitate to share their superior resources, and reduce development risk. However, it has suffered relatively high ratio of failure at present. In this paper, an evolutionary game model is presented to analyze resource sharing of technology alliance under the dynamic view of evolutionary economics, which leads to several key variables that affecting the stability of technology alliance: reverse research capabilities of enterprises, profit distribution proportion and default cost. Based on the analysis, some suggestions are proposed to promote stability of technology alliance.

KEYWORDS

Technology alliance; Resource sharing; Evolutionary game; Reverse research capabilities.

INTRODUCTION

Technology alliance is functional alliance in which two or more enterprises (or departments) collaborate on the new technology development. The aim of technology alliance is to share their information and complementary advantages, so as to decrease development costs of individual enterprises, reduce development risk and obtain more profits[1]. The contents of technology alliance include sharing information and resources, joint research and development, sharing cooperation technological fruits, etc. It becomes an important way for enterprises to improve technological level and enhance core competitiveness; even it is known as the most important organizational innovation in the contemporary[2].

Some researchers investigate the motivation of joining technology alliance for enterprises based on different views. Resource dependency theory claims that it can solve the problem of lacking resources for single enterprise by joining technology alliance. Through integration of enterprise resources, the goal of sharing resources and complementary advantages can be achieved. Network theory argues that technology alliance should be viewed as an inter-enterprise network system, so it can realize to share resources among enterprises. On the one hand, the utilization efficiency of enterprise resources can be improved, with that comes decrease of buried costs; on the other hand, the switching costs can be reduced, so as to increase flexibility of adjusting enterprises' strategies[3]. Therefore, resource dependency theory and network theory both hold that the primary motivation of establishing technology alliance is to realize resource sharing, profit sharing, and achieve a win-win situation within technology alliance.

However, technology alliances usually end up in failure during operating process. According to a report from U.S. consulting firm McKinsey shows that: Since the 1980s, by investigating more than 800 U.S. companies involved in technology alliances, only 40% of them maintained more than four years, most of the rest disintegrated in a short time. The high failure rate of technology alliance leads some observers to draw such conclusion: Alliance is very dangerous; it is just competitors' Trojan Horse to grab market shares and steal important technology[4]. Hagedoorn et al. believes that the main failure reason of technology alliance is the existence of moral hazard and opportunism, which undermine the effectiveness of innovation alliance[5].

Thus it can be seen that technology alliance should be regarded as complex system engineering, and how to avoid or effectively prevent the loss caused by fraud in the alliance, is a very worthwhile question to research[6]. In this paper, evolutionary game theory is applied to analyze the reasons that lead resources sharing of technology alliance to unstable, and then some suggestions are proposed to promote stability of technology alliance.

EVOLUTIONARY GAME MODEL FOR RESOURCE SHARING OF TECHNOLOGY ALLIANCE

Evolutionary game theory originated in biological evolutionism, and grew out of behavioral ecology theory; it is a combination theory of game analysis and dynamics evolution. The theory starts from individuals' bounded rationality, and keeps group behavior as research object, which explains the development history of biological species selection. In the process of biological development, only the species that get higher payment can survive, and the species that get lower payment would be eliminated from the competition, that is 'survival of the fittest'. The species that get lower payment can get higher payment by imitating and improving the long-term strategy, so that all participants in the game will tend to a stable strategy for survival, and the strategy might be long-term stabilized in the group[7]. In this paper we adopt evolutionary game theory to study the strategic selection of resources sharing within technology alliance, and to analyze the factors affecting the stability of technology alliance.

The model assumptions are as follows:

H1: Assuming that two enterprises A, B have the behavior of bounded rationality, they choose to join a technology alliance in order to share respective resources and increase profits. Since they have limited capability of perception and cognition in the process of acquiring and applying information, it is hard to get precise information for them. That is to say, perfectly rational person does not exist[8].

H2: Assuming that enterprises *A*, *B* have two behavioral strategies: Resource-Sharing (RS) and Not Resource-Sharing (NRS). Enterprise *A* chooses RS with probability X, thus the probability of NRS is $1-X$. Enterprise *B* chooses RS with probability Y, so the probability of NRS is $1-Y; X, Y \in (0,1)$.

H3: Assuming that two enterprises *A*, *B* have profits of π_A and π_B, respectively, which do not consider the profits obtained from resource sharing. An incremental profit of π could be obtained by taking advantage of resource sharing; it is the best embodiment of the advantage of technology alliance, and it also provides a strong stimulus for inter-enterprise to establish technology alliance. According to devoted resources, the two enterprises allocate a certain percentage of the incremental profits. Assuming enterprise *A* gets incremental profits of $\beta\pi$, then enterprise *B* gets incremental profits of $(1-\beta)\pi$.

H4: Resource-sharing also exists certain risk for enterprises; this is mainly due to the presence of opportunism: a member within alliance may defraud core technology through technical alliance. If enterprise *A* chose to share resources, and enterprise *B* chose midway breach, (i.e., no longer shared resources), then enterprise *B* would acquire all or part technique knowledge from enterprise *A* due to technology spillover. By reverse Engineering and then after further research, enterprise *B* would get value-added profits of $\Delta\pi'_{\mathrm{B}}$ (the size depended on the absorptive capacity of enterprise *B*). On the other hand, enterprise *A* would decrease certain profits $\Delta\pi_{\mathrm{A}}$ because of technical spillover, which led to foster a strong competitor (usually the more profits enterprise *B* increased, the more profits enterprise *A* decreased). Similarly, if enterprise *A* defaulted midway, it would also do reverse research so as to increase profits of $\Delta\pi'_{\mathrm{A}}$ by absorbing the technology from enterprise *B*, meanwhile enterprise *B* would decrease profits of $\Delta\pi_B$.

H5: After establishing technology alliance, a default punishment mechanism must be set in order to prevent losses from default. We assume that if one member defaulted halfway, it needs to pay the default cost of *C*. Because of the default risk, generally it is assumed that $-\Delta\pi_{\mathrm{A}} + C < 0, -\Delta\pi_{\mathrm{B}} + C < 0$, that is to say, one member to default will lead the other members to decrease profits.

Following the previous assumption, when two enterprises *A*, *B* choose different strategies of profit functions, they will respectively get profits of π_{A} and π_{B} if both take NRS strategies, and they will respectively get profits of $\pi_{\mathrm{A}} + \beta\pi$ and $\pi_{\mathrm{B}} + (1-\beta)\pi$ if both take RS strategies, due to RS strategy would increase value-added profits. The profit functions discussed above are as shown in TABLE 1.

TABLE 1 : The payoff matrix when enterprises *A*, *B* choose different strategies

Profit Functions		Enterprise *B*	
		RS	**NRS**
Enterprise *A*	RS	$\pi_{\mathrm{A}} + \beta\pi, \quad \pi_{\mathrm{B}} + (1-\beta)\pi$	$\pi_{\mathrm{A}} - \Delta\dot{\pi}_{\mathrm{A}} + C, \quad \pi_{\mathrm{B}} + \Delta\pi'_{\mathrm{B}} - C$
	NRS	$\pi_{\mathrm{A}} + \Delta\dot{\pi}'_{\mathrm{A}} - C, \quad \pi_{\mathrm{B}} - \Delta\pi_{\mathrm{B}} + C$	π_{A} , π_{B}

RS: Resource Sharing; NRS: Not Resource Sharing

According to TABLE 1, we can calculate the expected revenue and average revenue of the two enterprises, considering the two cases of RS and NRS. The expected revenue $U_{1\mathrm{A}}$ (RS), $U_{2\mathrm{A}}$ (NRS) of enterprise *A*, and the average revenue U_{A} can be expressed as:

$$U_{1\mathrm{A}} = y(\pi_{\mathrm{A}} + \beta\pi) + (1-y)(\pi_{\mathrm{A}} - \Delta\pi_{\mathrm{A}} + c)$$

$$U_{2\mathrm{A}} = y(\pi_{\mathrm{A}} + \Delta\dot{\pi}'_{\mathrm{A}} - C) + (1-y)\pi_{\mathrm{A}}$$

$$U_{\mathrm{A}} = xU_{1\mathrm{A}} + (1-x)U_{2\mathrm{A}}$$

Likewise the expected revenue U_{1B}(RS), U_{2B}(NRS) of enterprise *B*, and the average revenue U_B can be expressed as:

$$U_{1B} = x[\pi_B + (1-\beta)\pi] + (1-x)(\pi_B - \Delta\pi_B + C)$$

$$U_{2B} = x(\pi_B + \Delta\pi'_B - C) + (1-x)\pi_B$$

$$U_B = yU_{1B} + (1-y)U_{2B}$$

According to the above mathematical expression, the replicated dynamic equation of enterprises *A* and *B* are constructed as follows:

$$F(x) = dx/dt = x(U_{1A} - U_A)$$
$$= x(1-x)[y(\beta\pi - \Delta\pi'_A + \Delta\pi_A) + (C - \Delta\pi_A)]$$

$$F(y) = dy/dt = y(U_{1B} - U_B)$$
$$= y(1-y)\{x[(1-\beta)\pi - \Delta\pi'_B + \Delta\pi_B] + (C - \Delta\pi_B)\}$$

The evolutionary process of resource sharing can be described by the replicated dynamic equation. Let $F(x) = F(y) = 0$, we can find out five equilibrium points of the evolutionary game, respectively denoted by $O(0,0)$, $A(1,0)$, $B(0,1)$, $C(1,1)$, $D(x^*, y^*)$, where

$$x^* = (\Delta\pi_B - C)/[(1-\beta)\pi - \Delta\pi'_B + \Delta\pi_B]$$

$$y^* = (\Delta\pi_A - C)/(\beta\pi - \Delta\pi'_A + \Delta\pi_A)$$

Dynamic Analysis of Evolutionary Game for technology alliance

The evolutionarily stable strategy of the technology alliance can be obtained by analyzing local stability of Jacobian matrix[9], and the equations of Jacobian matrix can be expressed as:

$$J = \begin{bmatrix} dF(x)/dx & dF(x)/dy \\ dF(y)/dx & dF(y)/dy \end{bmatrix}$$

So the trace of the matrix *J* is calculated as:

$$Tr(J) = (1-2x)[y(\beta\pi - \Delta\pi'_A + \Delta\pi_A) + (C - \Delta\pi_A)]$$
$$+ (1-2y)\{x[(1-\beta)\pi - \Delta\pi'_B + \Delta\pi_B)] + (C - \Delta\pi_B)\}$$

We can analyze local stability of the five equilibrium points based on Jacobian matrix:

(1) If $(\beta\pi - \Delta\pi'_A + \Delta\pi_A) > (\Delta\pi_A - C)$, $[(1-\beta)\pi - \Delta\pi'_B + \Delta\pi_B] > (\Delta\pi_B - C)$, that is $\beta\pi > (\Delta\pi'_A - C)$, $(1-\beta)\pi > (\Delta\pi'_B - C)$, in this case the incremental profits of enterprises *A* and *B* owing to resource sharing are more than the value-added profits arising from halfway breach, the evolutionary stability results of resource sharing systems of technology alliance are shown in TABLE 2.

Where $A(1,0)$ and $B(0,1)$ are unstable points, $D(x^*, y^*)$ is a saddle point, $O(0,0)$ and $C(1,1)$ are the evolutionary equilibrium points, then the evolutionarily stable strategy is (RS, RS) or (NRS, NRS). The dynamic evolutionary process satisfied the condition of the system can be represented in Figure 1.

Figure 1 shows that the broken line connected the saddle point D with the unstable points A and B is the critical line of different states that the system converges on them. In the part of OADB, the strategic choice of enterprises *A*, *B* is (NRS, NRS), namely it is the evolutionarily stable strategy of the system. In the part of ADBC, the strategic choice of enterprises *A*, *B* is (RS, RS), and it is also the evolutionarily stable strategy of the system. Thus the evolutionary trend of the system will move on to different converged strategies when the saddle point D changes.

TABLE 2 : Stability analysis of local equilibrium point when $\beta\pi > (\Delta\pi'_A - C)$, $(1-\beta)\pi > (\Delta\pi'_B - C)$

Equilibrium Points	Determinant Sign of *J*	Trace Sign of *J*	Equilibrium Results
$O(0,0)$	+	-	ESS
$A(1,0)$	+	+	UP
$B(0,1)$	+	+	UP
$C(1,1)$	+	-	ESS
$D(x^*, y^*)$	-	0	SP

ESS: Evolutionarily Stable Strategy; UP: Unstable Point; SP: Saddle Point

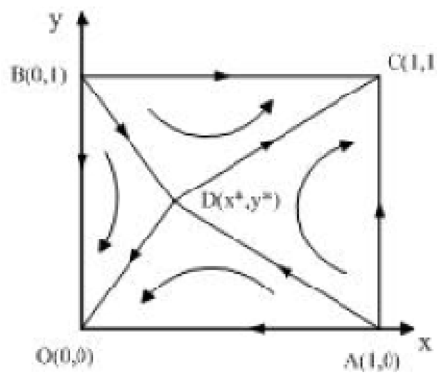

Figure 1 : The dynamic evolution of case 1

(2) If $(\beta\pi - \Delta\pi'_A + \Delta\pi_A) < (\Delta\pi_A - C)$, $[(1-\beta)\pi - \Delta\pi'_B + \Delta\pi_B] > (\Delta\pi_B - C)$, that is $\beta\pi < (\Delta\pi'_A - C)$, $(1-\beta)\pi > (\Delta\pi'_B - C)$, in this case the incremental profits of enterprise *A* owing to resource sharing are less than the value-added profits arising from default, while the incremental profits of enterprise *B* owing to resource sharing are more than the value-added profits arising from default, then enterprise *A* has the desire to breach of contract, and the evolutionary stability results of the resource sharing system are shown in TABLE 3.

TABLE 3 : Stability analysis of local equilibrium point when $\beta\pi < (\Delta\pi'_A - C)$, $(1-\beta)\pi > (\Delta\pi'_B - C)$

Equilibrium Points	Determinant Sign of J	Trace Sign of J	Equilibrium Results
$O(0,0)$	+	-	ESS
$A(1,0)$	-		SP
$B(0,1)$	+	+	UP
$C(1,1)$	+		SP

Where $B(0,1)$ is an unstable point, $A(1,0)$ and $C(1,1)$ are saddle points, $O(0,0)$ is the evolutionary equilibrium point, then the evolutionary stable strategy is (NRS, NRS), the system started from any initial state, will eventually converge to $O(0,0)$. The dynamic evolutionary process satisfied the condition of the system can be represented in Figure 2.

(3) If $(\beta\pi - \Delta\pi'_A + \Delta\pi_A) > (\Delta\pi_A - C)$, $[(1-\beta)\pi - \Delta\pi'_B + \Delta\pi_B] < (\Delta\pi_B - C)$, that is $\beta\pi > (\Delta\pi'_A - C)$, $(1-\beta)\pi < (\Delta\pi'_B - C)$, in this case the incremental profits of enterprise *A* owing to resource sharing are more than the value-added profits arising from default, while the incremental profits of enterprise *B* owing to

resource sharing are less than the value-added profits arising from default, then enterprise *B* has the desire to breach of contract, and the evolutionary stability results of the resource sharing system are shown in TABLE 4.

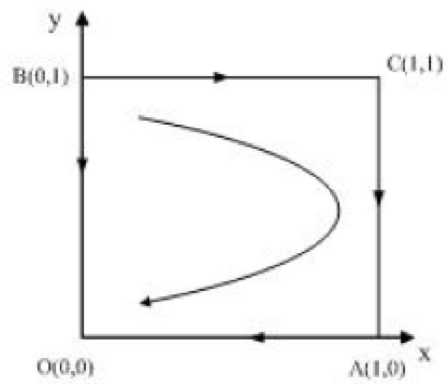

Figure 2 : The dynamic evolution of case 2

TABLE 4 : Stability analysis of local equilibrium point when $\beta\pi > (\Delta\pi'_A - C)$, $(1-\beta)\pi < (\Delta\pi'_B - C)$

Equilibrium Points	Determinant Sign of J	Trace Sign of J	Equilibrium Results
$O(0,0)$	+	-	ESS
$A(1,0)$	+	+	UP
$B(0,1)$	-		SP
$C(1,1)$	-		SP

Where $A(1,0)$ is an unstable point, $B(0,1)$ and $C(1,1)$ are saddle points, $O(0,0)$ is the evolutionary equilibrium point, then the evolution of the system remains stable strategy (NRS, NRS), similarly the system started from any initial state, will eventually converge to $O(0,0)$. The dynamic evolutionary process satisfied the condition of the system can be represented in Figure 3.

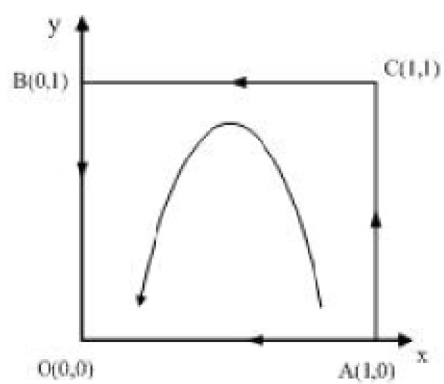

Figure 3 : The dynamic evolution of case 3

(4) If $(\beta\pi - \Delta\pi'_A + \Delta\pi_A) < (\Delta\pi_A - C)$, $[(1-\beta)\pi - \Delta\pi'_B + \Delta\pi_B] < (\Delta\pi_B - C)$, that is $\beta\pi < (\Delta\pi'_A - C)$, $(1-\beta)\pi < (\Delta\pi'_B - C)$, in this case the incremental profits of enterprises *A* and *B* owing to resource sharing are less than the value-added profits arising from halfway breach, then enterprises *A* and *B* both have the desire to breach of contract, and the evolutionary stability results of the resource sharing system are shown in TABLE 5.

Where $C(1,1)$ is an unstable point, $A(1,0)$ and $B(0,1)$ are saddle points, $O(0,0)$ is the evolutionary equilibrium point, then the evolutionary stable strategy is (NRS, NRS), likewise the system started from any initial state, will eventually converge to $O(0,0)$. The dynamic evolutionary process satisfied the condition of the system can be represented in Figure 4.

TABLE 5 : Stability analysis of local equilibrium point when $\beta\pi < (\Delta\pi'_A - C)$, $(1-\beta)\pi < (\Delta\pi'_B - C)$

Equilibrium Points	Determinant Sign of J	Trace Sign of J	Equilibrium Results
$O(0,0)$	+	-	ESS
$A(1,0)$	-		SP
$B(0,1)$	-		SP
$C(1,1)$	+	+	UP

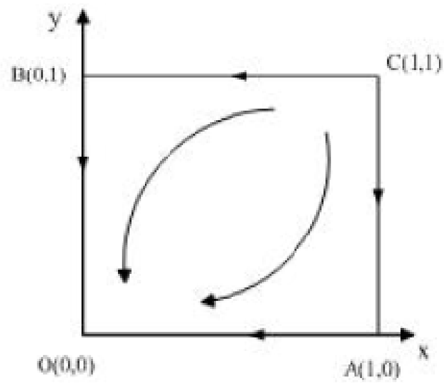

Figure 4 : The dynamic evolution of case 4

RESULT AND DISSCUSS

According to the dynamic analysis of evolutionary game for technology alliance, we can draw the following results: For any enterprise within technology alliance, if the incremental profit owing to resource sharing is less than the value-added profit brought from breach of contract, the system will eventually converge to $O(0,0)$, regardless of any initial state it started from (see Figure 2-4). Namely, (NRS, NRS) is the final strategy of evolutionary equilibrium, and the technology alliance ultimately failed. On the contrary, for each enterprises within the alliance, if the incremental profit owing to resource sharing are all more than the value-added profit brought from breach of contract, the system has two evolutionary equilibrium points: $O(0,0)$ and $C(1,1)$. Figure 1 shows that the position of saddle point D determines which equilibrium point the system will converge to. At the saddle point D, it has:

$$x^* = (\Delta\pi_B - C)/[(1-\beta)\pi - \Delta\pi'_B + \Delta\pi_B]$$

$$y^* = (\Delta\pi_A - C)/(\beta\pi - \Delta\pi'_A + \Delta\pi_A)$$

With reference to Figure 1 we can calculate the area of ADBC:

$$1 - 1/2\begin{Bmatrix}(\Delta\pi_B - C)/[(1-\beta)\pi - \Delta\pi'_B + \Delta\pi_B] \\ +(\Delta\pi_A - C)/(\beta\pi - \Delta\pi'_A + \Delta\pi_A)\end{Bmatrix}$$

From the above equation, we can see that there are four main variables affecting area ADBC: π (the incremental profit owing to resource sharing); β (the distribution proportion of resource sharing profits); $\Delta\pi'_A$ and $\Delta\pi'_B$ (the value-added profits brought from technology spillover by means of reverse research); C (the default penalty that the defaulting member should pay to the other members), and the four parameters how to impact the system stability are discussed as follows:

(1) π is the incremental profit owing to resource sharing, the bigger π is, the larger area ADBC has, and the probability that the system converging to $C(1,1)$ will be greater. That is to say, the final strategy of evolutionary equilibrium is (RS, RS). At this time the technology alliance is stable; the enterprises within the alliance can share their resources and profits, and achieve a win-win situation. Therefore, the more incremental profits the enterprise makes from technology alliance, the more stable the system of resource sharing will tend to.

(2) β is the distribution proportion of the profits owing to resource sharing, which is too large or too small can cause area ADBC reduced, and the probability that the system converging to the equilibrium point $O(0,0)$ will be greater. The final strategy of evolutionary equilibrium is (NRS, NRS); at this time the technology alliance is unstable. In order to improve the stability of the technology alliance, it is necessary to reasonably allocate the incremental profits, so as to prevent defaults because of low incremental profit, which will eventually lead technology alliance to fail.

(3) $\Delta\pi'_{\mathrm{A}}$ and $\Delta\pi'_{\mathrm{B}}$ are the value-added profits brought from technology spillover by means of reverse research. The stronger reverse research capability the enterprises have, the small area ADBC has, and the probability that the system converging to $O(0,0)$ will be greater. That is, the final strategy of evolutionary equilibrium is (NRS, NRS). At this time the technology alliance is unstable, which means that the stronger reverse research capability the enterprises have, the more value-added profits the defaulting enterprises will get, which leads the enterprises to breach of contract. In contrast, the weaker reverse research capability the enterprises have, the bigger area ADBC has, and the probability that the system converging to $C(1,1)$ will be greater, namely the final strategy of evolutionary equilibrium is (RS, RS), at this time the technology alliance is stable. Therefore, the enterprises should consider the reverse research capability of other alliance members when they want to join a technology alliance, and the alliance will be more stable if the enterprises within technology alliance have weak capacity to do reverse research.

(4) C is the default penalty that the defaulting member should pay to the other members. The bigger C is, the larger area ADBC has, and the probability that the system converging to $C(1,1)$ will be greater, the final strategy of evolutionary equilibrium is (RS, RS); at this time the technology alliance is stable. So the technology alliance should raise default cost to guard the members against midway breach, but with the increase of default cost C, it may lead the enterprises to not share their resources in the initial stage if the default cost is too large, so that the enterprises cannot establish their technology alliance.

Based on the above analysis, when an enterprise joins a technology alliance, it is expected to increase the overall profits within the alliance and achieve a win-win situation by reallocating the social resources and integrating of innovative elements. However, the technology alliance maybe unstable for the following reasons: 1) There is usually no strict organizational constraints and guarantees within technology alliances; 2) When conflicts arise within technology alliances, it is hard to effectively coordinate and manage. 3) The competition and cooperation simultaneously occur within technology alliances, which would prone to opportunism. Therefore, if enterprises plan to establish technology alliances to share their resources, they should choose suitable alliance members, reasonably allocate the profits owing to resources sharing, set the appropriate default costs, protect their vested interests and core competencies in the process of resource sharing, and avoid opportunistic behavior within technology alliances.

CONCLUSIONS

In this paper, we have analyzed the strategies of resource sharing under different states of technology alliance by utilizing evolutionary game theory, and the results show that:

(1) Resource sharing of technical alliance can improve the utilization efficiency of enterprise resources by reallocating the social resources, and increase the overall profit within the Alliance, finally achieve a win-win situation.

(2) In the process of resource sharing, enterprises can effectively prevent fraud losses brought from alliance members by taking certain preventive mechanisms, such as strict selection of alliance members, a reasonable distribution proportion of profits, an appropriate penalty mechanism for breach of contract, etc.

Based on the results above, we can get the following conclusion: The enterprise in technology alliance should strengthen communication and interaction among enterprises, and rationally choose alliance members according to the reverse research capabilities of them, so as to make up for the insufficient resources of each enterprises; meanwhile a reasonable allocation of profits and setting an appropriate punishment mechanism for breach of contract can effectively prevent fraud from other alliance members, so that promote the stability of resource sharing mechanism of technology alliance, and achieve a win-win situation within the alliance members.

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