

Stability Analysis with Game Theory in Virtual Enterprise Alliances

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Abstract. The emergence of virtual enterprise alliances enables enterprises to quickly seize opportunities and gain an advantage in the face of unpredictable and changeable market competition. However, the existence of opportunism poses a great threat to the successful implementation and stable development of the alliance. To address this issue, this paper analyzes the mechanisms of cooperation norms of enterprises in alliances based on the study of cooperation dilemmas. The game model of the choice of the integrity strategy with penalty constraint, reputation discounting factor and cold strategy are constructed by different divisions of the number of enterprise cooperation. The study concludes that the inclusion of three types of governance facilitates the active participation of enterprises in cooperation and ensures the stable operation of virtual business alliances under the influence of opportunism.

Keywords: virtual enterprise; cooperative dilemma; penalty factor; reputation; cold strategy

1. Introduction

Due to the increasingly fierce competition in the external market environment and the fleeting market opportunities, enterprises increasingly feel that it is difficult to adapt to the changes of this environment alone. Therefore, enterprise cooperation for win-win or multi-win has become the best model to adapt to the modern competitive environment. The virtual enterprise is formed under this background[1][2]. Through mutual cooperation and complementary advantages, enterprises themselves only invest related resources in their best functions to form a functional virtualization operation mode. The alliance provides a flexible way of cooperation, allowing some independent and autonomous individuals to spontaneously organize together to solve a goal and form a cooperative team within a certain period. Thus, the alliance can achieve the specified objectives more flexibly and efficiently and maximize the benefits.

However, the alliance formed is a mixed organizational form. For the sake of maximizing their own utility, enterprises in the alliance will try to protect and increase their interests by violating their commitments, lowering the quality of their products and services, reducing their investment in the alliance, etc. Obviously, there is a natural contradiction between this and the original intention of building the alliance to maximize the overall utility and achieve a win-win goal. The virtual enterprise alliance will inevitably fall into the cooperative dilemma of a conflict between individual interests and the interests of other members or collective common interests. The conflict seriously threatens the alliance's stability, development and successful operation.

Therefore, it is necessary to consider maintaining the stable operation of the alliance[3][4]. An effective enterprise alliance needs a complete set of governance mechanisms to restrain the opportunistic behavior in the cooperative relationship. Scholars have given many explanations for the stability or instability of alliance. The research results on alliance stability represented by Das et al.[5] are the most prominent. Combined with the cooperative characteristics of enterprise alliance, they have deeply analyzed the three pairs of forces in alliance decision-making: cooperation and competition, long-term and short-term cooperation oriented and flexible and rigid partnership. They also devised ways and mechanisms of trust and control to maintain the alliance's stability based on the resource-based theory. Meanwhile, the use of punishment mechanism to regulate cooperative behavior is also a very effective way to maintain the alliance's stability and get out of the dilemma of cooperation. Ye et al.[6] explored the impact of penalty intensity on enterprises' integrity choices

in short-term cooperation and gave conditions to improve alliance stability. Liu et al.[7] promoted a stable cooperation among supply chain enterprises by implementing regulatory penalty strategies, thus avoiding free-rider behavior. The author in [8] obtained an effective regulatory mechanism to support green technology innovation by taking enterprises as the research object. In addition, the reputation model (KMRW) also gives a good explanation for the problem of stable cooperation between two parties[9].

This paper makes a game analysis on the choice of integrity strategy of egoistic enterprises among alliances and puts forward a cooperation dilemma model with punishment, reputation and cold strategy. This cooperation dilemma is broken by introducing the concept of penalty constraint in short-term cooperation and the concept of reputation discount factor and cold strategy in long-term cooperation, ensuring the stability of the alliance in the operational phase.

The remainder of this paper is organized as follows: The second section presents the problem. The third part gives the governance mechanism to ensure the stability of the alliance. The fourth section gives the conclusion.

2. Problem Presentation

According to the organizational characteristics of virtual enterprise alliances, we know that the situation of cooperation dilemma will inevitably arise in the process of alliance cooperation. Although the alliance members have signed a cooperation agreement, the future transaction risk is still unpredictable. Next, we introduce the concept of honesty into the virtual enterprise alliance, that is, the behavior choice of enterprises in the alliance has two strategies: Honesty and dishonesty. The enterprise's honesty strategy or behavior shows that after signing the cooperation agreement, it follows the content of the agreement and does not damage the operation of the alliance for its interests. The dishonesty strategy or behavior of the enterprise is manifested in the opportunistic behavior of blindly pursuing its benefits after signing the cooperation agreement.

Parkhe[10] believes that the behavior choice between self-interest enterprises essentially constitutes a prisoner's dilemma. Similarly, we model the choice of integrity in virtual enterprise alliance by random matching game. In order to simplify the model description without losing generality, we now assume that there are two enterprises in the alliance: Enterprise 1 and enterprise 2. The strategies of the two enterprises are honesty and dishonesty. Considering that the alliance studied in this paper is an unbalanced alliance, we give the income matrix of two enterprises under different integrity strategy choices. As shown in Table I:

Table 1. game income matrix of two enterprises

Enterprise 1	Enterprise 2	
	honesty	dishonesty
honesty	R_1, R_2	S_1, T_2
dishonesty	T_1, S_2	D_1, D_2

By analogy with the prisoner's dilemma analysis, for this game income matrix, if there are

$$\begin{cases} S_1 < D_1 < R_1 < T_1 \\ S_2 < D_2 < R_2 < T_2 \end{cases} \quad (1)$$

both enterprises will choose dishonesty, which constitutes a cooperative dilemma. According to Liu's[11] analysis of the game scenario in which participants sign an agreement in advance in the prisoner's dilemma, similarly, we put forward the following proposition for the cooperative dilemma.

Proposition 1: Without any conditions, even if a cooperation agreement is signed in advance, it will not affect the game result of cooperation dilemma.

Proof: In general, a virtual enterprise alliance is formed after each enterprise has signed a cooperation agreement, and they all promise to be loyal to this alliance beforehand. That is, they all guarantee that their strategies are honesty. Since we study the cooperation among members of a

virtual enterprise alliance during the period of response to a market opportunity, the alliance arises and disappears as the opportunity arises and disappears. It is uncertain whether the cooperation will continue in the next opportunity response. Therefore, we conduct a game analysis of the integrity choice among enterprises from the perspective of the number of times of cooperation.

- **Single Collaboration.** If a virtual enterprise alliance cooperates only once in response to a market opportunity, the alliance will automatically dissolve. Then the game of the enterprises in the alliance is a single game at this time. Take enterprise 1 as an example: If it thinks that enterprise 2 will abide by its promise and choose the honesty strategy, through the analysis of the income matrix, the income after it chooses the honesty strategy is R_1 . While the income of it chooses the dishonest strategy is T_1 . Without any additional conditions, due to $R_1 < T_1$, it will choose to violate the agreement and choose dishonesty out of egoism. If it thinks that enterprise 2 will violate the cooperation agreement, the benefit of it chooses the honesty strategy is S_1 , and the benefit of it chooses the dishonesty strategy is D_1 . Because there are no additional conditions, from $S_1 < D_1$, it can be seen that it will still choose to violate the agreement to maximize benefits. The same conclusion can be drawn from the analysis of enterprise 2. In this way, the signed cooperation agreement is meaningless and will not affect the game result of cooperation dilemma. The proposition is proved.
- **Multiple Collaborations.** If a virtual enterprise alliances cooperates more than one time in response to a market opportunity, they will continue to cooperate until the end of this market opportunity. Then the cooperation dilemma game between them will be repeated. Based on the characteristics of the repeated game, we use the inverse induction method to analyze the solution of this game below. Suppose that the game of cooperative dilemma is repeated n times ($n > 1$). In the n th game, since it is already the last game, any strategy of the participating enterprises will have no effect on the subsequent games. So, the choices of the participating enterprises will be the same as in the single game, and they will all choose dishonesty. Since enterprises know that whatever they do will not affect the last game, in the $n-1$ th game, both sides will choose the dishonesty strategy to pursue the maximum gain. And so on, the strategies of the participating enterprises are dishonest until the first game, which is the only Nash equilibrium of the game. Therefore, the proposition is proved.

3. Enterprises Cooperative Governance Mechanism

After the analysis of the problem in the previous section, almost all collaborations experience similar dilemmas. How to design a complete governance mechanism is the key to maintain the stable operation of the alliance. Next, we give the governance mechanism to maintain the stable operation of the alliance in different cooperation cycles.

3.1 Stability Analysis of Virtual Enterprises with a Single Collaboration

Yamagishi's[12] research shows that when group members have fewer cooperation expectations, people are more inclined to set or introduce some punishment norms to maintain the stability of the alliance. Thus, for a single cooperation in response to a market opportunity, the addition of penalty is a strong constraint on dishonest behavior which makes opportunistic behavior less powerfully attractive. In the following, we construct the inter-enterprise game model with penalty constraints. From the game analysis of enterprises' integrity strategy choice in the previous section, we know that cooperation between enterprises will fall into a dilemma. The penalty variable C is introduced in order to change this dilemma. For the dishonest enterprises, the penalty must be paid to compensate the honest enterprises if they want to betray the alliance. The new game income matrix is shown in Table II, in which $a \in [0, 1]$.

Table 2. game income matrix of two enterprises under penalty constraints

Enterprise 1	Enterprise 2	
	honesty	dishonesty
honesty	R_1, R_2	$S_1 + aC, T_2 - C$
dishonesty	$T_1 - C, S_2 + aC$	$D_1 - C, D_2 - C$

In order to change the game result and make the alliance cooperate stably, the only Nash equilibrium of the game matrix must be (honesty, honesty), then the following formula must be satisfied:

$$\begin{cases} R_1 > T_1 - C \\ S_1 + aC > D_1 - C \\ R_2 > T_2 - C \\ S_2 + aC > D_2 - C \end{cases} \quad (2)$$

According to the formula, we get the conditions for stable cooperation of the alliance as follows:

$$C > \max\{T_1 - R_1, T_2 - R_2, \frac{D_1 - S_1}{1+a}, \frac{D_2 - S_2}{1+a}\} \quad (3)$$

In this case, the addition of penalty variable C forcibly changes the comparison relationship of game returns under different strategic environments and guides enterprises to choose a high level of integrity to ensure the alliance's cooperation.

3.2 Stability analysis of virtual enterprises with multiple collaborations

We have shown that in long-term and longer-term cooperation, cooperation dilemmas can still arise between enterprises that threaten the stable operation of the alliance. Unlike short-term games, enterprises need to consider protecting the long-term benefits they may obtain at this time. For the multiple repetition cooperation dilemma game, we study it from two aspects: The game with a definite number of times and the game with an uncertain number of times.

3.2.1 The game with a definite number of times

Assuming that members within the alliance cooperate n times in response to market opportunities, that is, the cooperative dilemma is repeated n times. Next, we introduce the reputation model (KMRW) in the multiple cooperative dilemma game, which actually considers reputation as a binding force to study its impact on the long-run benefits that enterprises may obtain. The reputation discount factor $\delta (0 < \delta < 1)$ is used to calculate the discounted benefits of n -period cooperation of the alliance members. When enterprises want to improve their reputation to get more cooperation opportunities, they will comply with the cooperation agreement and choose the honesty strategy. We denote the total gain by U_i^x . From table I, we have:

$$U_i = R_i + R_i \times \delta + R_i \times \delta^2 + \dots + R_i \times \delta^{n-1}, i=1,2 \quad (4)$$

If enterprise $i (i=1,2)$ behaves opportunistically for the first time in the m th ($m < n$) cooperation process, then the other members will distrust the enterprise. In order to protect their own interests, they will choose a dishonest strategy in the next round of cooperation process. Their discounted returns in this case are:

$$U_i' = R_i + R_i \times \delta + \dots + R_i \times \delta^{m-1} + T_i \times \delta^m + D_i \times \delta^{m+1} + \dots + D_i \times \delta^{n-1}, i=1,2 \quad (5)$$

In the case of finite period game, due to the arbitrariness of m , as long as:

$$U_i > U_i' \Leftrightarrow \frac{R_i(1-\delta^n)}{1-\delta} > \frac{R_i(1-\delta^{m-1})}{1-\delta} + \frac{D_i\delta^m(1-\delta^{n-m})}{1-\delta} + T_i\delta^{m-1}, i=1,2 \quad (6)$$

that is:

$$(T_i - D_i)\delta - (R_i - D_i)\delta^{n-m-1} + (R_i - T_i) > 0, i=1,2 \quad (7)$$

it would ensure that the long-term gains of enterprises choosing honesty are greater than the long-term gains of choosing dishonesty. The (honesty, honesty) is the perfect Nash equilibrium of each subgame. This provides an incentive for enterprises to maintain the stable operation of the alliance and avoid opportunistic or free-riding behavior.

3.2.2 The game with an uncertain number of times

In the process of repeated games, if the last cooperation cannot be determined, all firms are not sure whether there will be another cooperation. Then, it is not clear to the enterprises that the long-term gain from choosing honesty to build a good reputation is better than the gain from choosing dishonesty. So, there will not be the Nash equilibrium mentioned above. The ordinary

reverse induction method also cannot be applied. At this time, in order to achieve the ideal perfect cooperative equilibrium of mutual benefit, the enterprises in the alliance can declare before cooperation that once another partner occurs opportunistic behavior, it will adopt a cold strategy also known as trigger strategy. It means that once a participant chooses a dishonest strategy, the other participants will also choose a dishonest strategy in the next round of the game in order to retaliate. And it keeps repeating.

Proposition 2: In case of uncertainty about the number of collaborations, the cold strategy used by enterprises can effectively maintain the stable operation of the alliance.

Proof: Suppose the cooperation between enterprises has been carried out n times, and we take x and y to be the nodes where any game participant takes a cold strategy and $x < y$. Next, we compare the payoffs of the enterprises under two nodes. When node is taken as x

$$U_i^x = R_i(x-1) + T_i + D(n-x), i=1,2 \quad (8)$$

When node is taken as y

$$U_i^y = R_i(y-1) + T_i + D(n-y), i=1,2 \quad (9)$$

Due to

$$U_i^x - U_i^y = (R_i - D_i)(x-y) < 0, i=1,2 \quad (10)$$

and the arbitrariness of the values of x and y , we know that U_i^n is an increasing function. Therefore, in order to maximize their total gain, the enterprise always hopes that the trigger strategy of other enterprises happens as late as possible, and this also motivates it to choose the integrity strategy all the time. Thus, the stable operation of the coalition is maintained. The proposition is proved.

4. Conclusion

In this paper, the cooperation norms of virtual enterprise alliances are studied. Through the analysis of the classic case of prisoner's dilemma in game theory, we propose several governance mechanisms on the cooperation dilemma of virtual enterprise alliances. And the impact of these mechanisms on the stability of the alliance is analyzed according to the cooperation cycle.

In short-term cooperation, we add a penalty constraint to the game model, leading to the punishment to be paid by enterprises for violating the agreement is greater than the income. The temptation outside the alliance is no longer a strong attraction. In long-term cooperation with a definite number of times, we added the concept of reputation discount factor which leads the enterprises to establish a good reputation in order to obtain long-term benefits. Last, in long-term cooperation with an uncertain number of times, the addition of cold strategy motivates enterprises to choose to be loyal to the alliance and avoid opportunism.

The conditions for maintaining stable cooperation among enterprises are obtained through these three mechanisms which break the cooperation dilemma in the course of alliance operation.

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