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Analysis of evolutionary game on construction of dynamic alliance of engineering project

The paper constructs an evolutionary game model on dynamic alliance of engineering project and analyzes the process of the game. Finally, it is concluded that the expected return, risk and alliance resources are the important factors that affect dynamic alliance of engineering project. On the basis, a solution of dynamic alliance is proposed to accelerate the development of the construction.

Keywords: Engineering project, Dynamic Alliance, Evolutionary Game.

1.0 Introduction

The enterprise boundary has been the focus since the introduction of Coase's transaction cost of enterprise into economic analysis, in which the cost of different enterprise behaviours is attributed to the capital specificity, uncertainty and frequency of transaction. (Williamson, 1985), and the boundary is determined by the ratio between the transaction cost and internal cost of enterprise. However, the dynamic alliance, neglecting the boundary, is a loose one formed by enterprise associated with others based on market prediction, in which the members offer core competitiveness voluntarily apart from sharing the resources from others. The alliance dismisses when opportunity is over, and the members choose to be cooperative or not according to the future market chance. It is characterized by flexibility, looseness, and shared revenues and ventures, which helps enterprises to lower the internal cost by breaking the limits of tradition of group-building and to decrease the transaction cost of the members by sharing resources and ventures.

Dynamic alliance is highlighted in architecture study both home and abroad for its advantages in complementary superiorities, quick reaction to market, efficient project construction, comprehensive improvement of competitivenes and promoting industry transformation. [1] Study on dynamic alliance covers its operation advantages, structure and mode as well as benefit distribution. O. Abudayyeh [2], Jorgensen [3], Charles Tennant [4], Tarek M. Hassan[5] dealt with respectively its advantages in project management from different angles; Sherif Mohamed [6] analyzed its operation structure in architecture projects; Lei Liu [7] studied its operation mode; and Ping Lv [8] probed into its benefit distribution between general contractor and distributors. Concentrating on evolutionary game model of dynamic alliance of engineering project, this paper analyzes the mechanism of different factors and simulates the evolutionary trend with data to testify the proposal of constructing dynamic alliance for win-win situation, which significantly supplements related theory and helps improve the competitiveness and efficient of enterprises in transformation and sustainable development.

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2.0 Evolutionary game model of dynamic alliance of engineering project

Different parts are involved in project including proprietor, designer, inspector, contractor, and so on, whose alliance currently named "general contact" is a preliminary form of evolutionary one that is much more advantageous in sharing information and integrating the resources. However, the "general contact" prevents the enterprises from information communication aiming at developing the core competitiveness, while the dynamic alliance, initiated by general contractor or proprietor, allots resources in accordance with project need instead of maximum revenue of individual enterprise, selects more advantageous member to complement and reconstruct the productivity for more specialization and lower cost, and organizes the information communication inside to reduce the uncertainty and transaction cost, which all quicken integration of core resources to meet the market need and specialize the co-operation for higher efficiency and quality needed by win-win development, transformation and sustainability.

The evolutionary game model of dynamic alliance of engineering project is built to analyze the its mechanism and influential factors, in which the initiator is "leader" and the other participators are "members". The incomes and ventures are assumed as following:

Assumption 1: i_x is expected income when leader x unallied, r_x is his resources for alliance, λ_x is x' income coefficient in alliance, showing the multiple increase of income when allied; v_x is x' venture coefficient when allied, $r_y\lambda_x$ is expected income of leader for alliance; and $r_x v_x$ is x' initiative cost to construct dynamic alliance.

Assumption 2: i_y is expected income when member y unallied; r_y is his resources for alliance, λ_y is $y's$ income coefficient in alliance, showing the multiple increase of income when allied; v_y is $y's$ venture coefficient when allied; $r_x\lambda_y$ is expected income of member for alliance; and $ryvy$ is x' initiative cost to construct dynamic alliance.

The Payoff matrix is as shown in Table 1:

TABLE 1: PAYOFF MATRIX OF LEADER AND MEMBER IN DYNAMIC ALLIANCE GAME

Income		Member	
		Allied	Unallied
Leader	Allied	$i_x + r_y\lambda_x - r_x v_x$, $i_y + r_x\lambda_y - r_y v_y$	$i_x - r_x v_x$, i_y
	Unallied	i_x, $i_y - r_y v_y$	i_x, i_y

Assume that alliance begin, the ratio of leaders choosing to ally be $p=p(t)$, and that of members $q=q(t)$, of which the dynamic evolution is shown that:

The incomes of leaders when allied and unallied respectively are:

$$EUx_p = q(i_x + r_y\lambda_x - r_x v_x) + (1-q)(i_x - r_x v_x)$$
$$EUx_{1-p} = q(i_x) + (1-q)(i_x)$$

And: The average income of leaders' mixed strategy is:

$$\begin{aligned} EUx &= pEUx_p + (1-p)EUx_{1-p} \\ &= p[q(i_x + r_y\lambda_x - r_x v_x) + (1-q)(i_x - r_x v_x)] + (1-p)i_x \end{aligned}$$

Due to mutual imitation and elimination between leaders, $p=p(t)$ evolves by mimicking the dynamic equation, shown as dynamic differential equation;

$$\frac{dp}{dt} = p(EUx_p - EUx) = p(1-p)(qr_y\lambda_x - r_x v_x) \quad \text{... (1)}$$

Thus, that of members is:

$$\frac{dq}{dt} = q(EUyq - EUy) = q(1-q)(pr_x\lambda_y - r_y v_y) \quad \text{... (2)}$$

In Equation (1), when $\frac{dp}{dt} = 0$, $p = 0$, $p = 1$, or $q = \frac{r_x v_x}{r_y \lambda_x}$ and the ratio of leaders choosing to ally is stable;

In (2), when $\frac{dq}{dt} = 0$, $q = 0$, $q = 1$, or $p = \frac{r_y v_y}{r_x \lambda_y}$, and the ratio of members choosing to ally is stable;

Thus, the balanced point of evolutionary game when both leaders and members select alliance are (0,0), (1,0), (0,1), (1,1), (p*, q*), where $p^* = \frac{r_y v_y}{r_x \lambda_y}$, $q^* = \frac{r_x v_x}{r_y \lambda_x}$.

3.0 Evolution of dynamic alliance of engineering project

Based on method by Friedman [9], the evolution stability of dynamic alliance of leaders and members can be analyzed by Jacobian matrix where:

Jacobian matrix of equation (1) and (2) is

$$J = \begin{pmatrix} (1-2p)(qr_y\lambda_x - r_x v_x) & pr_y\lambda_x(1-p) \\ qr_x\lambda_y(1-q) & (1-2q)(pr_x\lambda_y - r_y v_y) \end{pmatrix}$$

then,

The five balanced points mentioned above are defined in Table 2.

TABLE 2: PARTIAL STABILITY ANALYZED WITH JACOBIAN MATRIX

Balanced points	$\|J\|$	$tr(J)$
$p=0, q=0$	$r_x v_x \cdot r_y v_y$	$-r_x v_x - r_y v_y$
$p=1, q=0$	$r_x v_x(r_x\lambda_y - r_y v_y)$	$r_x v_x + r_x\lambda_y - r_y v_y$
$p=0, q=1$	$r_y v_y(r_y\lambda_x - r_x v_x)$	$r_y v_y + r_y\lambda_x - r_x v_x$
$p=1, q=1$	$(r_y\lambda_x - r_x v_x)(r_x\lambda_y - r_y v_y)$	$r_x v_x - r_y\lambda_x + r_y v_y - r_x\lambda_y$
$p=\frac{r_y v_y}{r_x\lambda_y}, q=\frac{r_x v_x}{r_y\lambda_x}$	$(r_y\lambda_x - r_x v_x)(r_x\lambda_y - r_y v_y)\cdot\frac{v_x v_y}{\lambda_x\lambda_y}$	0

Then four preposition are concluded:

Preposition 1: when $r_y\lambda_x > r_x v_x$, $r_x\lambda_y > r_y v_y$, $|J|>0$, (0,0) and (1,1) are Evolutionary Stable Strategy (ESS).

Proof: when $r_y\lambda_x > r_x v_x$, $r_x\lambda_y$, $|J|>0$ at (0,0) and (1,1), and $tr(J)<0$; thus both points are ESS. At (p^*, q^*), $|J|>0$, and $tr(J)=0$ is saddle point, while, at (1,0) and (0,1), $|J|>0$ and $tr(J)>0$ is unstable balanced points.

Proposition 1 tells: if the expected revenues of leader and member in alliance is respectively higher than their costs, (0,0) and (1,1) are stable points. The broken line ABC is a critical line when the system converges to different levels. When initiation is in ADCO, it converges to (0,0), and the leader and member select unallied strategy; when in ADCB, it converged to (1,1), alliance forms as ideal situation. Therefore, different initiations may evolve to various levels where there is (allied, allied), or (unallied, unallied).

Proposition 2: When $r_y\lambda_x > r_x v_x$, $r_x\lambda_y > r_y v_y$ the stable strategy is (0,0).

Proof: when $r_y\lambda_x > r_x v_x$, $r_x\lambda_y > r_y v_y$, $|J|>0$ at (0,0), and $tr(J)<0$ where there is an ESS. And $|J|>0$ at (1,0) 和 (1,1), with uncertain $tr(J)$, the two are saddle points; while $|J|>0$ at (0,1) as unstable balanced one with $tr(J)>0$.

Proposition 2 defines: the leader x with lower expected revenue than cost and member y with higher one than cost will select (unallied, unallied) as ESS. Both sides unallied strategy leads to convergence to (0,0).

Proposition 3: when $r_y\lambda_x > r_x v_x$, $r_x\lambda_y < r_y v_y$, evolution stability point is at (0,0).

Proof: when $r_y\lambda_x > r_x v_x$, $r_x\lambda_y < r_y v_y$, $|J|>0$ at (0,0), and $tr(J)<0$ and (0,0) is an ESS. $|J|>0$ at both saddle points (0,1) and (1,1) with uncertain $tr(J)$, while $|J|>0$ at (1,0), and $tr(J)>0$ is an unstable balanced point.

Proposition 3 indicates: x with higher expected revenue than cost and y with lower one choose (unallied, unallied) as

ESS where the system converges to (0,0).

Proposition 4: when $r_y\lambda_x<r_xv_x$, $r_x\lambda_y<r_yv_y$ ESS is (unallied, unallied).

Proof: when $r_y\lambda_x<r_xv_x$, $r_x\lambda_y<r_yv_y$, |J|>0 at (0,0), and $tr(J)<0$; thus, (0,0) is an ESS. At saddle points (0,1) and (1,0), |J|<0 with uncertain $tr(J)$ but |J|>0 at (1,1) and $tr(J)>0$ is unstable balanced point.

Proposition 4 presents: x and y both predicting lower revenue than cost respectively will refuse alliance for stability that it converges to (0,0).

4.0 Parameter simulation

In order to verify the 4 propositions, numerical simulation is used to show the evolution trajectory from initiative to balanced point. Assume the r_x is 200, λ_x is 2, and v_x is 1; r_y is 200; λ_y is 2, and v_y is 1. Random points (0.7, 0.4), (0.3, 0.8), (0.4, 0.1) and (0.2, 0.5) represented respectively four ratios of building dynamic alliance initially. It is assumed that (p, q) being initial situation of dynamic alliance game lies randomly and evenly in $\{(p,q)|0\le p\le 1, 0\le q\le 1\}$

4.1 Calculation based on initial assignment

Based on the parameter assignment above, $r_y\lambda_x > r_xv_x$, $r_x\lambda_y > r_yv_y$, meets $r_y\lambda_x > r_xv_x$, and $r_x\lambda_y > r_yv_y$ as shown in Fig.1, that when the ratios of initial alliance strategy are (0.7, 0.4) and (0.3, 0.8), the system evolves to (1,1) but (p,q) is initially (0.4, 0.1) and (0.2, 0.5), it evolves to (0,0). The strategy selection evolvement is determined by the proportion of initial enterprises in dynamic alliance. And the preliminary comparison between the two initial proportions showed that the higher the proportion of selecting alliance is, the more likely it is to evolve to dynamic one, and vice versa. Therefore, the different initiation evolves to different result which is characterized by route dependence [10].

4.2 When v_x rises

If v_x rises, v_x=2.5, $r_x\lambda_y > r_yv_y$, but $r_x\lambda_y > r_yv_y$, meet and as

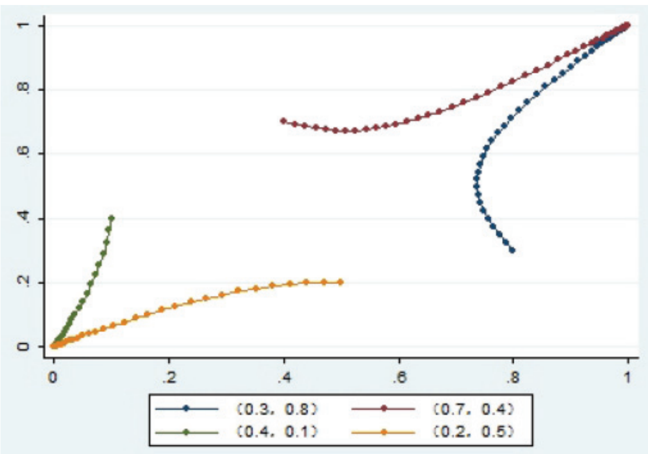

Fig .1: Dynamic evolution of proposition 1

shown in Fig.2. that the evolution result shows (p,q) is approaching to (0, 0) that is, the strategy is (unallied, unallied).

4.3 When r_x drops

If r_x drops, r_x=90, $r_y\lambda_x > r_xv_x$, but $r_x\lambda_y < r_yv_y$, meets $r_y\lambda_x > r_xv_x$ and $r_x\lambda_y < r_yv_y$ shown as in Fug.3, which tells strategy (unallied, unallied) is finally adopted.

4.4 When both x and y drop

When both λ_x and λ_y drop, λ_x= 0.9, λ_y= 0.9, and meet $r_y\lambda_x > r_xv_x$, $r_x\lambda_y > r_yv_y$, which is shown in Fig.4, that the unallied strategy is finally selected.

The parameter simulation above analyzed the change of risk coefficient, resources etc., which is true of that of members. It defines that the leader and member are inclined to strategy (allied, allied) with more probability for alliance when lowering the risks, increasing revenue and improving allying resources.

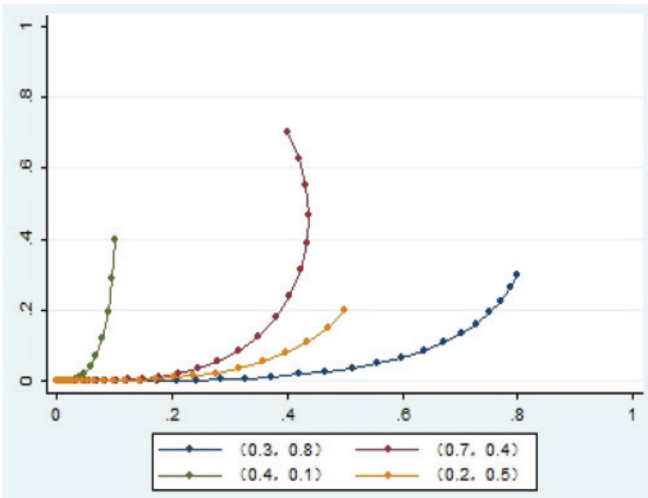

Fig.2: Dynamic evolution of proposition 2

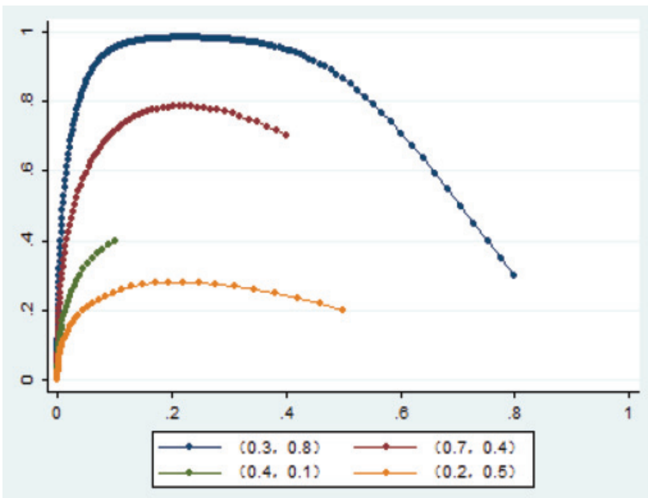

Fig.3: Dynamic evolution of proposition 3

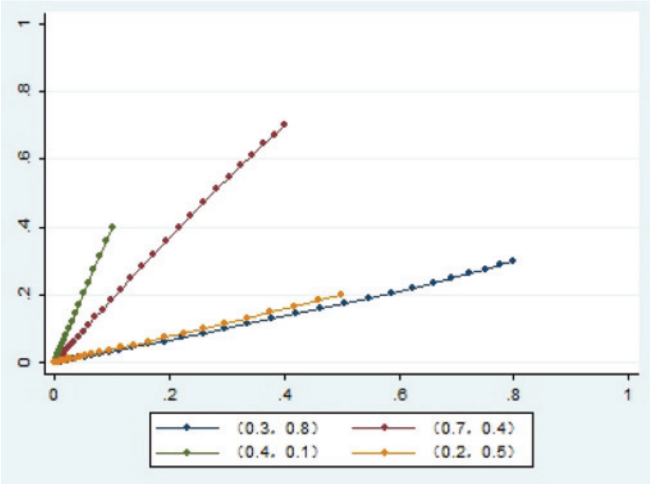

Fig.4: Dynamic evolution of proposition 4

5.0 To construct cooperative route selection of dynamic alliance of engineering

The paper analyzed strategic selection among architectural enterprises and evolution process of its equilibrium condition by means of game model, and it was found that the long-term equilibrium is affected by payoff parameter based on parameter simulation and the strategy could be evolved to (allied, allied) by parameter adjustments like increasing revenue coefficient, lowering risk and promoting resources sharing, etc..Then, the cooperative route of engineering project based on dynamic alliance at higher level was proposed.

5.1 To construct risk prevention to decrease the risk for building the alliance

The risk-sharing principle in dynamic alliance may lead to more risks rather than reduce the risk of architecture enterprises because of multiple cooperation, information asymmetry, cooperative dynamics and other factors, which result in more management risk for enterprises. Thus, A risk prevention system should be developed through the alliance, a evaluation system should be adopted to find the possible risk and assess its occurrence and related loss in order to classify its influences for future prevention and strategy.

5.2 To stimulate the innovation to improve core competitiveness of alliance members

The alliance breaks the boundary of enterprises and enables them to make full use of their core competitiveness for lower cost and risk and benefit-sharing. The competiveness exists in the form of resources strength, technical innovation, managing efficiency, or marketing ability, which helps the enterprise ally with complementary advantages to focus the development on its strength by stimulating innovation instead of unfavourable competition and to raise core competitiveness by more fund in technique, human resources, and equipment.

5.3To distribute the benefit rationally to raise the members revenue

The dynamic alliance, as a typical cooperative game, requires higher revenue from its cooperation than the sum of that of individual enterprises, higher revenue of each allied enterprise than that when allied, and fair revenue distribution as well because rational selection contributes dynamic alliance for more revenue while irrational one lower the efficiency even failure in allying. Moreover, according to fair principle, the investment from enterprises with different cultures should be rewarded with appropriate revenue in order to stimulate the efficiency in the long run, and even some enterprises may benefit less in a short period, the alliance can be developed without reluctance.

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