Research on the Tripartite Evolution Game of Cooperative Relationship of Collaborative Innovation Network of New Energy Vehicle Industry under the Dominant Roles of Core Enterprises

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Keywords: The Dominant Roles of Core Enterprises, New Energy Vehicle Industry, Collaborative Innovation Network, Evolutionary Game.

Abstract: The paper uses evolutionary game theory to establish an evolutionary game model and software simulation to simulate the impact of the dominant roles of core enterprise on the evolution of collaborative innovation network of new energy vehicle industry. The research shows that the dominant roles of core enterprises can better guide the evolution of the cooperative relationship of the collaborative innovation network, the network reward and punishment mechanism, collaborative innovation benefits distribution mechanism, market risk taken mechanism and knowledge transfer mechanism all have an important impact on the selection of multi-agent strategy behavior and the evoluti1on of collaborative innovation network, and the strategy selection behavior of industry, university and research institutes has an important impact on the exercise of the dominant roles of core enterprises.

1 INTRODUCTION

With the ever-increasing contradiction between energy supply and demand, research and development (R&D) and promotion of new energy vehicles have become effective measures to alleviate resource scarcity and environmental problems. China's new energy vehicle market promotion level ranks among the top in the world, but the development of technology research and development compared with Germany and other automotive powers is lagging behind (Tang, 2019). Collaboration is conducive to identify and discover direct or potential opportunities (Xu, 2018), build rich information channels (Wang, 2020; PEMARTIN, 2018) and collaborative innovation networks are the ideal carrier for innovation in strategic emerging industries such as new energy vehicles (Jiao, 2015).

New energy vehicles and other strategic emerging industries have great potential and growth space, and dominance plays a great role in improving network construction (Lovejoy, 2010). Many scholars, such as Zhong Taiyong (Zhong, 2015), Sun Hongxia (Sun, 2018), Jiang Cailou (Jiang, 2020) from the perspective of government leadership, have conducted important theoretical and exploratory analysis of the government dominant roles of collaborative innovation network of China's new energy vehicle industry, the collaborative innovation networks' development of strategic emerging industries under the dominant roles of core enterprises are more effective than under the dominant roles of government (Jiao, 2015), but there are still certain research gaps in dominant roles of core enterprises. Aiming at the existing research gaps and combining the research results of relevant scholars, this paper uses evolutionary game theory to establish an evolutionary game model among enterprises, URIs and core enterprises and software simulation to simulate the impact of the dominant roles of core enterprise on the evolution of collaborative innovation network of new energy vehicle industry.

2 EVOLUTIONARY GAME MODEL CONSTRUCTION

2.1 Analysis of The Interests of Various Members

(1) The core enterprises' strategy space is positive or

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negative exercising dominant roles, and its strategy selection probability is z and $(1-z)$ ($z \in [0,1]$). The dominance of the core enterprise in the collaborative innovation network is realized by reward and punishment mechanism, collaborative innovation benefits distribution mechanism, market risk taken mechanism and knowledge transfer mechanism. When the core enterprises actively exercises dominant roles, the network management cost ' C_e ' will be paid, but can obtain the subsidies ' G_3 ', generate the innovative benefits ' R_c ' with the enterprises and URIs, and obtain the income ' $(1-P_1-P_2)R$ 'of the management network and at the same time, take a corresponding market risk ' $(1-P_1-P_2)D$ ', the core enterprises have a greater voice for the allocation of the collaborative innovation earnings; if the core enterprises are negatively exercising dominant roles, it does not participate in the cooperation, only helping the enterprises and URIs to distribute the benefits and risk.

(2) The strategy space of the enterprises is cooperation (x) or default $(1-x)$ When enterprises choose to default, costs ' C_1 ' and obtains revenue ' R_1 ', and also gets betrayal benefits ' E_1 ', but if the enterprises' unilateral default should pay a contract ' F ', and have a reputation loss ' L_e '. When the enterprises' choose cooperation, at the time, collaborative innovation costs ' C_3 ', enterprises always obtain government subsidies ' G_1 ' and undertake marketization risks ' P_1D '. If the core enterprises actively exercise dominant roles, enterprises can always have knowledge transfer benefits ' R_e '. If URIs choose to cooperate, the enterprise and URIs have produced collaborative innovation benefits ' R ', and collaborative innovation revenue is allocated among enterprises, URIs and core enterprises with ' P_1 ', ' P_2 ' and' $(1-P_1-P_2)$ '. if the URL choose default, the enterprises receive compensation ' F '.

(3) The strategy space of URIs is cooperation (y) or default $(1-y)$. When the URIs choose to default, the independent innovation costs URIs ' C_2 'and obtains benefits' R_2 ', and also gains betrayal benefits ' E_2 ', but if the unilateral default is required to pay ' F ', and have a reputation loss ' L_u '. When URIs choose collaborative innovation, the costs are ' C_4 ' and marketization risks are ' P_2D ', it always able to obtain subsidies ' G_2 '

2.2 Payoff Matrix Construction

The payoff matrix of three populations under dominant roles of the core enterprises is as follows. The dynamic replication system of enterprises, URIs and core enterprises can be obtained as follows:

$$\begin{cases} V(x)=\frac{d_x}{d_t}=x(1-x)[(P_1R-P_1D-E_1)y+(R_e+F)z+G_1+C_1+L_e-C_3-R_1] \\ V(y)=\frac{d_y}{d_t}=y(1-y)[(P_2R-P_2D-E_2)x+(R_e+F)z+G_2+C_2+L_u-C_4-R_2] \\ V(z)=\frac{d_z}{d_t}=z(1-z)(R_cx+R_cy-R_cxy+G_3-C_e-\alpha R_e) \end{cases}$$

2.3 Stability Analysis

Table 1: Payoff matrix of three populations.

Strategy of Core enterprises	Strategy of Enterprises and URIs	Payoff		
		Enterprises	URIs	Core enterprises
The positive dominant roles	(cooperation, cooperation)	$P_1+R_e+G_1-C_3-P_1D$	$P_2+R_e+G_2-C_4-P_2D$	$(1-P_1-P_2)R+R_c+G_3-C_e-\alpha R_e-(1-P_1-P_2)D$
	(default, cooperation)	$R_1+E_1-C_1-F-L_e$	$R_e+G_2+F-C_4$	$R_c+G_3-C_e-\alpha R_e$
	(cooperation, default)	$R_e+G_1+F-C_3$	$R_2+E_2-C_2-F-L$	$R_c+G_3-C_e-\alpha R_e$
	(default, default)	$R_1-C_1-L_e$	$R_2-C_2-L_u$	$G_3-C_e-\alpha R_e$
The negative dominant roles	(cooperation, cooperation)	$P_1R+G_1-C_3-P_1D$	$P_2R+G_2-C_4-P_2D$	$(1-P_1-P_2)R-(1-P_1-P_2)D$
	(default, cooperation)	$R_1+E_1-C_1-L_e$	G_2-C_4	0
	(cooperation, default)	G_1-C_3	$R_2+E_2-C_2-L_u$	0
	(default, default)	$R_1-C_1-L_e$	$R_2-C_2-L_u$	0

Table 2: Eigenvalues of each equilibrium point corresponds to the Jacobi matrix.

Equilibrium point	Eigenvalues λ_1	Eigenvalues λ_2	Eigenvalues λ_3
$E_1(0,0,0)$	$G_1+C_1+L_e-C_3-R_1$	$G_2+C_2+L_u-C_4-R_2$	$G_3-C_e-\alpha R_e$
$E_2(0,1,0)$	$P_1R-P_1D-E_1+G_1+C_1+L_e-C_3-R_1$	$-(G_2+C_2+L_u-C_4-R_2)$	$R_C+G_3-C_e-\alpha R_e$
$E_3(0,1,1)$	$P_1R-P_1D-E_1+R_e+F+G_1+C_1+L_e-C_3-R_1$	$-(R_e+F+G_2+C_2+L_u-C_4-R_2)$	$-(R_C+G_3-C_e-\alpha R_e)$
$E_4(0,0,1)$	$R_e+F+G_1+C_1+L_e-C_3-R_1$	$R_e+F+G_2+C_2+L_u-C_4-R_2$	$-(G_3-C_e-\alpha R_e)$
$E_5(1,0,0)$	$-(G_1+C_1+L_e-C_3-R_1)$	$P_2R-P_2D-E_2+G_2+C_2+L_u-C_4-R_2$	$R_C+G_3-C_e-\alpha R_e$
$E_6(1,0,1)$	$-(R_e+F+G_1+C_1+L_e-C_3-R_1)$	$P_2R-P_2D-E_2+R_e+F+G_2+C_2+L_u-C_4-R_2$	$-(R_C+G_3-C_e-\alpha R_e)$
$E_7(1,1,0)$	$-(P_1R-P_1D-E_1+G_1+C_1+L_e-C_3-R_1)$	$-(P_2R-P_2D-E_2+G_2+C_2+L_u-C_4-R_2)$	$R_C+G_3-C_e-\alpha R_e$
$E_8(1,1,1)$	$-(P_1R-P_1D-E_1+R_e+F+G_1+C_1+L_e-C_3-R_1)$	$-(P_2R-P_2D-E_2+R_e+F+G_2+C_2+L_u-C_4-R_2)$	$-(R_C+G_3-C_e-\alpha R_e)$

Table 3: The judgment of the eigenvalues of each equilibrium point corresponds to the Jacobi matrix.

Equilibrium point	Situation1-1	Situation 1-2	Situation 2-1	Situation2-2	Situation 3-1	Situation3-2	Situation 4-1	Situation4-2
	$\lambda_1,\lambda_2,\lambda_3$	$\lambda_1,\lambda_2,\lambda_3$	$\lambda_1,\lambda_2,\lambda_3$	$\lambda_1,\lambda_2,\lambda_3$	$\lambda_1,\lambda_2,\lambda_3$	$\lambda_1,\lambda_2,\lambda_3$	$\lambda_1,\lambda_2,\lambda_3$	$\lambda_1,\lambda_2,\lambda_3$
$E_1(0,0,0)$	+++	++-	+-+	+--	-++	-+-	--+	---(ESS)
$E_2(0,1,0)$	+-+	+-+	+++	+++	--+	--+	-++	-++
$E_3(0,1,1)$	+--	+--	++-	++-	---(ESS)	---(ESS)	-+-	-+-
$E_4(0,0,1)$	++-	+++	+--	+-+	-+-	-++	---(ESS)	--+
$E_5(1,0,0)$	-++	-++	--+	--+	+++	+++	+-+	+-+
$E_6(1,0,1)$	-+-	-+-	---(ESS)	---(ESS)	++-	++-	+--	+--
$E_7(1,1,0)$	--+	--+	-++	-++	+-+	+-+	+++	+++
$E_8(1,1,1)$	---（ESS)	---(ESS)	-+-	-+-	+--	+--	++-	++-

The conditions in each situation are as follows:

1-1: When $P_1R-P_1D+G_1-C_3>R_1-C_1-L_e+E_1, P_2R-P_2D+G_2-C_4>R_2-C_2-L_u+E_2, G_3>C_e+\alpha R_e,$

1-2: When $P_1R-P_1D+G_1-C_3>R_1-C_1-L_e+E_1, P_2R-P_2D+G_2-C_4>R_2-C_2-L_u+E_2, G_3<C_e+\alpha R_e,$

2-1: When $P_1R-P_1D+G_1-C_3>R_1-C_1-L_e+E_1, P_2R-P_2D+R_e+F+G_2-C_4<R_2+E_2-C_2-L_u, G_3>C_e+\alpha R_e,$

2-2: When $P_1R-P_1D+G_1-C_3>R_1-C_1-L_e+E_1, P_2R-P_2D+R_e+F+G_2-C_4<R_2+E_2-C_2-L_u, G_3<C_e+\alpha R_e,$

3-1: When $P_1R-P_1D+R_e+F+G_1-C_3<R_1+E_1-C_1-L_e, P_2R-P_2D+G_2-C_4>R_2-C_2-L_u+E_2, G_3>C_e+\alpha R_e,$

3-2: When $P_1R-P_1D+R_e+F+G_1-C_3<R_1+E_1-C_1-L_e, P_2R-P_2D+G_2-C_4>R_2-C_2-L_u+E_2, G_3<C_e+\alpha R_e,$

4-1: When

$P_1R-P_1D+R_e+F+G_1-C_3<R_1+E_1-C_1-L_e, P_2R-P_2D+R_e+F+G_2-C_4<R_2+E_2-C_2-L_u, G_3>C_e+\alpha R_e,$

4-2: When

$P_1R-P_1D+R_e+F+G_1-C_3<R_1+E_1-C_1-L_e, P_2R-P_2D+R_e+F+G_2-C_4<R_2+E_2-C_2-L_u, G_3<C_e+\alpha R_e,$

In summary, in situation 4-1 and situation 4-2 the evolutionary stability strategy is (default, default, play positive dominant roles) and (default, default, play negative dominant roles),the two situations are less in reality; in addition to these two situations, it can be seen that the new energy vehicle industry collaborative innovation network are more effective under the positive dominant roles of core enterprise, the dominant roles of core enterprise can better guide the evolution of innovative network partnerships, while how core enterprises play dominant roles to make the enterprises and URIs tend to cooperate more efficiently, is one of the important directions of research.

3 MULTI-BODY SIMULATION AND ANALYSIS

In order to simulate the distribution law of the situation and evolutionary stability strategy in realities better, this paper uses software to simulate the evolutionary process, and discuss the different parameters' influence to the network's evolution under the dominant roles of core enterprises. According to the consultation of experts and combined with the setting rules of simulation parameters in related literature (Cao, 2020), setting C_1=6, C_2=2, C_3=12, C_4=5, C_e=5, α=0.2, R_1=9, R_2=7, R=30, R_c=7, G_1=2, G_2=1, G_3=2, D=9, E_1=12, E_2=9, $L_e = 6, L_u = 4$, $F = 6$; $P_1 = 0.5$, $P_2 = 0.3$, $(1 - P_1 - P_2) = 0.2$, $R_e = 7$, setting the initial cooperation willingness of enterprises, URIs and core enterprises is 0.5.

3.1 The Influence of Reward and Punishment Mechanism on the Evolution of New Energy Vehicle Industry under the Dominant Roles of Core Enterprises

As can be seen from the figures, under low-intensity rewards and punishment mechanisms, due to higher betrayal benefits and lower default punishment, the cooperation willingness of the enterprises and URIs will show a decline and tend to default strategy, and their collaborative innovation revenue is reduced, so that core enterprises' benefits of management collaborative innovation network have reduced, causes that core enterprises tend to adopt negatively dominant roles; under the mid-intensity and high-intensity rewards and punishment mechanisms, the network reward highly the single cooperation, and penal highly the single default, the cooperation willingness of enterprises and URIs will rise and higher collaborative innovation benefits have produced, and core enterprises have obtained visual management collaborative innovation benefits, which tends to adopt positive dominant roles.

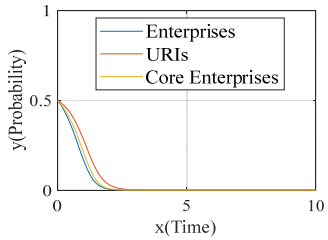

Figure 1: Evolution path under $F = 1$.

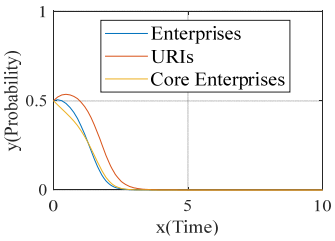

Figure 2: Evolution path under $F = 3$.

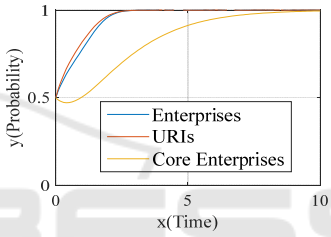

Figure 3: Evolution path under $F = 6$.

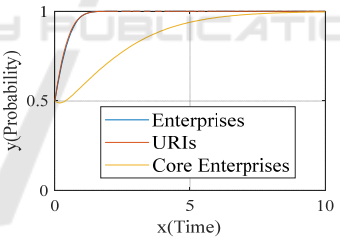

Figure 4: Evolution path under $F = 10$.

3.2 The Influence of Benefits Distribution Coefficients and Market Risk Taken Coefficients on the Evolution of New Energy Vehicle Industry under the Dominant Roles of Core Enterprises

When $P_1 = 0.5, P_2 = 0.3, (1 - P_1 - P_2) = 0.2; P_1 = 0.7, P_2 = 0.2, (1 - P_1 - P_2) = 0.1; P_1 = 0.4, P_2 = 0.4, (1 - P_1 - P_2) = 0.2$, the benefits distribution coefficient and the market risk taken coefficient of the enterprises, the URIs and core enterprises basically meet the cost and elements investment laws, the network ultimately tends to (cooperation,

cooperation, play positive dominant roles). When$P_1 = 0.3, P_2 = 0.2$, $(1 - P_1 - P_2) = 0.5$, the core enterprises' investments in the cost and elements of the collaborative innovation project are less than that of enterprises and the URIs, but the benefits allocation coefficient is higher than the two, enterprises and URIs adopt a default strategy and produce small collaborative innovation benefits, the core enterprises finally choose negative dominant roles.

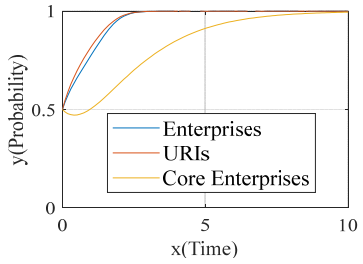

Figure 5: Evolution path under $P1 = 0.5, P2 = 0.3$.

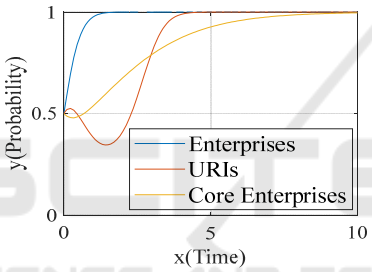

Figure 6: Evolution path under $P1 = 0.7, P2 = 0.2$.

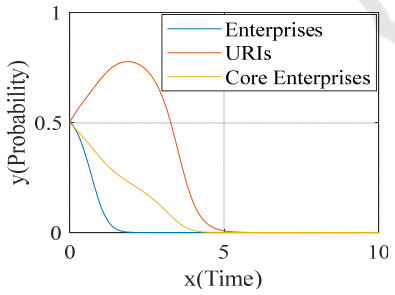

Figure 7: Evolution path under $P1 = 0.3, P2 = 0.2$.

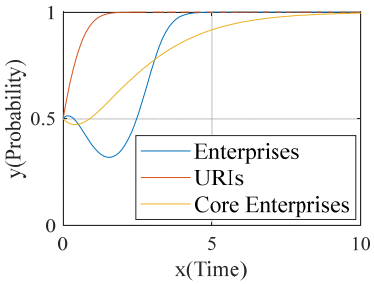

Figure 8: Evolution path under $P1 = 0.4, P2 = 0.4$.

3.3 The Influence of Core Enterprises Knowledge Transfer Revenue on the Evolution of New Energy Vehicle Industry under the Dominant Roles of Core Enterprises

Low core enterprise knowledge transfer is not conducive for enterprise and URIs to knowledge accumulation and technical breakthrough, higher core enterprise knowledge transfer does not meet the investment law of core enterprises, enterprises and URIs obtain moderate core enterprise knowledge transfer benefits, that is, core enterprises pay in moderate core enterprises knowledge transfer costs, it is good for multi-body selection cooperation strategies and the optimal stability evolution of the network.

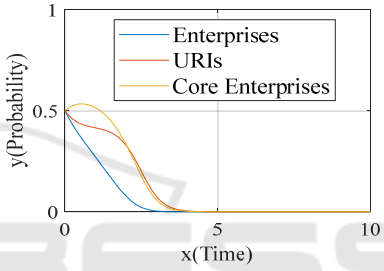

Figure 9: Evolution path under $R_e = 1$.

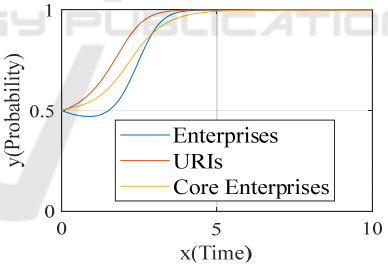

Figure 10: Evolution path under $R_e = 3$.

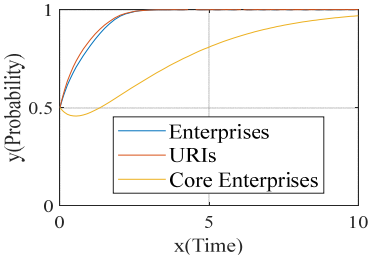

Figure 11: Evolution path under $R_e = 8$.

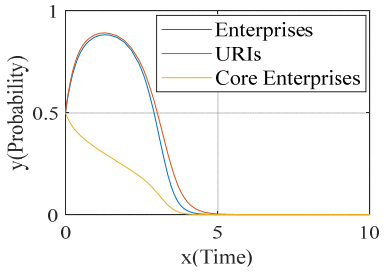

Figure 12: Evolution path under $R_e = 12$.

4 CONCLUSION

Based on the results and discussions presented above, the conclusions are obtained as below:(1) The new energy vehicle industry collaborative innovation network is more effective under the positive dominant roles of core enterprises; (2) The dominant roles of core enterprises have an important influence on multi-body strategic behavior and collaborative innovation network evolution , and the choice of subjects' behavior selection has an important influence on the dominant roles of core enterprises as well; (3) With the increasing of the reward for the only cooperation members and the penalty for the only breaching members, enterprises and URIs in the network have tend to the stable strategy of cooperation, and the greater the improvement, the faster the speed of cooperation; (4)When the benefits distribution and the marketing risk taken basically meet the cost and elements investment laws, the network ultimately tends to the optimal stability condition; (5)Enterprises and URIs obtain moderate core enterprise knowledge transfer benefits, that is, core enterprises pay in moderate core enterprises knowledge transfer costs, it is good for the optimal stability evolution of the network.

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