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RESEARCH ARTICLE

Dynamic Mechanism of Intelligent Logistics Talent Cultivation in the Guangdong-Hong Kong-Macao Greater Bay Area: An Evolutionary Game Perspective on Industry-Education Integration

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Abstract

Based on the perspective of industry-education integration, this paper constructs an evolutionary game dynamic model of "enterprises (EN) - universities and research institutions (RI)". It examines the dynamic mechanism of cultivating intelligent logistics talent in the Guangdong, Hong Kong, and Macao Greater Bay Area and identifies the conditions for the stability of this mechanism. The conclusions indicate that when RI chooses the "Negative R&D" strategy, EN obtains higher benefits from "Continued Cooperation" than from "Exit". When RI chooses the "Active R&D" strategy, EN also obtains higher benefits from "Continued Cooperation" than from "Exit". Furthermore, when EN chooses the "Exit" strategy, RI obtains higher benefits from "Active R&D" than from "Negative R&D". When the benefit to RI from choosing "Active R&D" exceeds that from "Negative R&D" under the "Exit" strategy of EN, the system eventually evolves to the strategy combination of "Continued Cooperation" and "Active R&D".

Keywords: Guangdong-Hong Kong-Macao Greater Bay Area, intelligent logistics talent cultivation, evolutionary game, power mechanisms.

1 Introduction

On February 18, 2019, the Central Committee of the Communist Party of China and the State Council issued the Outline of the Plan for the Development of the Guangdong-Hong Kong-Macao Greater Bay Area. This plan aims to establish the most dynamic international first-class bay area and create a hub for emerging industries, advanced manufacturing, and modern services globally. Over the past two years, driven by various new policies and leveraging the advantages of large-scale manufacturing and a robust industrial foundation, the Guangdong-Hong

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Kong-Macao Greater Bay Area has propelled rapid development in advanced and high-tech manufacturing industries, with a focus on intelligent manufacturing. The added value of the advanced manufacturing industry in the Greater Bay Area increased from 12,562.2 billion yuan in 2015 to 16,886.6 billion yuan in 2020, accounting for 51.1% of the scale industry's added value in Guangdong Province. Similarly, the added value of the high-tech manufacturing industry rose from 711.59 billion yuan in 2015 to 1,156.64 billion yuan in 2020, constituting 35% of the scale industry's added value in Guangdong Province. Intelligent manufacturing in the Greater Bay Area has experienced rapid development, gradually establishing a comprehensive automated, digitalized, and intelligent industrial system [1].

The development of the intelligent manufacturing industry in the Guangdong-Hong Kong-Macao Greater Bay Area relies heavily on robust support from intelligent logistics. Intelligent manufacturing represents a novel production paradigm that integrates cutting-edge information technologies across all facets of manufacturing, encompassing design, production, management, and service. This approach achieves production and manufacturing through intelligence, automation, and informatization. The advancement of the intelligent manufacturing industry in the Greater Bay Area necessitates a growing demand for highly skilled intelligent logistics professionals. These professionals must possess advanced capabilities in intelligent warehouse management, strategic planning and design of intelligent logistics systems, management of intelligent logistics transportation and distribution, development and maintenance of intelligent logistics facilities and equipment, as well as intelligent logistics supply chain management. However, the supply of intelligent logistics professionals in the Guangdong-Hong Kong-Macao Greater Bay Area falls short of meeting the industry's needs in terms of both quantity and quality. This shortfall has emerged as a bottleneck that constrains the coordinated development of intelligent manufacturing and intelligent logistics [10].

Currently, scholars at home and abroad have made corresponding research on talent cultivation in the Greater Bay Area of Guangdong, Hong Kong and Macao from different perspectives. Liu et al. [2] proposed the construction of an artificial intelligence display and experience training base that integrates scene display, technology experience, industrial cooperation, consulting services, and demonstration training to promote the construction of artificial intelligence disciplines in higher vocational colleges and universities in the Greater Bay Area with the core of AI+X composite talent training. Tang et al. [4] puts forward the path of deepening the integration of industry and education and reconstructing the relationship between industry and education in view of the lack of pertinence in the talent cultivation mechanism of Guangdong, Hong Kong and Macao Greater Bay Area, such as deepening the synergistic cooperation among multiple parties, perfecting the mechanism of deepening the integration, constructing the innovative professional clusters, and perfecting the construction of practical training bases. Ma et al. [6] proposed to implement the reform of the experimental teaching system for cultivating talents in optoelectronic new engineering disciplines for the Guangdong-Hong Kong-Macao Greater Bay Area in accordance with the reform idea of "one center, two fusions, and three reliances", the center of students' engineering practical ability development, as well as the fusion of science, education, and industry. Li et al. [7] proposed to implement the reform of experimental teaching system for cultivating talents in optoelectronic new engineering disciplines for the Guangdong-Hong Kong-Macao Greater Bay Area based on current situation and future development of marine tourism in Guangdong, Hong Kong and Macao Greater Bay Area, analyzed the current situation and problems of marine tourism talents in the Greater Bay Area, and provided a theoretical basis for the coordinated development of tourism development and marine tourism talents development. Li and Wei [8], for the cultivation of marketing talents in the Greater Bay Area of Guangdong, Hong Kong and Macao, put forward to build a marketing curriculum system matching with the capacity of the new industries in the Greater Bay Area,"college + new industry + marketing" and "industry-university-research integrated practice teaching base" [11] systematically analyzed the core of the accumulation of educational resources in the Greater Bay Area of Guangdong, Hong Kong and Macao, the current status of the development of international education in the Greater Bay Area, future opportunities and development paths.

Throughout the literature, both domestically and internationally, it is evident that there are several theoretical gaps in current research [3]. These gaps primarily include:

1. There is a notable lack of studies focusing on the development of intelligent logistics talents,

particularly in the Guangdong-Hong Kong-Macao Greater Bay Area from the perspective of industry-education integration. The practical pathways for cultivating intelligent logistics talents in this region remain unclear.

2. Existing research on talent cultivation in the Greater Bay Area tends to be one-sided and predominantly qualitative, lacking empirical analysis and simulation studies.

3. The current literature emphasizes talent cultivation models, development paths, curriculum reforms, and similar aspects. However, there is a lack of systematic research results concerning empirical analysis of motivational factors for talent cultivation in the Greater Bay Area under the framework of industry-education integration and the simulation of motivational mechanism systems.

This paper seeks to explore the dynamic mechanisms of cultivating intelligent logistics talent in the Guangdong-Hong Kong-Macao Greater Bay Area through the lens of industry-education integration [4]. It constructs a game model depicting the evolution of collaborative innovation between enterprises and educational institutions, aiming to enrich existing research on intelligent logistics talent cultivation in the region. Additionally, it provides theoretical guidance for fostering innovative, multi-skilled, and versatile intelligent logistics professionals who can adapt to the new challenges posed by intelligent manufacturing in the Greater Bay Area.

2 Construction and Analysis of Evolutionary Game Models

2.1 Basic assumptions of the model

The issue of "enterprises being hesitant while research institutes remain static" in the integration of industry and education has long been a barrier to collaborative innovation in industry-university research partnerships. To address this challenge, it is crucial to encourage enterprises to actively engage in University-Industry Collaborative Innovation Alliances, leveraging research institutes' scientific research strengths. This approach aims to achieve mutual benefit through cooperation, fostering stable partnerships between enterprises and research institutes for a win-win outcome. Such efforts hold significant theoretical and practical implications for enhancing the efficiency and effectiveness of industry-university-research collaborations [5].

- **Hypothesis 1:** Considering the actual situation, the main task of most research institutions is to cultivate more innovative talents and promote the transformation of scientific and technological achievements. Therefore, in this article, universities and research institutions are collectively referred to as Research and Innovation (RI). Ultimately, RI and enterprises (EN) become the main participants in collaborative innovation between academia, industry, and research.

- **Hypothesis 2:** In the process of collaborative innovation between academia, industry, and research, the strategy set of enterprises (EN) consists of {continuing cooperation, exiting midway}, while the strategy set of RI consists of {active research and development, passive research and development}.

- **Hypothesis 3:** It is assumed that the costs of EN and RI investing in the alliance are Ce and Cr, respectively, and the benefits of EN are R_{11}, R_{12}, R_{13}, and R_{14} for RI under the strategy combinations of "continue to collaborate, active R&D", "continue to collaborate, negative R&D", "exit, active R&D" and "exit, negative R&D", respectively. In addition, it is assumed that under the strategy combinations of "continued cooperation, active R&D", "continued cooperation, negative R&D", "withdrawal, active R&D", and "withdrawal, negative R&D", the benefits of EN are R_{11}, R_{12}, R_{13}, and R_{14}, respectively, and the benefits of RI are R_{21}, R_{22}, R_{23}, and R_{24}, respectively.In the process of collaborative integration of education and industry, if an enterprise withdraws in the middle of the process, it will suffer from reputation, opportunity cost of R&D output, and government penalty, etc., which is recorded as C_1. At the same time, the RI's negative R&D will also suffer reputation, opportunity to declare research projects, etc., which is recorded as C_2. In addition, if both parties participate in the alliance and eventually achieve results (EN chooses to continue to participate since the beginning, and the RI all along and its participation in R&D), then both parties will receive rewards from the government. Assume that the sum of the incentives is S, and that EN and RI are allocated β and $1-\beta$, respectively. The definitions of all parameters involved in the model are summarized in Table 1.

Table 1. Parameter settings for the evolutionary game model.

Parameters	Clarification
x	Probability of EN quitting in the middle
y	Probability of RI's negative R&D
R_{ij}	Benefits to EN and RI under various combinations of strategies
C_e	Cost of EN investing in the alliance
C_r	Cost of RI investing in the alliance
C_1	Losses incurred when EN withdraws from the alliance
C_2	Losses incurred by RI in case of negative R&D
S	Government incentives
β	Percentage of EN participation in government incentives

2.2 Dynamic payment matrix construction

The returns of EN and RI subjects in different strategy selection scenarios are analyzed to obtain the payment matrix shown in Table 2.

Table 2. Payoff matrix for EN and RI.

		RI	
		Negative R&D (y)	Active R&D (1-y)
EN	Exit (x)	$R_{14}-C_e-C_1$	$R_{13}-C_e-C_1$
		$R_{24}-C_r-C_2$	$R_{23}-C_r$
	Continued Cooperation (1-x)	$R_{12}-C_e$	$R_{11}-C_e+\beta S$
		$R_{22}-C_r-C_2$	$R_{21}-C_r+(1-\beta)S$

Note: Probability of choosing the strategy in parentheses.The first row of each cell is the gain for EN and the second row is the gain for RI .

2.3 Expected gains for EN and RI and improved replicator dynamic equations

As can be seen from Table 2, suppose that the EN's expected return from choosing the "continued cooperation" strategy in the game is E_{11}, the expected return from choosing the "Exit" strategy is E_{12}, The average expected return is E_1. Then

$$E_{11}=(R_{12}-C_e)y+(R_{11}-C_e+\beta S)(1-y) \quad (1)$$

$$E_{12}=(R_{14}-C_e-C_1)y+(R_{13}-C_e-C_1)(1-y) \quad (2)$$

$$E_1=(1-x)E_{11}+xE_{12} \quad (3)$$

The dynamic replication equation for EN's participation in an industry-education alliance is:

$$\begin{aligned}\Phi_1(t)&=\frac{dx}{dt}=x(1-x)(E_{11}-E_{12})\\&=x(1-x)\big(y(R_{12}+R_{13}-R_{11}-R_{14}-\beta S)\\&\quad+R_{11}-R_{13}+C_1+\beta S\big).\end{aligned} \quad (4)$$

As can be seen from Table 2, suppose that the RI's expected return from choosing the "active R&D" strategy in the game is E_{21}, the expected return from choosing the "Exit" strategy is E_{22}, The average expected return is E_2. Then

$$E_{21}=(R_{23}-C_r)x+(R_{21}-C_r+(1-\beta)S)(1-x) \quad (5)$$

$$E_{22}=(R_{24}-C_r-C_2)x+(R_{22}-C_r-C_2)(1-x) \quad (6)$$

$$E_2=(1-y)E_{21}+yE_{22} \quad (7)$$

The dynamic replication equation for RI's participation in the industry-academia alliance is:

$$\begin{aligned}\Phi_2(t)&=\frac{dy}{dt}=y(1-y)(E_{21}-E_{22})\\&=y(1-y)\big(x(R_{22}+R_{23}-R_{21}-R_{24}-(1-\beta)S)\\&\quad+R_{21}-R_{22}+C_2+(1-\beta)S\big)\end{aligned} \quad (8)$$

3 Evolutionary stability analysis

3.1 Solving equilibrium points and asymptotic stability analysis

The evolutionary stability analysis is based on the replicator dynamics framework introduced by Taylor and Jonker [9]. According to their model, the strategy frequencies evolve according to the difference between a strategy's payoff and the average payoff in the population. **A. Solution of Equilibrium Points**

Theorem 1: There are 5 local equilibrium points in the system $A_1(0,0)$, $A_2(1,0)$, $A_3(0,1)$, $A_4(1,1)$, and

$$A_5\left(\frac{-R_{21}+R_{22}-C_2-(1-\beta)S}{R_{22}+R_{23}-R_{21}-R_{24}-(1-\beta)S},\ \frac{R_{13}-R_{11}-C_1-\beta S}{R_{12}+R_{13}-R_{11}-R_{14}-\beta S}\right)$$

Proof: let $\Phi_1(t)=0$, which gives $x=0,1$, or

$$y=\frac{R_{13}-R_{11}-C_1-\beta S}{R_{12}+R_{13}-R_{11}-R_{14}-\beta S}$$

So, these three are the stationary points of differential equation (4).

Similarly, let $\Phi_2(t)=0$, then $y=0,1$ or

$$x=\frac{-R_{21}+R_{22}-C_2-(1-\beta)S}{R_{22}+R_{23}-R_{21}-R_{24}-(1-\beta)S}.$$

So, these three are the stationary points of differential equation (8).

B. Calculate Jacobian matrix We will calculate the first-order partial derivatives for $\Phi_1(t)$, $\Phi_2(t)$, respectively, to obtain the Jacobian matrices of equations (4) and (8).

$$J = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$$

when

$$a_{11} = (1-2x)(y(R_{12}+R_{13}-R_{11}-R_{14}-\beta S)+R_{11} - R_{13}+C_1+\beta S)$$
$$a_{12} = x(1-x)(R_{12}+R_{13}-R_{11}-R_{14}-\beta S)$$
$$a_{21} = y(1-y)(R_{22}+R_{23}-R_{21}-R_{24}-(1-\beta)S)$$
$$a_{22} = (1-2y)(x(R_{22}+R_{23}-R_{21}-R_{24}-(1-\beta)S) + R_{21}-R_{22}+C_2+(1-\beta)S)$$

C. Calculate the value detJ and trace trJ of the Jacobi matrix

$$\det J = a_{11}a_{22} - a_{12}a_{21}, \quad \operatorname{tr} J = a_{11} + a_{22}$$

D. Calculate the detJ and trJ of each Nash equilibrium point separately According to Friedman's discriminant method, an equilibrium $A_i(x_i, y_i)$ $(i = 1, 2, \ldots, 5$ and $0 \le x_i, y_i \le 1)$ is stable if it has $\det J > 0$ and $\operatorname{tr} J < 0$.

1. Equilibrium point $A_4(0,0)$:

$$\det J = (R_{11}-R_{13}+C_1+\beta S)(R_{21}-R_{22}+C_2 + (1-\beta)S)$$

$$\operatorname{tr} J = R_{11}-R_{13}+R_{21}-R_{22}+C_1+C_2+S$$

2. Equilibrium point $A_4(1,0)$:

$$\det J = (-R_{11}+R_{13}-C_1-\beta S)(R_{23}-R_{24}+C_2)$$

$$\operatorname{tr} J = -R_{11}+R_{13}+R_{23}-R_{24}-C_1+C_2-\beta S$$

3. Equilibrium point $A_4(0,1)$:

$$\det J = (R_{12}-R_{14}+C_1)(-R_{21}+R_{22}-C_2-(1-\beta)S)$$

$$\operatorname{tr} J = R_{12}-R_{14}-R_{21}+R_{22}+C_1-C_2-(1-\beta)S$$

4. Equilibrium point $A_4(1,1)$:

$$\det J = (-R_{12}+R_{14}-C_1)(-R_{23}+R_{24}-C_2)$$

$$\operatorname{tr} J = -R_{12}+R_{14}-R_{23}+R_{24}-C_1-C_2$$

5. Equilibrium point:

$$A_5 = \left(\frac{-R_{21}+R_{22}-C_2-(1-\beta)S}{R_{22}+R_{23}-R_{21}-R_{24}-(1-\beta)S}, \frac{R_{13}-R_{11}-C_1-\beta S}{R_{12}+R_{13}-R_{11}-R_{14}-\beta S} \right)$$

$$\det J = -\frac{(-R_{21}+R_{22}-C_2-(1-\beta)S)(R_{23}-R_{24}+C_2)}{R_{22}+R_{23}-R_{21}-R_{24}-(1-\beta)S} \times \frac{(R_{13}-R_{11}-C_1-\beta S)(R_{12}-R_{14}+C_1)}{R_{12}+R_{13}-R_{11}-R_{14}-\beta S}$$

$$\operatorname{tr} J = 0$$

3.2 Analysis of evolutionary stabilization strategies

Obviously, the equilibrium point $A_4(1,1)$ of , when $R_{12} > R_{14}$ and $R_{23} > R_{24}$. Therefore, the equilibrium point $A_4(0,0)$ is stable at this time. That is, in the RI chooses "negative R&D" strategy, when EN chooses "continue to cooperate" benefit R_{12} is greater than the choice of "halfway out" benefit R_{14}; and in the EN choice of Under the "exit" strategy, when RI chooses "active R&D", the benefit R_{23} is greater than the benefit R_{24} of choosing "negative R&D", EN and RI will eventually choose the strategy of (continue to cooperate, active R&D). cooperation, active R&D) strategy.

4 Conclusions and recommendations of the study

From the above analysis, it can be seen that to cultivate intelligent logistics talents in the Guangdong-Hong Kong-Macao Greater Bay Area through the integration of industry and education, it is necessary to increase the expected benefits for enterprises and research institutes participating in industry-university-research innovation alliances. Only by doing so can enterprises and research institutes engage in these alliances in a long-term and stable manner. Therefore, the government should actively reward enterprises and research institutes for their participation in industry-university-research alliances to enhance the benefits R_{12} and R_{23}. Additionally, appropriate penalties should be imposed on enterprises that choose "Exit" or on research institutes that engage in "Negative R&D" to reduce the benefits R_{14} and R_{24}.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

Chunsheng Wang served as an Associate Editor of the *Journal of Social Systems and Policy Analysis* at the time of manuscript submission. To ensure the integrity of the peer-review process, Chunsheng Wang was not involved in the editorial handling, peer review, or decision-making process for this manuscript, which was handled independently by another editor. The remaining authors declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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