Research on the Evolutionary Stabilization Strategy of Coordinated Industrial Development in the Yellow River Basin

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Abstract. The Yellow River Basin faces the major national strategic priority of constructing a green industrial structure and forming an ecological pioneer zone. Grounded in the assumption of bounded rationality, this paper develops a dynamic evolutionary game model among the government, strategic emerging enterprises, and resource-based enterprises. Through formulating replicated dynamic equations, it investigates the patterns of coordinated development between strategic emerging industries and resource-based industries under various government policies. Analysis conducted through simulated experiments demonstrates that: (1) The final strategy of the three parties depends not only on the initial participation probability of each agent but is also influenced by other initial parameter configurations. (2) Government policy constitutes a salient factor impacting the equilibrium, exercising a regulatory effect on the participation of strategic emerging industries and resource-based enterprises in coordinated industrial development. (3) The regulatory role of government manifests time-heterogeneous properties. (4) Strategic emerging enterprises and resource-based enterprises decide whether to participate in the coordinated development of the industry based on the regulatory role and benefits of innovation. Finally, it puts forth policy recommendations to inform coordinated industrial development in the Yellow River Basin.

Keywords: industrial coordination; innovation adjustment mechanism; evolutionary game; evolutionary stability strategy

1 Introduction

Under the new development pattern, coordinated industrial development constitutes a viable approach to optimize the regional industrial structure and improve comprehensive performance in the Yellow River Basin. The coordination of strategic emerging industries and resource-based industries can facilitate the optimization of the regional industrial structure. Technological advancement and improved technological efficiency

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promote increases in technological innovation efficiency within strategic emerging sectors over time [1]. In a broad sense, resource-based industries refer to industries that rely on social resources and natural resources [2]. As traditional resource-based industries transform into strategic emerging industries, cultivating emerging sectors can facilitate the upgrading of conventional industries [3]. Investigating how local governments employ policy regulation to enable the transformation of natural resource industries and promote strategic emerging industries in the Yellow River Basin, as the three actors engage in a game of interests, holds economic theoretical significance.

During his inspection in Henan, General Secretary Xi Jinping proposed a major national strategy to harness scientific and technological innovation for ecological protection and high-quality development in the Yellow River Basin [4]. The Yellow River flows through 9 provinces (regions) with significant regional disparities in urban cluster development between upper, middle, and lower reaches. For instance, Inner Mongolia, Shanxi, and other regions heavily rely on depletable natural resource-based industries like coal and mineral extraction, resulting in a relatively homogeneous industrial structure and specialized labor force [5]. Existing literature offers useful insights into planning coordinated industrial development in the Yellow River Basin to realize upgrades in both industrial structure and ecological protection. Sun [6], Peng et al. [7], Yang and Zhu [8], and Wang [9] have conducted research on various facets including defining strategic emerging industries, delineating natural resource-based industries, developing theoretical models of industrial coordination's impact on sustainable economic growth, and empirically analyzing the ecological effects of technological innovation. Moufid et al. [10] developed a game-theoretic model to analyze the strategic choice of resource sharing between two enterprises and potential cheating behaviors. Liu et al. [11] formulated a multi-agent evolutionary game framework comprising carbon fiber producers, application enterprises, and government to study dynamics. Benjamin et al. [12] theoretically investigated negotiation interactions among communities, enterprises, government, and stakeholders in the mining industry. Wang et al. [13] constructed a tripartite evolutionary game model with the central government, local governments, and coal enterprises as agents to analyze governance of excess capacity and substitution policy dilemmas.

While existing literature has provided valuable insights into the economic impacts of industrial coordination, some gaps remain: Firstly, as the national strategic focus on cultivating strategic emerging industries has only recently emerged, the literature lacks investigation into the regulatory role of technological innovation in enabling both the upgrading of natural resource-based industries and the development of strategic emerging sectors, as well as the convergence of these industries. Secondly, existing work has limited empirical analysis of the specific conditions in the Yellow River Basin, with minimal attention to positive environmental externalities attained through industrial coordination. This paper addresses the challenges of resource constraints, environmental pressures, and structural transition for high-quality economic development in the Yellow River Basin. It contributes solutions for cultivating strategic emerging industries, upgrading traditional natural resource-based industries, and enabling industrial integration through mechanisms of local government regulation, within-industry technological innovation, and cross-industry collaborative innovation. This paper develops an evolutionary game theoretic model to analyze the strategic interactions among three key entities - local government, strategic emerging enterprises, and resource-based enterprises. It incorporates these actors into a unified analytical framework, capturing the evolutionary game dynamics under different strategy combinations adopted by governments and enterprises. Through formulating and analyzing replicator dynamic equations, this research investigates the process of attaining coordinated industrial development. Simulation experiments are conducted under varied parameterizations to elucidate the impact pathways influencing the final equilibrium strategies. This paper contributes a theoretical basis and practical policy recommendations for enabling coordinated industrial development in the Yellow River Basin.

2 Basic Assumptions and Model Construction

2.1 Basic Assumptions and Parameter Settings

To develop the evolutionary game theoretic model, the following assumptions are proposed:

(1) Strategic emerging industries comprise groups of enterprises focused on innovative technologies or processes with high growth potential. Resource-based industries, concentrated in a particular region, encompass many enterprises dependent on the extraction and processing of natural resources. These traditional industries require upgrading, adjustment, and transformation to remain competitive. In certain regions, strategic emerging enterprises coexist alongside resource-based enterprises rooted in legacy industries.

(2) Innovation regulation mechanisms aim to introduce innovation into organizational production to identify new development opportunities and build economic capabilities. For strategic emerging enterprises, innovation regulation encompasses raw material and intermediate product sourcing, production technology changes, and new industrial organizational models. Similarly, resource-based enterprises can demonstrate innovation in raw material production, production factor sourcing, technology, and organizational patterns. Guided by cost-benefit principles, strategic emerging and resource-based enterprises may adopt “participation” or “non-participation” strategies for industrial coordination. Realizing innovative adjustment mechanisms requires local government regulation and management. Measures and policies from local governments across the Yellow River Basin regarding ecological protection and economic development will profoundly impact high-quality development in the region. Depending on conditions, local governments may take “strong control” or adopt “weak control” approaches that allow the market to play a leading role. The research model is depicted in Fig. 1. Key parameters are defined in Table 1.

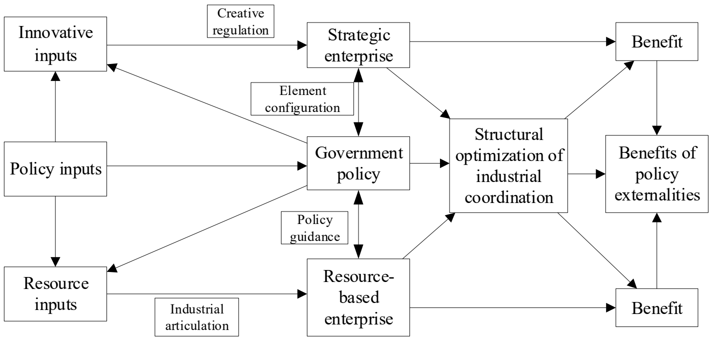

Fig. 1. Research model of game strategy selection for the coordinated development of strategic emerging industries and resource-based industries in the Yellow River Basin

Table 1. Main indicators and parameter definitions

Notation	Definition	Notation	Definition
R_A	Mean benefits from independent development for strategic emerging enterprises	R_B	Mean benefits from independent development for resource-based enterprises
C_A	Participation costs for strategic emerging enterprises in coordinated industrial development	C_B	Participation costs for resource-based enterprises in coordinated industrial development
m	Technological innovation coefficient for strategic emerging enterprises	n	Technological innovation coefficient for resource-based enterprises
T_A	Additional benefits from the participation of strategic emerging enterprises with resource-based enterprises independent	T_B	Additional benefits from the participation of resource-based enterprises with strategic emerging enterprises independent
S_A	Excess benefits for strategic emerging enterprises when both enterprises are involved in industrial coordination	S_B	Excess benefits for resource-based enterprises when both enterprises are involved in industrial coordination
α_E	Probability of successful industrial articulation under strong government regulation	α_F	Probability of successful industrial articulation under weak government regulation
C_E	Policy costs under strong government regulation	C_F	Policy costs under weak government regulation
Q_A	Quantity of strategic emerging enterprises participating in industrial integration under strong government regulation	Q_B	Quantity of resource-based enterprises participating in industrial integration under strong government regulation

β_A	Proportion of the quantity of strategic emerging enterprises participating in industrial coordination under weak government regulation	β_B	Proportion of the quantity of resource-based enterprises participating in industrial coordination under weak government regulation
ε_A	Coefficient of externalities of government-implemented policies on strategic emerging enterprises	ε_B	Coefficient of externalities of government-implemented policies on resource-based enterprises

2.2 Model Construction

Derived from the modeling assumptions, strategy combinations were formulated and the resulting payment matrix was presented in Table 2.

Table 2. Payment matrix of government, strategic emerging enterprises and resource-based enterprises

Game participants		Participation of strategic emerging enterprises		Strategic emerging enterprises independence	
Strategy		Participation of resource-based enterprises	Independence of Resource-based enterprises	Participation of resource-based enterprises	Independence of resource-based enterprises
Government	Strong regulation	$\varepsilon_A Q_A + \varepsilon_B Q_B - C_E$ $R_A - C_A + mT_A + \alpha_E S_A$ $R_B - C_B + nT_B + \alpha_E S_B$	$\varepsilon_A Q_A - C_E$ $R_A - C_A + mT_A$ R_B	$\varepsilon_B Q_B - C_E$ R_A $R_B - C_B + nT_B$	$-C_E$ R_A R_B
	Weak regulation	$\varepsilon_A \beta_A Q_A + \varepsilon_B \beta_B Q_B - C_F$ $R_A - C_A + mT_A + \alpha_F S_A$ $R_B - C_B + nT_B + \alpha_F S_B$	$\varepsilon_A \beta_A Q_A - C_F$ $R_A - C_A + mT_A$ R_B	$\varepsilon_B \beta_B Q_B - C_F$ R_A $R_B - C_B + nT_B$	$-C_F$ R_A R_B

The anticipated benefits from implementing strong or weak control, along with the mean benefit, are as follows:

$$U_{z1} = x\varepsilon_A Q_A + y\varepsilon_B \beta_B Q_B - C_E \tag{1}$$

$$U_{z2} = x\varepsilon_A \beta_A Q_A + y\varepsilon_B \beta_B Q_B - C_F \tag{2}$$

$$\overline{U}_z = x\varepsilon_A Q_A\left[1-(1-z)(1-\beta_A)\right] + y\varepsilon_B Q_B\left[1-(1-z)(1-\beta_B)\right] - (1-z)C_F - zC_E \tag{3}$$

The anticipated benefits for strategic emerging enterprises pursuing participation or independence strategies, along with the mean benefit, are:

$$U_{x1} = yS_A[z(\alpha_E - \alpha_F) + \alpha_F] + R_A - C_A + mT_A \tag{4}$$

$$U_{x2} = R_A \tag{5}$$

$$\overline{U}_x = xyS_A[z(\alpha_E-\alpha_F)+\alpha_F]+x(mT_A-C_A)+R_A \tag{6}$$

The anticipated benefits for resource-based enterprises pursuing participation or independence strategies, along with the mean benefit, are:

$$U_{y1} = yS_B[z(\alpha_E-\alpha_F)+\alpha_F]+R_B-C_B+mT_B \tag{7}$$

$$U_{y2} = R_B \tag{8}$$

$$\overline{U}_y = xyS_B[z(\alpha_E-\alpha_F)+\alpha_F]+y(nT_B-C_B)+R_B \tag{9}$$

Analysis of the Replication Dynamics of Government Strategies.

The replication dynamic equation of the government strategy is expressed as:

$$\begin{aligned} F(z) &= \frac{dz}{dt} = z(U_{z1}-\overline{U}_z) \\ &= z(1-z)\left[x(1-\beta_A)\varepsilon_A Q_B + y(1-\beta_B)\varepsilon_B Q_B + C_F - C_E\right] \end{aligned} \tag{10}$$

Given the conditions required to achieve stable equilibrium, the parameters must satisfy $F(z)=0$ and $F'(z)<0$. Two cases are examined: First, when $x \equiv \frac{C_E-C_F-y(1-\beta_B)\beta_B Q_B}{(1-\beta_A)\beta_B Q_B}$, then $F(z)\equiv 0$, denoting all states are steady under this condition. Second, if $x \neq \frac{C_E-C_F-y(1-\beta_B)\beta_B Q_B}{(1-\beta_A)\beta_B Q_B}$, to attain $F(z)=0$, z adopts either 0 or 1, indicating any government policy constitutes a stable point.

Deriving $F(z)$ yields:

$$F'(z) = (1-2z)\left[x(1-\beta_A)\varepsilon_A Q_B + y(1-\beta_B)\varepsilon_B Q_B + C_F - C_E\right] \tag{11}$$

The evolutionary stabilization strategy necessitates $F'(z)<0$. When $(1-\beta_A)\beta_B Q_B<0$, if $x>\frac{C_E-C_F-y(1-\beta_B)\beta_B Q_B}{(1-\beta_A)\beta_B Q_B}$, resulting $F'(1)>0$ and $F'(0)<0$, then $z=0$ is the evolutionary stabilization strategy point; if $x<\frac{C_E-C_F-y(1-\beta_B)\beta_B Q_B}{(1-\beta_A)\beta_B Q_B}$, resulting $F'(1)<0$ and $F'(0)>0$, then $z=1$ is the evolutionary stabilization strategy point. When $(1-\beta_A)\beta_B Q_B>0$, if $x>\frac{C_E-C_F-y(1-\beta_B)\beta_B Q_B}{(1-\beta_A)\beta_B Q_B}$, resulting $F'(1)<0$ and $F'(0)>0$, then $z=1$ is the evolutionarily stable strategy point; if $x < \frac{C_E - C_F - y(1-\beta_B)\beta_B Q_B}{(1-\beta_A)\beta_B Q_B}$, resulting $F'(1) > 0$ and $F'(0) < 0$, then $z = 0$ is an evolutionarily stable strategy point. According to the analysis, the evolution trend of the government's strategy is shown in Fig. 2. Given an initial strategy in space $V11$ with $(1-\beta_A)\beta_B Q_B < 0$, $z = 1$ is the evolutionary stable strategy point. When the government's initial strategy is in space $V12$ with $(1-\beta_A)\beta_B Q_B > 0$, $z = 0$ is the evolutionary stable strategy point. As β_A increases, fixing $x_0 = \frac{C_E - C_F - y(1-\beta_B)\beta_B Q_B}{(1-\beta_A)\beta_B Q_B}$, space $V11$ will gradually expand with the increasing of x_0, evolving to reach the stable strategy point $z = 1$. It signifies the government implementing a strong regulating strategy, requiring participation of both strategic emerging enterprises and resource-based enterprises in coordinated industrial development.

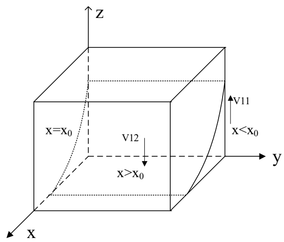

Fig. 2. Trend map of governmental dynamics

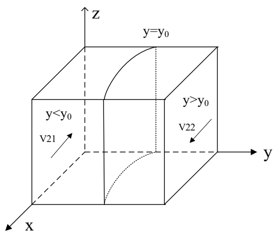

Fig. 3. Evolution of strategies of strategic emerging enterprises

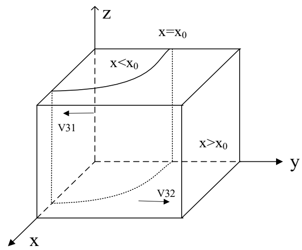

Fig. 4. Evolution of strategies of resource-based enterprises

Dynamic Analysis of the Replication Strategy of Strategic Emerging Enterprises. The dynamic equation for the replication of strategic emerging enterprise strategies is expressed as:

$$\begin{aligned} F(x) &= \frac{dx}{dt} = x(U_{x1} - \overline{U}_x) \\ &= x(1-x)\{yS_A[z(\alpha_E - \alpha_F) + \alpha_F] + mT_A - C_A\} \end{aligned} \tag{12}$$

Given the conditions required to achieve stable equilibrium, the parameters must satisfy $F(x) = 0$ and $F'(x) < 0$. Discussion is divided into two cases: First, when $y \equiv \frac{C_A - mT_A}{S_A[z(\alpha_E - \alpha_F) + \alpha_F]}$, then $F(x) \equiv 0$, denoting that under this condition, the system resides in a stable state regardless of the proportion of strategic emerging enterprises participating in or independent from the coordinated development of the industry and their participation or independence , the strategies of strategic emerging enterprises will not change over time. Second, given $y \neq \frac{C_A - mT_A}{S_A[z(\alpha_E - \alpha_F) + \alpha_F]}$, attaining $F(x) = 0$ necessitates satisfying either $x = 0$ or $x = 1$. In this case, both independent and participatory strategies constitute stable equilibria for strategic emerging enterprises. This signifies that, absent external or internal conditions inducing strategy mutation, strategic emerging enterprises will persist with either independence or participation as invariant replication strategies.

Derive for $F(x)$ to obtain:

$$F'(x) = (1-2x)\{yS_A[z(\alpha_E - \alpha_F) + \alpha_F] + mT_A - C_A\} \tag{13}$$

The evolutionary stabilization strategy necessitates $F'(x) < 0$. Based on assumptions (1) and (2), it can be found that the premise for strategic emerging enterprises to participate in industrial coordination is that the benefits from technological adjustment are greater than the participation costs, but less than the benefits when both parties participate, namely $0 < C_A - mT_A < \alpha_F S_A < \alpha_E S_A$. Two cases are examined: First, when $y < \frac{C_A - mT_A}{S_A[z(\alpha_E - \alpha_F) + \alpha_F]}$, $F'(1) > 0$ and $F'(0) < 0$, then $x = 0$ is an evolutionarily stable strategy point. Second, when $y > \frac{C_A - mT_A}{S_A[z(\alpha_E - \alpha_F) + \alpha_F]}$, $F'(1) < 0$ and $F'(0) > 0$, then $x = 1$ is the evolutionarily stable strategy point. In this case, the strategic emerging enterprise opts for an independence strategy, abstaining from participation in industrial coordination. This indicates that if the strategic emerging enterprise pursued participation while the resource-based enterprise remained independent, the cost to the strategic emerging enterprise would be greater than the benefits of participating. Consequently, the strategic emerging enterprise would adopt an independent strategy. When the initial strategy is in space $V22$, $y > y_0$, thus $x = 1$ is the evolutionarily stable strategy point. As policy implementation intensifies, the willingness to participate by strategic emerging enterprises increases, space $V22$ expands, and evolution reaches the evolutionarily stable strategy point $x = 1$. This indicates that strategic emerging enterprises will choose participatory or independent strategies according to the strength of policies, which determines whether they will engage in coordinated industrial development.

Dynamic Analysis of the Replication Strategy of Resource-based Enterprises.

The dynamic equation modeling the replication of strategies among resource-based enterprises is:

$$F\left(y\right)=\frac{dy}{dt}=y(U_{y1}-\overline{U}_{y}) \\ =y(1-y)\{xS_{B}[z(\alpha_{E}-\alpha_{F})+\alpha_{F}]+nT_{B}-C_{B}\} \tag{14}$$

Per the conditional constraints to achieve stable equilibrium, $F\left(y\right)=0$ and $F'\left(y\right)<0$ must be satisfied. Two cases are analyzed: First, when $x\equiv\frac{C_{B}-nT_{B}}{S_{B}[z(\alpha_{E}-\alpha_{F})+\alpha_{F}]}$, then $F\left(y\right)\equiv 0$, indicating that under this condition, all states are steady regardless of the proportion of resource-based enterprises participating or remaining independent of coordinated industrial development, the strategy of resource-based enterprises will persist invariant over time. Second, when $x\neq\frac{C_{B}-nT_{B}}{S_{B}[z(\alpha_{E}-\alpha_{F})+\alpha_{F}]}$, to make $F\left(y\right)=0$, either $y=0$ or $y=1$. In this instance, either an independent strategy or a participatory strategy is a stable point for resource-based enterprises. Absent conditions inducing strategy mutation, the resource-based enterprises will remain stable with the independent (participatory) strategy in terms of coordinated industrial development.

Derive for $F\left(y\right)$ to obtain:

$$F'\left(y\right)=(1-2y)\{xS_{B}[z(\alpha_{E}-\alpha_{F})+\alpha_{F}]+nT_{B}-C_{B}\} \tag{15}$$

The evolutionary stabilization strategy requires that $F'\left(y\right)<0$, and it is clear from assumptions (1) and (2) that the participation of resource-based enterprises in industrial coordination is predicated on the premise that the benefits gained from technological adjustments are greater than the costs of participation but less than the benefits of participation for both parties, namely $0<C_{B}-nT_{B}<\alpha_{F}S_{B}<\alpha_{E}S_{B}$. Two cases are analyzed: First, when $x<\frac{C_{B}-nT_{B}}{S_{B}[z(\alpha_{E}-\alpha_{F})+\alpha_{F}]}$, $F'\left(1\right)>0$ and $F'\left(0\right)<0$, then $y=0$ is the evolutionarily stable strategy point. Second, when $x>\frac{C_{B}-nT_{B}}{S_{B}[z(\alpha_{E}-\alpha_{F})+\alpha_{F}]}$, $F'\left(1\right)<0$ and $F'\left(0\right)>0$, then $y=1$ is the evolutionarily stable strategy point. The analysis indicates the evolutionary trend for strategies of resource-based enterprises, as depicted in Fig. 4. When the initial strategy of the resource-based enterprises is in space $V31$, let $x_{0}=\frac{C_{B}-nT_{B}}{S_{B}[z(\alpha_{E}-\alpha_{F})+\alpha_{F}]}$, $x<x_{0}$, then $y=0$ is the evolutionary stable strategy point. Resource-based enterprises exhibit a propensity for independence strategies, abstaining from participation in industrial coordination. This indicates that if resource-based enterprises participated while strategic emerging enterprises remained independent, the incurred participation costs would exceed the attained benefits for resource-based enterprises, leading them to implement independence strategies. When

the initial policy is in space $V32$ with $x > x_0$, $y = 1$ is the evolutionary stable policy point. As the policy implementation is enhanced and resource-based enterprises increase their participation, the space $V32$ expands and the evolution reaches the $y = 1$ evolutionary stable strategy point. It signifies that resource-based enterprises will opt for participation or independence strategies based on the strength of the policy, determining whether to participate in the coordinated development of the industry or not.

Comprehensive Analysis of All Participating Entities.

Analyzing participating entities in the evolutionary game model independently enables examining the evolutionary process underlying each entity's strategy selection. Further analyzing the overall evolution of the three entities collectively, as tabulated in Table 3, yields evolutionary equilibrium results with conditional stability. Provided actual parameter values per the assumptions fluctuate within constrained bounds around the derived stable values absent extreme mutations, the attained equilibria will persist over a prospective period. From Table 3, it can be seen that when the initial state is located in the intersection of the three spaces - space V11 in Fig. 2, space V22 in Fig. 3, and space V32 in Fig. 4 - the stable strategies of the government, strategic emerging enterprises, and resource-based enterprises will converge to (1,1,1), indicating that in the short term, the government adopts a strong control strategy, while strategic emerging enterprises and resource-based enterprises participate in coordinated industrial development. This result exhibits proximity to the current state of coordinated industrial development in the Yellow River Basin, as this region remains in a period of independent progress, necessitating compulsory governmental measures to provide direction. When the initial state is in the intersection space of V12 in Fig. 2, V22 in Fig. 3, and V32 in Fig. 4, the stabilization strategies of the government, strategic emerging enterprises and resource-based enterprises will converge to (0, 1, 1). It indicates that the government gradually relaxes its management over time to adopt weak regulation, while strategic emerging enterprises and resource-based enterprises participate in the coordinated development of the industry. This result represents the anticipated status of coordinated industrial development in the Yellow River Basin. As industrial coordination deepens and structural evolution progresses, both resource-based and strategic emerging enterprises will proactively undertake industrial integration and convergence, voluntarily engaging in collaborative industrial development.

Table 3. Strategies of each participating entity in each space

Spatial strategy	V21		V22	
	V31	V32	V31	V32
V11	(1,0,0)	(1,0,1)	(1,1,0)	(1,1,1)
V12	(0,0,0)	(0,0,1)	(0,1,0)	(0,1,1)

3 Simulation of Evolutionary Game Equilibrium for the System

Numerical experiments were conducted to examine the impacts of initial participation willingness, policy externalities, and technological adjustment benefits on the evolutionary equilibrium benefits for the government, strategic emerging enterprises, and resource-based enterprises' strategy selections. Set the parameter value to be $R_A = 0$, $R_B = 0$, $C_A = 12$, $C_B = 8$, $m = 0.5$, $n = 0.7$, $T_A = 11$, $T_B = 7$, $\alpha_E = 0.8$, $\alpha_F = 0.6$, $S_A = 20$, $S_B = 14$, $C_E = 10$, $C_F = 6$, $Q_A = 30$, $Q_B = 35$, $\beta_A = 0.4$, $\beta_B = 0.3$, $\varepsilon_A = 0.4$, $\varepsilon_B = 0.5$, since R_A and R_B have no effect on the evolutionary equilibrium, take $R_A = 0$ and $R_B = 0$.

3.1 The Impact of Each Subject's Initial Participation Willingness on Evolutionary Results

With initial participation willingness parameterized as $x, y, z = 0.4$, $x, y, z = 0.6$ and $x, y, z = 0.9$, the evolutionary trends for strategy selections by strategic emerging industries, resource-based industries and government are shown in Fig. 5, Fig. 6 and Fig. 7. Regardless of variations in the probability values for initial participation willingness, the system ultimately reaches a stable equilibrium at (1,1,1). Increasing initial participation willingness decreases the time required for the system to converge to stability.

Additionally, simulations were conducted excluding the initial participant. With the initial participation willingness fixed at $x = 0, y = 0.5, z = 0.5$, $x = 0.5, y = 0, z = 0.5$, and $x = 0.5, y = 0.5, z = 0$, the evolutionary trends for strategy selections by strategic emerging industries, resource-based industries, and government are shown in Fig. 8, Fig. 9 and Fig. 10, respectively. The final system equilibriums will stabilize at (0,1,1), (0,1,1), and (1,1,1) respectively. It indicates that resource-based industries will eventually achieve coordinated development under government participation, irrespective of strategic emerging industries' participation.

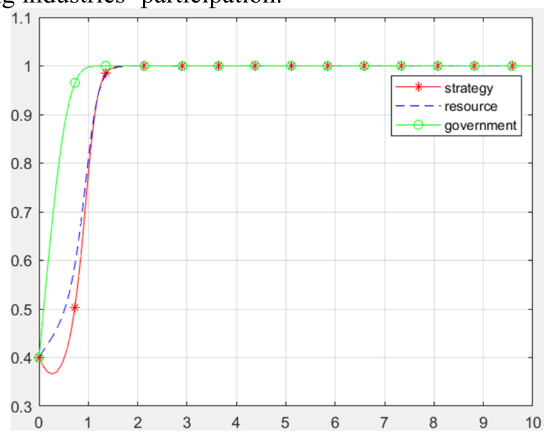

Fig. 5. Effect of $x, y, z = 0.4$ on equilibrium

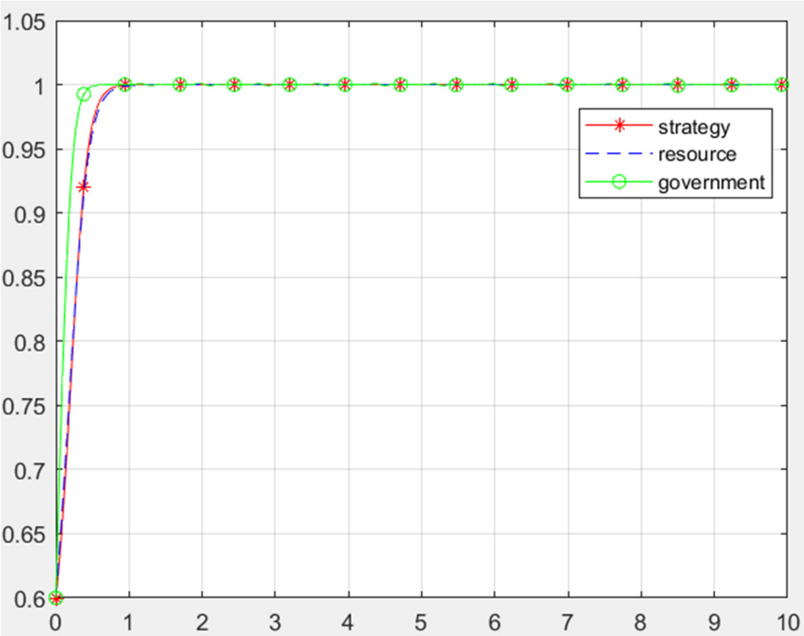

Fig. 6. Effect of $x, y, z = 0.6$ on equilibrium

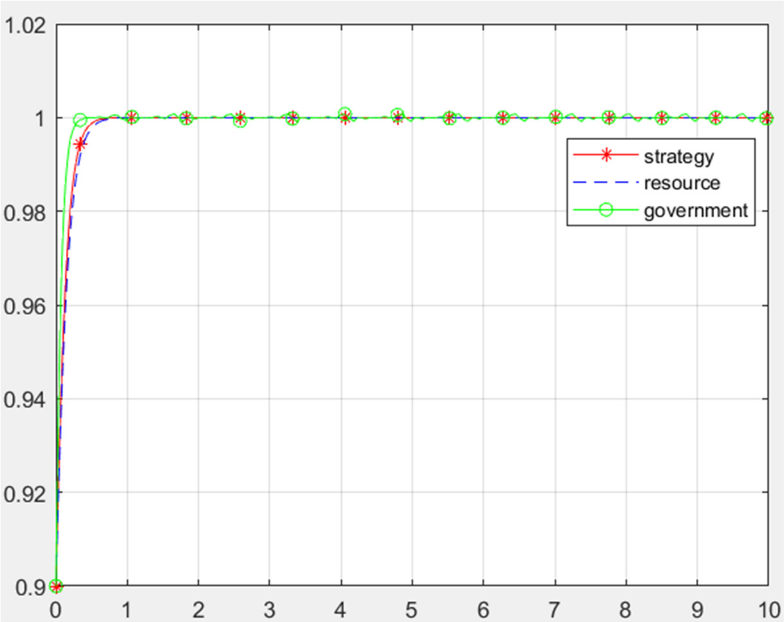

Fig. 7. Effect of $x, y, z = 0.9$ on equilibrium

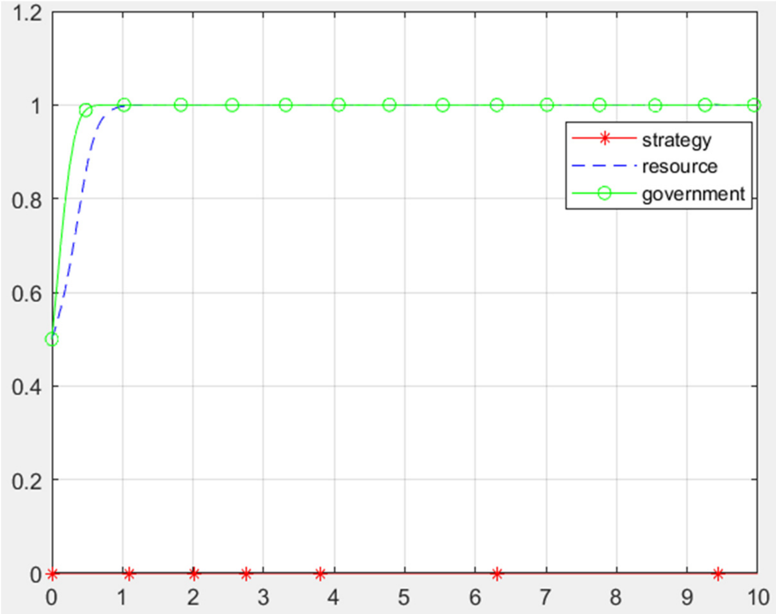

Fig. 8. Effect of $x = 0,\ y = 0.5,\ z = 0.5$ on evolutionary results

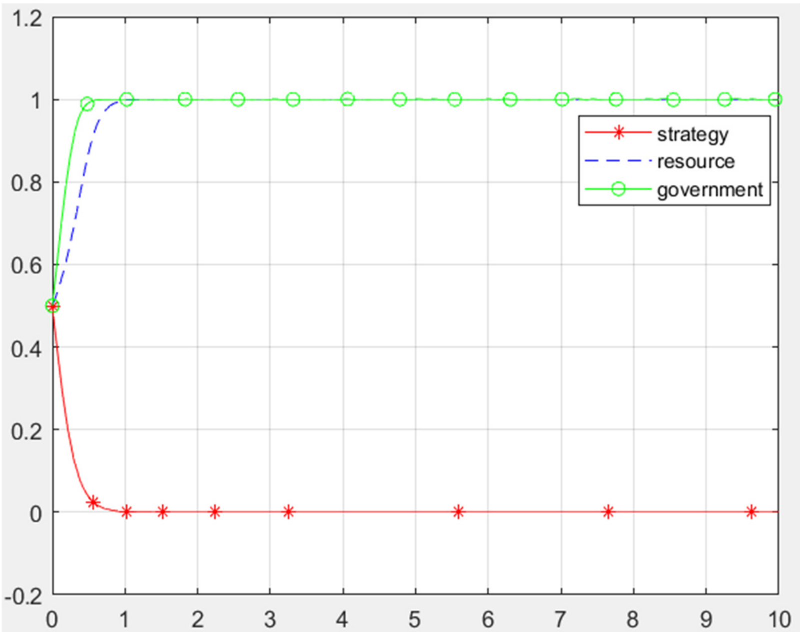

Fig. 9. Effect of $x = 0.5,\ y = 0,\ z = 0.5$ on evolutionary results

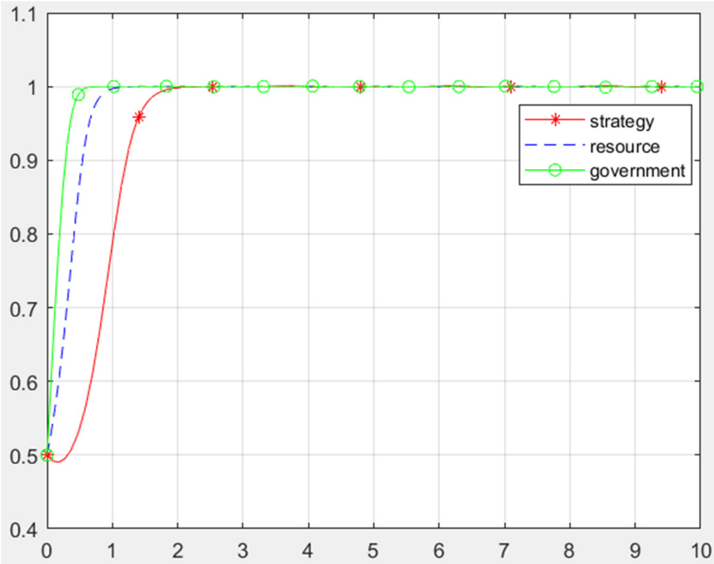

Fig. 10. Effect of $x = 0.5,\ y = 0.5,\ z = 0$ on evolutionary results

3.2 The Impact of Technological Innovation Benefits on Evolutionary Results

Focusing on strategic emerging enterprises, this study examines the impact of technological innovation on the results of system evolution. The simulations of the effect of changes in technological innovation benefits on evolutionary results are shown in Fig. 11, Fig. 12, and Fig. 13, with different values of T_A set as 6, 11, and 20, respectively. As the benefits of technological innovation increase, strategic emerging enterprises converge to system equilibrium at a higher rate, reaching a stable state earlier than resource-based enterprises.

3.3 The Impact of the Success Probability of Industrial Linkage on Evolutionary Results

The impact of varying the probability of successful technological evolution between strategic emerging enterprises and resource-based enterprises on evolutionary results is examined under the government's strong control strategy. The simulation of the effect of changes in the success probability of industrial linkage on evolutionary results is shown in Fig. 14, Fig. 15, and Fig. 16, with different values of α_E set as 0.4, 0.6, and 0.8, respectively. At low levels of successful technological evolution probability, both enterprises fail to achieve coordinated development. As the probability of successful technological evolution increases, the system evolves towards equilibrium (1,1,1) and stabilizes under government strong control with industrial coordination.

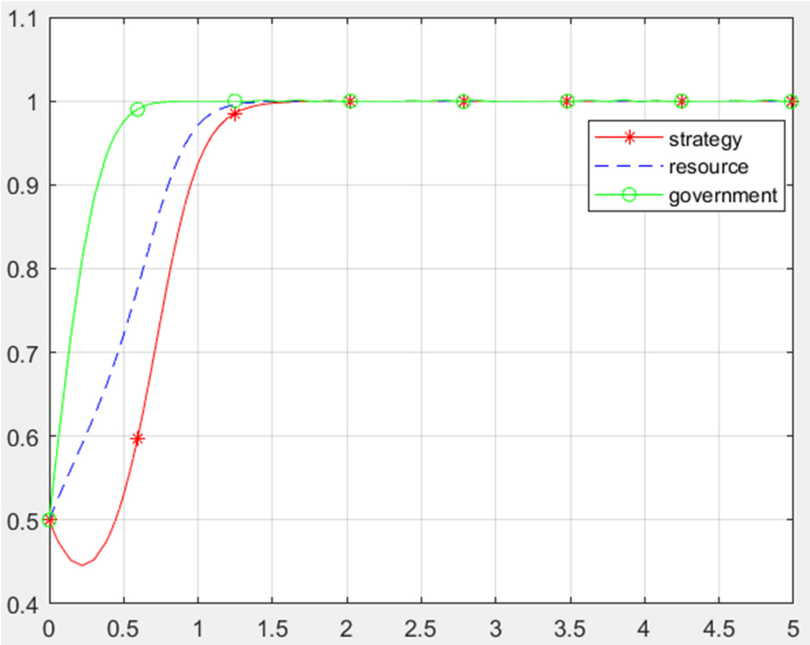

Fig. 11. Effect of $T_A = 6$ on evolutionary results

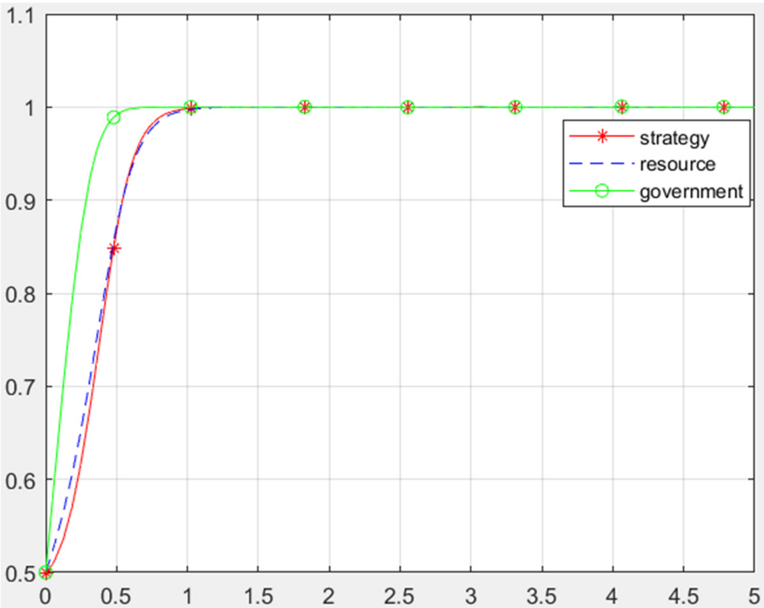

Fig. 12. Effect of $T_A = 11$ on evolutionary results

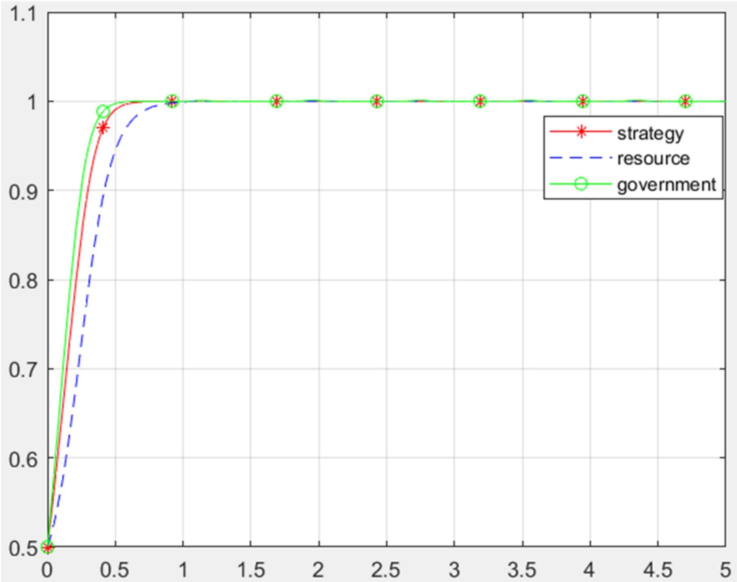

Fig. 13. Effect of $T_A = 20$ on evolutionary results

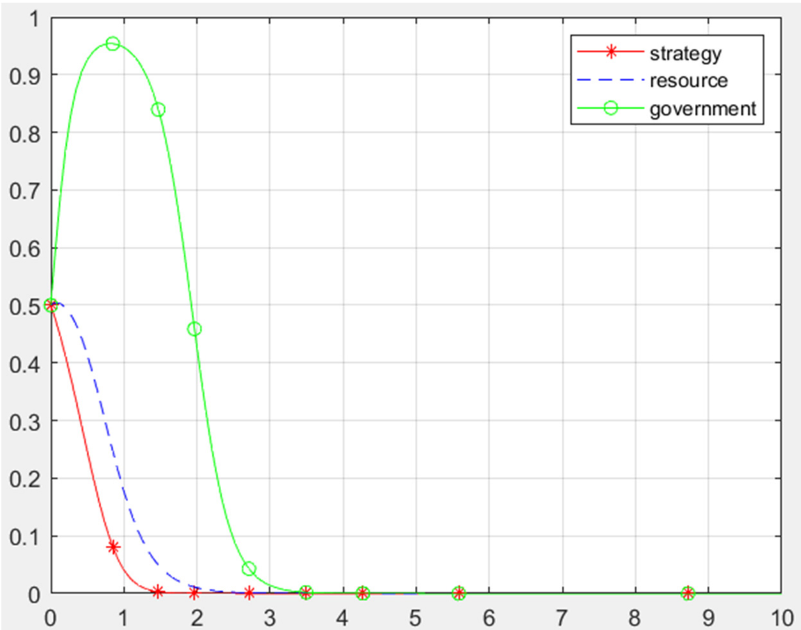

Fig. 14. Effect of α_E=0.4 on evolutionary results

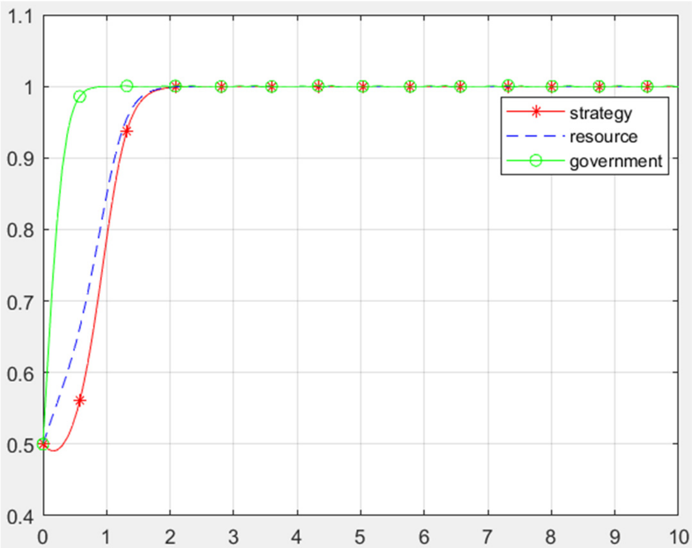

Fig. 15. Effect of α_E=0.6 on evolutionary results

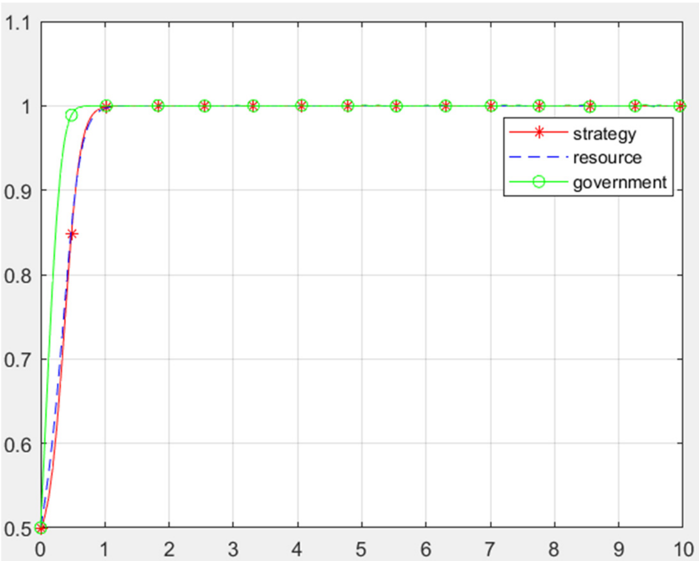

Fig. 16. Effect of α_E=0.8 on evolutionary results

4 Conclusions and Recommendations

This paper examines approaches to realize coordinated development between strategic emerging and resource-based industries under the background of high-quality development in the Yellow River Basin. We constructed a replicator dynamic equation model including three principal entities - government, strategic emerging enterprises, and resource-based enterprises to analyze the evolutionary game. We found that: (1) Government policies constitute pivotal factors influencing attained equilibria, with a steering role in participation by strategic emerging and resource-based enterprises in coordinated industrial development. (2) The final strategy selections for the three entities correlate not solely with initial participation probabilities but also with additional initialized parameter settings. (3) The three entities can achieve equilibrium through rational decision-making and strategy selection. Specifically, short-term government implementation of strong control, and long-term government implementation of weak control intervention, alongside participation by both strategic emerging and resource-based enterprises, can achieve coordinated development between the strategic emerging and resource-based industries in the Yellow River Basin.

Grounded in the model analysis results, targeted recommendations are proposed to achieve high-quality coordinated development between strategic emerging and resource-based industries in the Yellow River Basin.

Firstly, the upgrading of resource-based industries, the development of strategic emerging industries, and enabling coordinated evolution between the two constitute a pivotal role within the holistic strategic roadmap for the Yellow River Basin. Local governments need to delineate strategic objectives and implementation trajectories grounded in localized resource endowments, targeted towards optimizing regional resource allocation to attain high-quality development.

Secondly, regional governments across the Yellow River Basin prioritize integrated industrial development, leveraging localized resource and energy endowment strengths to achieve coordinated industrial advancement in the region. The transformation and upgrading of key manufacturing industries to emerging service industries can be realized through innovation-driven by relying on advanced common technologies. Local governments could encourage and guide strategic emerging industries and resource-based industries to realize the exchange of resource elements and upstream and downstream linkage by constructing information exchange platforms. By combining the comparative advantages and open linkages between strategic emerging industries and resource-based industries in the Yellow River Basin, the comprehensive development of industrial transformation, ecological protection and economic upgrading will be realized through development integration. Strategic emerging enterprises and resource-based enterprises need to capitalize on developmental prospects by furthering technological innovation exchanges and diffusion to accomplish industrial connectivity.

Thirdly, it is necessary to achieve technological advancement in strategic emerging industries and transformation in traditional resource-based industries through the development of industrial integration in the Yellow River Basin. Coordinated development can be achieved through technological exchanges, innovative production methods, and technology spillovers. Under the guidance of government policies, the dependency of resource-based industries on limited resources should be reduced. This can be achieved by encouraging technological innovation through investments and policy support, and formulating transition pathways that are suitable for market development. The direct or indirect production costs of resource-based enterprises can be reduced through the innovative diffusion of technologies or services of strategic emerging enterprises, breaking the industrial boundaries, thus promoting the exchange of production factors and industrial convergence within the region, and realizing the coordinated development of industries in the Yellow River Basin.

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