frontiers | Frontiers in Physics

TYPE Original Research
PUBLISHED 23 May 2025
DOI 10.3389/fphy.2025.1611590

OPEN ACCESS

EDITED BY
Dun Han,
Jiangsu University, China

REVIEWED BY
Yan Tan,
Yangzhou University, China
Zhou Hong,
Anhui University of Finance and Economics, China

*CORRESPONDENCE
Shuqi Li,
✉ 1710061@qq.com

RECEIVED 14 April 2025
ACCEPTED 28 April 2025
PUBLISHED 23 May 2025

CITATION
Zhao J, Li S, Zhang J and Zhang L (2025) Research on the interaction mechanism between cross-regional operating enterprises and local government: perspective based on evolutionary game.
Front. Phys. 13:1611590.
doi: 10.3389/fphy.2025.1611590

Research on the interaction mechanism between cross-regional operating enterprises and local government: perspective based on evolutionary game

Jin Zhao[1], Shuqi Li[2]*, Jiaxin Zhang[3] and Linrong Zhang[4]

[1]Commercial Factoring (Shanghai) Co., Yunnan Communications Investment and Construction Group Co., Ltd., Kunming, China, [2]School of Accounting, Zhejiang University of Finance and Economics Dongfang College, Haining, China, [3]School of Statistics and Mathematics, Shanghai Lixin University of Accounting and Finance, Shanghai, China, [4]School of Finance and Economics, Jiangsu University, Zhenjiang, Jiangsu, China

Against the background of a unified national market, the interaction between cross-regional operating enterprises and local governments involves factors such as investment scale, policy preferences, and industrial collaboration and has a profound impact on the innovation activities of enterprises and the improvement of regional innovation ecosystems. This study employs evolutionary game theory to construct a bilateral game model, elucidating the dynamic game–theoretic relationships between cross-regional operating enterprises and cross-entry local governments. Establishing interest interaction and government-enterprise gaming mechanisms was found to effectively promote the two sides from short-term gaming to stable cooperation and reduce strategic uncertainty. The aim is to explore in depth how cross-regional operations can further promote the improvement of innovation performance and even the high-quality development of enterprises through the strategic interaction with the governments of cross-regional places.

KEYWORDS

cross-regional operation, local government, evolutionary game theory, innovation ecosystem, knowledge spillover

1 Introduction

In an innovation ecosystem based on cross-regional operations, self-organization is an important mechanism that drives the co-evolution of cross-regional operating enterprises, local enterprises in target areas, and target regions. From a micro perspective, cross-regional operating enterprises show the characteristics of self-emergence and self-adaptation in the process of integrating resources, technology, and knowledge across regions. By continuously acquiring new market information and absorbing external talents and technologies, the internal management methods and innovation strategies of enterprises gradually adapt to the external environment and form new synergy models. While pursuing the maximization of their own interests, micro-subjects often give rise to innovative behaviors that benefit the system as a whole in dynamic games and cooperation networks, thereby achieving efficient utilization and integration of heterogeneous resources [1]. From a meso perspective, the industrial clusters formed in the same region are like organisms of "innovation populations." These clusters will continuously interact with local policies, industrial systems, technological atmosphere, and other environmental factors, and at the same time, they will show ups and downs and non-linear evolution due to the relationship between government and enterprises. When an enterprise achieves a first-mover advantage through cross-regional development or forms a new technological breakthrough, the entire innovation population will experience a ripple effect, promoting the reflow and reallocating resource elements within the cluster [2,3]. In this process, both win-win cooperation and joint expansion of new value chains between cross-regional enterprises and local governments of cross-entry places may occur. New industrial restructuring may be spawned due to the break-up of market competition patterns. From a macro perspective, the formation and evolution of innovation clusters result from mutual synergy among cross-regional resources, policies, and industrial environments. At the macro level, the formation and evolution of innovation clusters result from mutual synergy among cross-regional resources, policies, and industrial environments. In the ecosystem of cross-regional operations, the governments, industry associations, and various social resource networks of cross-regional regions constitute the external environment that supports the evolution of clusters. While exchanging information and energy in the macro-environment, the innovation community will continuously break the original equilibrium state and move towards a more advanced and orderly structure. Along with the fluctuation of market demand and the adjustment of policy support, non-linear effects such as competition, learning, and imitation will be generated among innovation subjects, which will provide endogenous power for the rise and fall of the system, thus accelerating the realization of new synergies and upgrading of enterprises [4,5].

In this process of self-organized evolution, the choices and strategies of each innovation subject may have an impact on the system. When a new technology or business model changes the original competition–cooperation pattern, the equilibrium state of the system is broken [6]. Subsequently, under the dominance of core technology, financial support, market potential, etc., the innovation cluster will form a new order that is more advanced and stable. It is in the rise and fall and reorganization over and over again that the innovation ecosystem operating across districts develops the robustness of self-adaptation, self-sustenance, and self-development, which continuously spawns the interactive game between advantageous cross-district firms and the government of the cross-entry place [7,8]. Through continuous self-organized evolution, innovation agents in the cross-regional context jointly promote economic growth as well as collaborative innovation, providing solid support for the overall sustainable competitiveness of the system.

2 Introduction of models

The formation of cross-regional business strategies is closely related to the upgrading of the enterprise's own industrial structure, the regional competition pattern, the regional economic environment, and the local policy orientation, and its decision-making motivation mainly comes from the integration of external resources and the need for complementarity of advantages, as well as the incentives of the local government for attracting investment and upgrading industry [9,10]. Therefore, the interaction between firms and the governments of cross-entry regions not only involves elements such as the scale of investment, policy incentives, and industrial synergies but also profoundly affects the innovation activities of the firms and the regional innovation ecosystem improvements.

Specifically, when choosing whether to conduct cross-regional operations and selecting target regions, cross-regional enterprises usually hope to obtain favorable conditions such as tax incentives, supporting resources and high-quality R&D environments, to reduce the overall risks and costs of innovation [11] and accelerate the connection with the local industrial chain and relevant public research institutions. Meanwhile, the government of the trans-boundary region expects enterprises to transfer their rich practical experience and cutting-edge technologies to inject new R&D impetus and innovation concepts into the local area and to drive the related industries and enterprises in the region to follow up through the knowledge spillover effect, to form the diffusion of innovation effect, enhance the technological innovation capability of the region or industry as a whole, further optimize the regional industrial structure, and improve the overall competitiveness and sustainable development capability. If the two sides can form an effective incentive mechanism between cross-region operations and policy support, cross-region enterprises will have more incentives to plough into the local innovation ecosystem, and the government will reap the double benefits of economic growth and regional innovation. In contrast, if the two sides fail to reach a reasonable balance, not only can the innovation potential of enterprises not be fully released, but it may also lead to resource mismatch and competitive imbalance. Based on the above analyses, a suitable mutual participation model is constructed, as shown in Figure 1.

The formation of cross-regional business strategies is closely related to the upgrading of the enterprise's own industrial structure, the regional competition pattern, the regional economic environment, and the local policy orientation. Its decision-making motivation mainly comes from the integration of external resources and the need for complementarity of advantages, as well as the incentives of the local government for investment attraction and industrial upgrading [9,10]. Therefore, the interaction between firms and the governments of cross-entry regions not only involves elements such as the scale of investment, policy incentives, and industrial synergies but also profoundly affects the innovation activities of the firms as well as the improvement of the regional innovation ecosystem. Specifically, when choosing whether to conduct cross-regional operations and selecting target regions, cross-regional enterprises usually hope to obtain favorable conditions such as tax incentives, supporting resources and high-quality R&D environments, so as to reduce the overall risks and costs of innovation [11], and accelerate the connection with the local industrial chain and relevant public research institutions. Meanwhile, the government of the trans-boundary region expects enterprises to transfer their rich practical experience and cutting-edge technologies to inject new R&D impetus and innovation

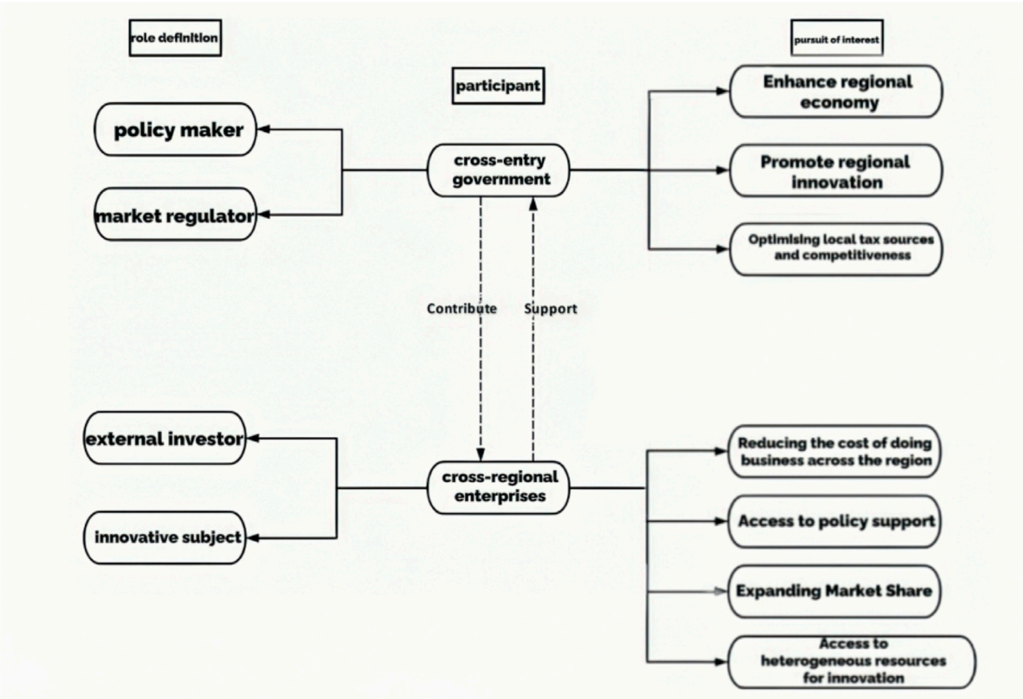

FIGURE 1
Participation model for both parties.

concepts into the local area and to drive the related industries and enterprises in the region to follow up through the knowledge spillover effect, so as to form the diffusion of innovation effect, enhance the technological innovation capability of the region or industry as a whole, further optimize the regional industrial structure, and improve the overall competitiveness and sustainable development capability.

If the two sides can form an effective incentive mechanism between cross-region operations and policy support, cross-region enterprises will have more incentives to plough into the local innovation ecosystem, and the government will be able to reap the double benefits of economic growth and regional innovation. In contrast, if the two sides fail to reach a reasonable balance, not only can the innovation potential of enterprises not be fully released, but it may also lead to resource mismatch and competitive imbalance. Based on the above analyses, a suitable model of mutual participation is constructed, as shown in Figure 1.

3 Model assumptions

The specific assumptions made to construct the game model of cross-region enterprises and cross-entry place government follow.

Assumption 1: Participating subject 1 is the enterprise, and participating subject 2 is the local government. Both parties are limited-rational, information-limited economic players who will adjust their strategies in response to external changes [12]. Firms may choose to operate across regions and set up subsidiaries in the target region to seek external heterogeneous resources to enhance their innovation capabilities, or they may not operate across regions and concentrate their resources locally to enhance their innovation capabilities through existing resources [13]. Therefore, the firm's strategy choice space $s_1 = \{Operateacrosstheregion, donotoperateacrosstheregion\}$. Meanwhile, the government of the cross-entry location can choose to provide supportive policies to attract external firms to set up subsidiaries locally so as to enhance the regional economic vitality and innovation capacity, or it can choose to remain neutral and not provide additional policy incentives. Therefore, the strategy choice space of the local government $s_2 = \{activesupport, noactivesupport\}$.

Assumption 2: Firms choose with probability x to engage in cross-regional operations and with probability $1 - x$ not to engage cross-regional operations; the government of the place where they cross into chooses with probability y to actively support them and with probability $1 - y$ not to actively support them. $x, y \in [0, 1]$ and are both functions of time t.

Assumption 3: For enterprises, it is their choice whether or not to operate across regions. If it chooses to operate across regions, its ability to access resources and the extent to which it can do so may be affected by resource conditions in the target region, government support, and local market expansion. The basic innovation investment cost for local development is C_1, and the innovation gain for local development is R_1. Cross-regional operations lead to increased internal management costs, resulting in direct costs of C_2. Cross-regional operations also incur competition costs in different locations, innovation investments in these areas, and initial investments and adaptation expenses required to enter new regions, collectively forming C_3. Additionally, heterogeneous

10.3389/fphy.2025.1611590

resources are obtained in different regions, generating innovation benefits R_2 and market expansion benefits R_3. When the host government adopts proactive support policies, companies can also receive fiscal subsidies and tax incentives provided by the host government, which constitute policy benefits S.

Assumption 4: An inbound government that chooses active support must provide policy support such as financial subsidies and tax incentives to attract external enterprises to operate in the region and increase their investment, and the cost of this is S. In addition to direct policy support, the inbound government must strengthen the supervision of the external enterprises and coordinate the competition and cooperation between them and the local enterprises, and this generates an additional cost of C_4. At the same time, the direct economic growth and tax benefits brought about by external firms' cross-border operations in the local area are D. When the inbound government chooses to actively support them, the inbound government can promote collaborative innovation through coordinating the establishment of close cooperation between the external firms and the local firms or research institutes, thus generating knowledge spillovers to the local area as H, and when the inbound government does not actively support them or sets up barriers to entry, the external firms might be inclined to give up cross-border operations and concentrate their resources on their own locations. Thus, a government of a trans-entry location that does not actively support collaborative innovation may miss out on potential opportunity gains such as economic growth, employment opportunities, knowledge spillovers, and increased tax revenue that can be brought about by the external firm, which are defined as T. Although local governments must bear the additional cost of C_4 when actively supporting external enterprises, C_4 represents the initial short-term costs. The opportunity benefits brought about by the introduction of external enterprises, including long-term economic growth, increased tax revenue, creation of job opportunities, knowledge spillover, and technological innovation, are far greater than the cost of C_4 in total.

The corresponding parameters are shown in Table 1, and the payoff matrix is shown in Table 2.

TABLE 1 Parameters of the bilateral game model and their meanings.

Parameter	Meaning
C_1	The basic innovation investment cost for local development
R_1	The innovation gain for local development
C_2	Direct costs of cross-regional operations
C_3	Developing competitive costs, innovation inputs, and market entry costs
R_2	Innovative gains from accessing heterogeneous resources
R_3	Market expansion gains
S	Financial subsidies and tax incentives
C_4	Regulatory and coordination costs
T	Gains from outside firms that may be lost if not actively supported
D	Direct economic growth and tax benefits from external enterprises
H	Local knowledge spillovers from external firms when actively supported by the government

TABLE 2 Matrix of payoff for both parties.

The bilateral game		Local government active support y	Not active support $1-y$
Cross-regional enterprises	cross-regional operation	$R_2+R_3+S-C_2-C_3$	$R_2+R_3-C_2-C_3$
	x	$D+H-S-C_4$	D
	Local development	R_1-C_1	R_1-C_1
	$1-x$	$-C_4$	$-T$

4 Model solution and evolutionary stability analysis

Based on the above game analysis between cross-region enterprises and local government, the behavioral strategy choices are suitable for further analysis using the dynamic replication equation in evolutionary game theory. Therefore, this section constructs the dynamic replication equations of cross-district enterprises and local government to further describe the strategy evolution process of both sides of the game.

The firm's expected return from choosing to operate across the region is U_1, and the earnings expectation function, defined in Equations 1–13:

$$U_1 = y(R_2+R_3+S-C_2-C_3)+(1-y)(R_2+R_3-C_2-C_3) \quad (1)$$

The expected return from not choosing to operate across the region is U_{1n}, and the earnings expectation function is

$$U_{1n} = y(R_1-C_1)+(1-y)(R_1-C_1) \quad (2)$$

The average expected return for a firm adopting a mixed strategy is $\bar{U}_1$, and the earnings expectation function is

$$\bar{U}_1 = xU_1+(1-x)U_{1n} \quad (3)$$

Therefore, the dynamic replication equation for a firm undertaking a cross-regional business strategy is

$$\begin{aligned} F(x) = \frac{dx}{dt} &= x(U_1-\bar{U}_1) = x(1-x)(U_1-U_{1n}) \\ &= x(1-x)(S_y+C_1+R_3-C_2-C_3-R_1+R_2) \end{aligned} \quad (4)$$

The expected payoff of the local government's choice of active support is U_2 given by the earnings expectation function:

$$U_2 = x(D+H-S-C_4)+(1-x)(-C_4) \quad (5)$$

The expected payoff for a local government that chooses not to actively support is U_{2n}, and the earnings expectation function is

$$U_{2n} = x(D) + (1-x)(-T) \tag{6}$$

The average expected return of a mixed strategy by a local government is $\bar{U}_2$, and the earnings expectation function is

$$\bar{U}_2 = yU_2 + (1-y)U_{2n} \tag{7}$$

Therefore, the dynamic replication equation for the trans-entry local government is

$$\begin{aligned} F(y) = \frac{dx}{dt} &= y\left(U_2 - \bar{U}_2\right) = y(1-y)\left(U_2 - U_{2n}\right) \\ &= y(1-y)\left((H-S-T)x - C_4 + T\right) \end{aligned} \tag{8}$$

The union of the above two replicated dynamic equations leads to a two-dimensional dynamical system (I) reflecting the evolution of the behavior of the two parties over time.

$$\begin{cases} F(x) = \dfrac{dx}{dt} = x(1-x)\left(S_y + C_1 + R_3 - C_2 - C_3 - R_1 + R_2\right) \\ F(y) = \dfrac{dx}{dt} = y(1-y)\left((H-S-T)x - C_4 + T\right) \end{cases} \tag{9}$$

The essential properties of a system are determined by the system's stationary state, which is often portrayed by the equilibrium point equation of the system, which consists of the points in the system where the derivatives of all state variables with respect to time are zero. When the system is in a stationary state, the state of the system no longer changes; that is, the system is in equilibrium. Therefore, the equilibrium point equation of the system is

$$\begin{cases} F(x) = \dfrac{dx}{dt} = 0 \\ F(y) = \dfrac{dx}{dt} = 0 \end{cases} \tag{10}$$

From Equations 6–10, the points $O(0,0), A(0,1), B(1,0), C(1,1)$ are the equilibrium points of the system, and let

$$x_0 = \frac{C_4 - T}{H - S - T} \tag{11}$$

$$y_0 = \frac{-C_1 + C_2 + C_3 + R_1 - R_2 - R_3}{S} \tag{12}$$

Because both X_O and y_0 are probabilities, they must be satisfied such that they take values between 0 and 1 when $0 < C_4 - T < H - S - T, 0 < -C_1 + C_2 + C_3 + R_1 - R_2 - R_3 < S$, in order to ensure that $0 < x_0 < 1$, $0 < y_0 < 1$, but because the hypothesis analysis has already been stated as $C_4 - T < 0$, and X_O can be considered to lack practical significance, (x_0, y_0) is not an evolutionary stabilization point.

According to Friedman's findings, it is known that the equilibrium point of the system is not necessarily the stable point of the system, and the local stability of the equilibrium point can be judged by the Jacobian matrix. Taking J to represent the Jacobian matrix of the two-dimensional dynamical system () in the static regime, it is obtained that

$$\begin{aligned} J &= \begin{bmatrix} \dfrac{\partial F(x)}{\partial x} & \dfrac{\partial F(x)}{\partial y} \\ \dfrac{\partial F(y)}{\partial x} & \dfrac{\partial F(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \\ &= \begin{bmatrix} (1-2x)\left(Sy + C_1 + R_3 - C_2 - C_3 - R_1 + R_2\right) & x(1-x)Sy \\ y(1-y)\left((H-S-T)x\right) & (1-2y)\left((H-S-T)x - C_4 + T\right) \end{bmatrix} \end{aligned} \tag{13}$$

An equilibrium point is an evolutionarily stable strategy for the system only if the Jacobian matrix corresponding to the equilibrium point simultaneously satisfies the determinant $Det(J) > 0$ and $Tr(J) < 0$. The stability analysis of the five equilibrium points obtained for the dynamical system(I) is shown in Table 3.

According to the calculation results in Table 3 and the judgment conditions of the evolutionary stability strategy, it can be seen that the signs of the equilibrium points $(0,0), (0,1)$ and $(1,1)$ are uncertain, and it is necessary to further analyze the parameters before determining whether they are evolutionary stability points (ESSs).

4.1 Analysis of stable case 1 of the evolutionary game system

Because $C_4 - T < 0$, it is only necessary to conduct relevant analysis on the symbols of $(C_1 + S - C_2 - C_3 - R_1 + R_2 + R_3)$ when $(C_1 + S - C_2 - C_3 - R_1 + R_2 + R_3) < 0$. At that time, $R_2 + R_3 + S - C_2 - C_3 < R_1 - C_1$, the net benefit to firms from local development, the return on local innovation investment minus the cost of basic innovation inputs for local development, is higher than the net benefit that would have been obtained through cross-border operations with the support of active policies introduced by the government of the place of cross-entry. At this point, firms tend to choose to develop their innovations locally, which means that they believe that concentrating their resources locally will not only maximize their economic efficiency but also effectively enhance their innovation capabilities. At the same time, the governments of cross-entry regions still choose to provide active support in this situation as they aim to promote economic growth, job creation, and technological progress in the region. By providing policy support such as financial subsidies and tax incentives, the government can attract more external capital and form an industrial cluster effect, thus enhancing the overall competitiveness of the region, upgrading the technological level and innovation capacity of local enterprises, and facilitating knowledge spillovers and technological diffusion, which in turn promotes the upgrading and optimization of the entire industrial chain. Therefore, in this case, the evolutionary stabilization strategy (ESS) is $(0,1)$, and the enterprise chooses not to engage in cross-regional operations but focuses on local development.

4.2 Analysis of stable case 2 of the evolutionary game system

When $-C_1 + C_2 + C_3 + R_1 - R_2 - R_3 < 0$ and $H - S - C_4 < 0$, scenario 2, that is $(1,0)$, can become an evolutionary stable strategy. At this point, $R_2 + R_3 - C_2 - C_3 > R_1 - C_1$ and $H < S + C_4$ indicate that despite the local government not actively supporting. However, the net benefits obtained by enterprises operating across regions minus the costs associated with operating across regions exceed the net benefits obtained by firms investing in local development and innovation. Therefore, firms tend to choose to operate across regions in order to maximize their economic efficiency and innovation capacity. This choice not only enables firms to expand

TABLE 3 Parameters of the bilateral game model and their meanings.

local equilibrium point	$Det(J) > 0$	$Tr(J) < 0$	local stability point
$(0,0)$	$(C_1 - C_2 - C_3 - R_1 + R_2 + R_3)$ $(-C_4 + T)$	$C_1 - C_2 - C_3 - R_1 + R_2 + R_3 - C_4 + T$	saddle point
$(0,1)$	$(C_1 + S - C_2 - C_3 - R_1 + R_2 + R_3)$ $(C_4 - T)$	$C_1 + S - C_2 - C_3 - R_1 + R_2 + R_3 + C_4 - T$	unfixed
$(1,0)$	$(-C_1 + C_2 + C_3 + R_1 - R_2 - R_3)$ $(H - S - C_4)$	$-C_1 + C_2 + C_3 + R_1 - R_2 - R_3 + H - S - C_4$	unfixed
$(1,1)$	$(-C_1 - S + C_2 + C_3 + R_1 - R_2 - R_3)$ $(-H + S + C_4)$	$-C_1 - S + C_2 + C_3 + R_1 - R_2 - R_3 - H + S + C_4$	unfixed
(x_0, y_0)	$-x(1-x)Sy$ $y(1-y)((H-S-T)x)$	0	instability

into new markets and acquire more resources and technologies but also diversifies risks and improves overall competitiveness through diversification. However, for the government of the trans-entry location, although the establishment of local subsidiaries by external enterprises to operate across regions can bring some knowledge spillover benefits and thus innovation gains, the trans-entry government chooses not to actively support firms to operate across regions as the knowledge spillover gains are not enough to compensate for the cost inputs of the trans-entry government in terms of financial subsidies and regulatory coordination. Because firms can obtain higher net gains in cross-regional operations while the local government bears relatively heavier costs, the evolutionary stability strategy (ESS) is $(1,0)$ in this scenario. Enterprises choose to operate across regions, while the local government chooses not to actively support them to operate across regions. This combination of strategies reflects the rational decision-making of the enterprise driven by revenue maximization and the strategic choice of the local government after cost-benefit analysis, and overall, it achieves the best response to the respective objectives of the enterprise and the government.

4.3 Analysis of stable case 3 of the evolutionary game system

When $-C_1 - S + C_2 + C_3 + R_1 - R_2 - R_3 < 0$ and $-H + S + C_4 < 0$, scenario 3, that is $(1,1)$, can become an evolutionary stable strategy. At this point, $R_2 + R_3 + S - C_2 - C_3 > R_1 - C_1$ and $H > S + C_4$ indicate that under the condition of supportive policies introduced by the local government, the net benefits of all the benefits and subsidies received by cross-regional operating enterprises, less the costs of doing so, significantly exceed the net benefits received by firms from investing in local development and innovation. As a result, cross-regional operations become a preferred strategic choice for firms, prompting them to actively engage in cross-regional operations. This choice not only enables firms to expand into new markets and gain access to more resources and technologies but also diversifies risks and improves overall competitiveness through diversification. At the same time, for the government of the cross-entry location, the establishment of local subsidiaries by external firms to conduct cross-regional operations can bring certain knowledge spillover benefits and thus innovation gains, which outweigh the subsidies provided and costs borne by the local government in order to support firms' active cross-regional operations. This implies that local governments tend to introduce and maintain supportive policies, thus creating a more favorable environment and conditions for firms to operate across regions. Under this win–win interaction, the strategic choices of firms and local governments form a virtuous circle of mutual reinforcement. Enterprises choose to operate across regions in order to maximize their economic benefits and innovation capacity, while the governments of the regions they cross into enhance the sustainable upgrading of industries and the level of regional innovation in the region through active support.

5 Simulation analysis

In order to reflect more intuitively the influence of the changes of each decision variable on the evolution process and the results of the game between the enterprise and the government of the trans-entry place, MATLAB is used to carry out the simulation analysis. In case 1, the following values are assigned to each parameter: the basic innovation input cost of local development is 8, the direct cost of inter-regional operations is 15, the competition, innovation and market entry costs of inter-regional operations are 12, the innovation gain from accessing heterogeneous resources is 6, the market expansion gain is 9, the financial subsidies and tax incentives are 5, the government regulation and coordination cost is 4, the potential loss of gains when the government is not active is 15, the gain from external firms to local knowledge spillovers when the government is active is 8.5, and the innovation gain from local development is $\{10, 15, 20\}$. The potential loss of gains is 15, the gain in local knowledge spillovers from external firms is 8.5 when the government actively supports them, and the innovation gains from local development are $\{10, 15, 20\}$. The strategy evolution process and results for firms and cross-entry local governments are shown in Figure 2. It can be seen that firms tend to choose local development innovations when the net benefits from local

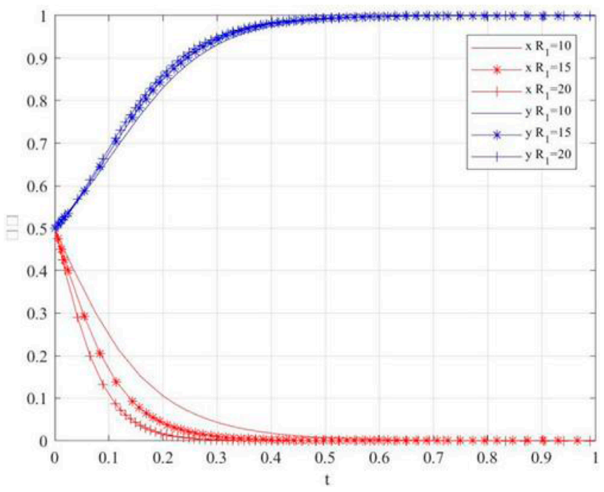

FIGURE 2
The impact of locally developed innovation gains on evolutionary outcomes.

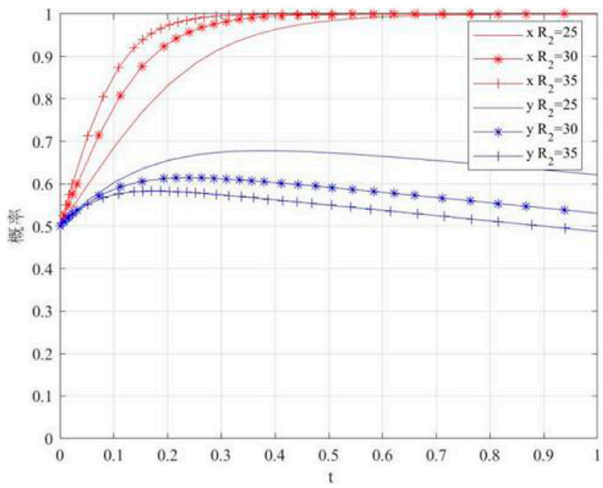

FIGURE 3
The impact of innovative gains from heterogeneous resources on evolutionary outcomes.

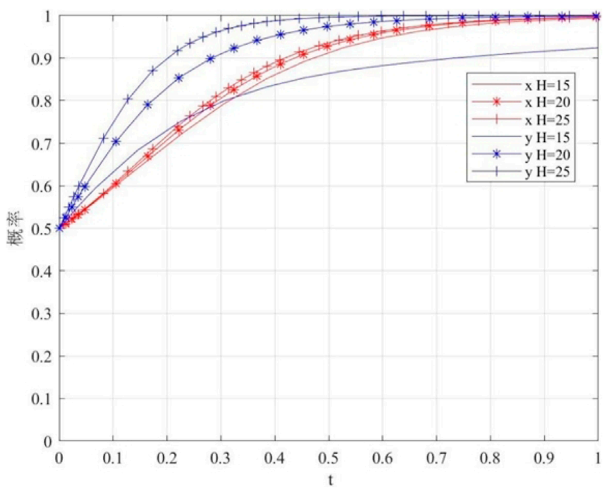

FIGURE 4
The impact of government strategies on evolutionary outcomes.

development are higher than the net benefits from innovations through cross-boundary operations. In addition, as the gap between the net return on innovation and the net return on innovation from operating across districts continues to widen, the evolution of firms' strategies toward local development accelerates significantly. This suggests that the increasing gap in net innovation gains reinforces firms' preference for local development, prompting them to adjust their strategies faster to maximize their economic efficiency and innovation capabilities. This suggests that the return gap is a significant driver of strategy choice.

In case 2, the following values are assigned to each parameter: the basic innovation input cost of local development is 8, the direct cost of inter-regional operations is 15, the competition, innovation and market entry costs of inter-regional operations are 12, the market expansion gain is 9, the financial subsidies and tax incentives are 5, the cost of government regulation and coordination is 4, the gain that may be lost if the government does not actively support it is 15, the gain in local knowledge spillovers from external firms if the government actively supports it is 8.5, the innovation gain from local development is 10, and the innovation gain from accessing heterogeneous resources is $\{25, 30, 35\}$ 8.5 for local knowledge spillovers from external firms with active government support, 10 for innovation gains from local development, and $\{25, 30, 35\}$ for innovation gains from access to heterogeneous resources. The strategy evolution process and results of the firms and the cross-entry local governments are shown in Figure 3. Enterprises tend to choose cross-entry operations when the net innovation benefit from cross-entry operations is higher than the net innovation benefit from local development. In addition, as the gap between the net innovation gains from cross-district operations and the net innovation gains from local development continues to widen, the evolution of firms' strategies for choosing cross-district operations accelerates significantly.

In case 3, the following values are assigned to each parameter: the basic innovation input cost of local development is 8, the innovation gain of local development is 10, the direct cost of inter-regional development is 15, the competition, innovation, and market entry costs of inter-regional development are 12, the innovation gain from accessing heterogeneous resources is 21, the market expansion gain is 9, the fiscal subsidy and tax incentives are 5, the government regulation and coordination costs are 4, the potential loss of gains when the government is not active is 15, and the gain in local knowledge spillovers from external firms when the government is active is $\{10, 15, 20\}$. The strategy evolution process and the results of firms and cross-entry local governments are shown in Figure 4. Firms tend to choose to operate across regions when the net innovation benefit they obtain from doing so is higher than the net innovation benefit from local development. When the benefits that the inbound government can obtain exceed the subsidies it provides and the costs it bears to support cross-border operations, the inbound government tends to introduce supportive policies. At the same time, the evolution of the cross-border government's strategy towards active support accelerates significantly as its benefits increase.

6 Conclusion

This paper explores the formation and dynamic evolution process of the interaction mechanism between cross-regional operating enterprises and local government based on evolutionary game theory. The study shows that the strategic choices of both parties are influenced by multiple factors such as benefit distribution, policy environment, risk cost, and cooperation expectation, and their interactive behavior shows significant dynamic adaptability and path dependence. The strategic evolution between cross-regional enterprises and local government is stable only if their respective returns are in line with their rational decision-making, and the choice of strategy is strongly influenced by each party's own net returns. In the long run, enterprises tend to invest more in regions with high policy support and low institutional costs, while local governments balance the goals of economic growth and the preservation of public interest by adjusting the intensity of regulation and incentives. It is found that the establishment of interest interaction and government-enterprise gaming mechanisms can effectively promote the two sides from short-term gaming to stable cooperation and reduce strategic uncertainty. In addition, the optimization of the external institutional environment (e.g., regional synergy policy and cross-regional governance framework) plays a key role in promoting the realization of cooperative equilibrium. Future research can further combine case validation and multi-subject simulation to deepen the exploration of the dynamic law of the interaction mechanism in the context of differentiated regions, so as to provide theoretical support for the design of cross-region governance policies.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

Author contributions

JZ: Data curation, Formal Analysis, Methodology, Writing – original draft. SL: Writing – original draft, Writing – review and editing. JiZ: Writing – review and editing. LZ: Funding acquisition, Writing – review and editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. China Postdoctoral Program 2024M752437 Major project of philosophy and social sciences in colleges and universities, Jiangsu Provincial Department of Education 2024SJZD059 Basic Science (Natural Science) Research Program of Jiangsu Provincial Universities 23KJB630005) Zhenjiang Soft Science (RK2024010).

Conflict of interest

Author JZ was employed by Commercial Factoring (Shanghai) Co., Yunnan Communications Investment and Construction Group Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

References

1. Wu M, Zhu Y, Yang T, Xu Y. Game-theoretic approach to understanding status transition dynamics and employee performance enhancement in organizations. *Front Phys* (2023) 11:1307672. doi:10.3389/fphy.2023.1307672

2. Sarkar A, Wang H, Rahman A, Azim JA, Memon WH, Qian L. Structural equation model of young farmers' intention to adopt sustainable agriculture: a case study in Bangladesh. *Renew Agric Food Syst* (2022) 37:142–54. doi:10.1017/s1742170521000429

3. Zhu Y, Wu M, Lu J. "zero-sum game" or "win-win cooperation": an analysis of the evolution effect of competition neutrality based on the participation of four parties. *Front Phys* (2024) 12:1429728. doi:10.3389/fphy.2024.1429728

4. Xiao L, Liu J, Ge J. Dynamic game in agriculture and industry cross-sectoral water pollution governance in developing countries. *Agric Water Management* (2021) 243:106417. doi:10.1016/j.agwat.2020.106417

5. Berthinier-Poncet A, Dubouloz S, Ruiz É, Thévenard-Puthod C. Innovation communities' contributions throughout firms' innovation processes: an outdoor sports industry case study. *Eur Management J* (2023) 41:575–89. doi:10.1016/j.emj.2023.01.007

6. Wang W, Liu Y. Does university-industry innovation community affect firms' inventions? the mediating role of technology transfer. *The J Technology Transfer* (2022) 47:906–35. doi:10.1007/s10961-021-09887-w

7. Khalifa I, Li Z, Nawaz A, Walayat N, Sobhy R, Jia Y, et al. Recent innovations for improving the techno-functional properties of plant-based egg analogs and egg-mimicking products to promote their industrialization and commercialization. *Compr Rev Food Sci Food Saf* (2025) 24:e70086. doi:10.1111/1541-4337.70086

8. Jimenez A, Pansera M, Abdelnour S. Imposing innovation: how ‘innovation speak’maintains postcolonial exclusion in Peru. *World Development* (2025) 189:106914. doi:10.1016/j.worlddev.2024.106914

9. Yu X, Gao X, Wang L, Wang X, Ding Y, Lu C, et al. Cooperative multi-uav task assignment in cross-regional joint operations considering ammunition inventory. *Drones* (2022) 6:77. doi:10.3390/drones6030077

10. Zhang W, Zhao B, Zhou L, Qiu C, Wang J, Niu K, et al. Development of a resource optimization platform for cross-regional operation and maintenance service for combine harvesters. *Appl Sci* (2022) 12:9873. doi:10.3390/app12199873

11. Liu P, Chen S. The effect of banking deregulation on r&d investment: evidence from the cross-regional operation of city banks. *J Innovation and Knowledge* (2023) 8:100451. doi:10.1016/j.jik.2023.100451

12. Serafeim G, Yoon A. Stock price reactions to esg news: the role of esg ratings and disagreement. *Rev Account Stud* (2023) 28:1500–30. doi:10.1007/s11142-022-09675-3

13. Earnhart D, Friesen L. Certainty of punishment versus severity of punishment: enforcement of environmental protection laws. *Land Econ* (2023) 99:245–64. doi:10.3368/le.030521-0024r1