DSI DATA SCIENCE AND INFORMETRICS
VOL.3, NO.2, MAY. 2023

RESEARCH ARTICLE

Open sharing of government data and enterprise decision making

Zhongyang Xu[a,b], Junping Qiu[a,b,c*]

a. School of Management, Hangzhou Dianzi University, Hangzhou, China

b. Chinese Academy of Science and Education Evaluation, Hangzhou Dianzi University, Hangzhou, China

c. Academy of Data Science and Informetrics, Hangzhou Dianzi University, Hangzhou, China

ABSTRACT

Data is a key factor of production in the so-called "digital economy" era. Thus, it is important to promote government data opening and sharing to advance the high-quality development of a digital economy. The article first constructs an evolutionary game model of government data opening and sharing (with local governments and enterprises as game participants) by combining realistic scenarios and evolutionary game models. Then, it discusses the evolutionary stabilization strategies under different scenarios in a categorical manner. Finally, it uses MATLAB to conduct numerical simulations to verify the accuracy of the model and analyze the key influencing factors. Several results were obtained. (1) the optimal evolutionary path to promote government data opening and sharing is for enterprises to choose to "use data" and for local governments to choose the "positive sharing" strategy, and the enterprises' decision is the internal driver. (2) The value of data assets provided by local governments when applying the "positive sharing" strategy, the cost of data used by enterprises, and the data value conversion rate of enterprises are the key factors influencing the decisions of both parties. To promote open sharing and exploitation of government data, enterprises should enhance their independent innovation capabilities, while governments should enhance the value of data assets and continuously optimize their business environments.

KEYWORDS

Digital economy; Government data; Opening and sharing; Evolutionary game model; Evolutionary stable strategy

1 Introduction

With the rapid development of big data, artificial intelligence and 5G network, and other Internet information technologies, China's digital economy has developed rapidly in recent years, resulting in the formation of a large-scale big data industry (Borjigin et al., 2021; Chen et al., 2021). In 2020, China's digital economy generated 39.2 trillion Yuan, accounting for

* Corresponding Author: jpqiu@whu.edu.cn

38.6% of GDP, while the scale of the big data industry reached 71.87 billion Yuan, ranking among the top of data market growth worldwide (China Academy of Information and Communications Technology [CAICT], 2021; Internet Society of China, 2021). In the era of the digital economy, data are considered a key element of economic development. However, at present, over 80% of China's data resources are still controlled by government agencies at all levels; therefore, the development of the digital economy has also given rise to a strong demand from various industries for the open sharing of government data (Wen, 2019).

Since 2015, with the introduction and implementation of a series of government data opening and sharing policies, such as the "Action Plan for Promoting Big Data Development" and "Promote the 'Internet plus government services' to Carry Out Information for the People Pilot Implementation Program," China has started to explore diverse data opening and sharing models of government– enterprise cooperation, such as project outsourcing, social crowdsourcing, and social service purchase (the State Council of China, 2021; Ran et al., 2022). At the same time, local governments have also established data management agencies to promote the integration of government data and open sharing, including Zhejiang Province ("Big Data Development Authority"), Shandong Province ("Big Data Bureau"), and Shanghai ("Big Data Center"), among others (Lian, 2021). It is not difficult to find that in China, local governments usually use the establishment of state-owned big data management agencies to dock business with enterprises in the data industry as a way to promote government data open-sharing projects (Song et al., 2020). Therefore, we believe that our study, with local governments and enterprises as research subjects, is consistent with the current environment of China's data industry and its findings are universal in China.

For local governments, although the open sharing of data can bring them improved credibility and satisfaction, at the same time, collecting, integrating, and providing high-value data also require additional administrative costs; furthermore, the disclosure of data may lead to the leakage of state secrets or private information, thus causing losses of a certain scale (Zhu & Xia, 2021). For enterprises, access to and use of government data are important for digital transformation, business model innovation, and market access, but they also have to pay for equipment, technology, capital, and other costs (Xu et al., 2020). Based on the above analysis, there exists a certain game relationship between local governments and enterprises on the topic of "government data open sharing and utilization," and both sides will constantly adjust their strategies according to their interests and the strategies adopted by the other side.

Based on the analysis of the game process between local governments and enterprises, this study attempts to establish an evolutionary game model, determine the optimal evolutionary stabilization strategy, and provide suggestions on how to achieve the optimal strategy. The aim is to achieve a win – win situation between local governments and enterprises by promoting the open sharing and exploitation of government data. Ultimately, this can lead to the high-quality development of China's digital economy.

2 Literature Review

At present, scholars in the fields of public management and library and information science—both at home and abroad—have conducted a series of studies regarding the open sharing of government data. Some scholars have analyzed the current research status and development trends of open government data by combing relevant literature. For example, Chen and Zhang (2022) systematically sorted out research related to the construction of open government data platforms at home and abroad from 2011– 2020 by using a literature survey, comparative analysis, and logical analysis. They then divided this research field into three stages: initial exploration, rapid development, and stable promotion. After a systematic review of the research literature on the visualization of government open data, Ansari et al. (2022) concluded that there are four main directions in the field: description and evaluation of typical cases of government open data, generic tools, and frameworks, the user needs assessment and usability evaluation, and other user-related results.

On the one hand, some scholars have also studied the policies and regulations on government data opening and sharing. For example, Liang and Chen (2022), Li and Chen (2021), and Zhai et al. (2021) investigated the government data opening policies of Mexico, the United States, the United Kingdom, and other countries. These studies compared and analyzed the differences between domestic and foreign policies from various perspectives, such as the opening system, data correction mechanism, and metadata standard construction, and proposed suggestions for the formulation and improvement of China's government data opening policies. Huang et al. (2020) argued that the implementation of government data openness policies must rely on good implementation by executives. Using national government survey data in Taiwan, they empirically tested the impacts of two types of perceived risks (personal responsibility and organizational responsibility) on the willingness to initiate government data openness. Their results showed that both types of perceived risks have a strong negative impact on government data openness willingness.

On the other hand, some scholars have studied the process of government data open sharing from an ecosystem perspective. For instance, Li and Zhao (2022) used dissipative structure theory, evolutionary game theory, and social network theory to construct an ecological chain structure model and evolutionary logic model of government open data. They then summarized the characteristics, motives, and dynamics of the evolutionary process based on the detailed combination of constituents and interactions. Zhao et al. (2022) constructed a dynamic symbiotic evolution equation of the government open data application ecosystem from a symbiotic perspective and used numerical analysis in performing the simulation. They concluded that the dynamic evolution of the ecosystem will reach a stable equilibrium state and that the mutually beneficial symbiotic model is the optimal evolution path of the ecosystem.

At the same time, data security and privacy risks have become hot topics among domestic and foreign scholars in recent years. For example, Di and Jiang (2022) found that the opening of government data in the context of big data may cause the leakage of citizens' privacy, the main reasons for which include the lagging legal system, unclear rights and obligations of subjects, and the inadequacy of the information management system. Therefore, they suggested that the government should build a classified and graded legal system for data opening, clarify the scope of data management and constraint mechanisms, and build a nationwide unified data opening platform. Meanwhile, Lee and Jun (2021) proposed an open government data integration approach that can appropriately balance the risk of privacy disclosure and data utility for the mining and utilization of identifier-free data from a technical aspect.

In general, there are abundant research results related to the open sharing of government data at home and abroad, with a solid theoretical foundation and various research perspectives. In terms of research themes, existing studies cover a variety of topics, such as the current research status, policy system, ecosystem, and privacy risks of open sharing of government data; however, the number of studies conducted on the willingness, behavior, or decision making related to the open sharing of government data is still relatively small, and only a few scholars, such as Zhu et al. (2022), Ran et al. (2022), and Kassen (2018), have analyzed it based on the government or public position. In terms of research methods, various methods have been widely used, such as bibliometrics, literature review, and mathematical modeling, but relatively few studies have applied evolutionary game models. Thus far, only a few scholars, such as Wang and Li (2019) and Wei et al. (2020), have introduced them to the study of the open sharing of government data.

Following the specific project implementation process regarding the open sharing of government data (see Figure 1), local governments and enterprises are the main participants because they are the providers and users of government data, respectively. Therefore, the willingness and decisions of both parties to initiate open data sharing have an important impact on the promotion of the project. Notably, their perceived benefits and costs are still the key influencing factors of their decision-making behaviors. Furthermore, the evolutionary game model can be combined with realistic scenarios to analyze the costs and benefits of both parties of the game, observe the strategy changes of both parties over time, and then derive an evolutionary stable strategy (ESS). Therefore, this study adopts the evolutionary game model to analyze the key factors influencing the decision of both parties in the process of open government data sharing from the perspective of local governments and enterprises. This work also aims to provide theoretical references for the promotion of open government data-sharing projects and the development of the digital economy.

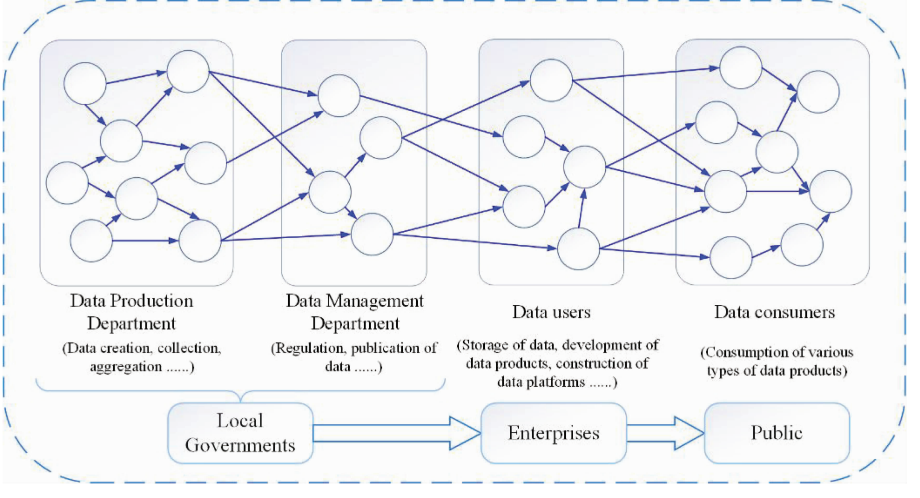

Figure 1 Government Data Development and Sharing Project

3 Research Hypothesis and Model Construction

This study assumes that the game subjects in the process of government data open sharing are mainly the providers and users of government data, namely, the local governments and enterprises, respectively. Therefore, the following hypotheses are proposed:

Hypothesis 1: For the game strategy of local governments, they use either "positive sharing" or "negative sharing." When local governments choose the latter, they only need to provide enterprises with government data that meet their minimum needs. Although there are costs and risks of public privacy leakage, when the data are used by enterprises, local governments can gain synergistic benefits, such as enterprise trust and public satisfaction. When local governments choose the positive sharing strategy, they can gain the trust of enterprises and public satisfaction. Furthermore, when local governments choose this strategy, they need to provide higher-value government data. On the one hand, they need to pay higher costs to enhance the value of their data assets. On the other hand, the increased value of government data assets provided by local governments can effectively reduce the risk of public privacy breaches and lead to greater synergistic benefits.

Hypothesis 2: The game strategy used by enterprises is either to "use data" or "don' t use data." When enterprises choose the latter, they do not have to pay any use cost but this also means that they will not gain the economic benefits from the development of government data. Thus, they will suffer some losses in the market competition because the competitors actively explore the value of data. In comparison, when enterprises choose the first strategy, they need to pay for the cost of collecting data, upgrading equipment, and training employees. In doing so, they can obtain the economic benefits of developing data, which are related to the value of data assets provided by local governments and the enterprises' ability to transform data value. In addition, when local governments choose the positive sharing of data and enterprises choose to use data, the latter can also gain additional trust from local governments.

Hypothesis 3: Local governments and enterprises are finite rational "economic people" who make decisions based only on their benefits and costs; furthermore, they will continuously adjust their strategies according to the changes in benefits and costs, which may eventually reach an evolutionarily stable state.

Based on the above assumptions, we use the following parameter symbols for the model construction and calculation (see Table 1).

Table 1 Parameter symbols and their meanings

Notation	Meanings
L_g	Loss of public privacy disclosure after the opening of government data, $L_g>0$
L_e	Loss of the data is not used by the enterprise but is used by competitors, $L_e>0$
C_{g1}	Cost of implementing the negative sharing strategy in local governments, $C_{g1}>0$
C_{g2}	Cost of implementing the positive sharing strategy in local governments, $L_{g1}>C_{g2}>0$
C_e	Cost of using government data for enterprises, $C_e>0$
B_{g1}	Synergistic benefits from enterprises´ use of data under the negative sharing strategy, $B_{g1}>0$
B_{g2}	Synergistic benefits from enterprises´ use of data under the "positive sharing" strategy,$B_{g2}>B_{g1}>0$
B_{ei}	Economic benefits to enterprises from using the data, $B_{ei}>0$
V_1	Value of data assets under the "negative sharing" strategy, $V_1>0$
V_2	Value of data assets under the "positive sharing" strategy, $V_2>0$
S	Data value conversion rate of enterprises, $S>0$
T	Trust gains for companies under the "positive sharing" strategy, $T>0$
a	Probability of privacy leakage under the "negative sharing," $0<b<a<1$
b	Probability of privacy leakage under the "positive sharing," $0<b<1$
x	The proportion of local governments choosing "positive sharing," $0\leqslant x\leqslant 1$
y	The proportion of enterprises choosing "use data," $0\leqslant y\leqslant 1$

As shown in Table 1, the proportions of local governments that choose to use the positive and negative sharing strategies are represented by *x* and *(1-x)*, respectively. Similarly, the proportions of enterprises choosing "use data" and "don't use data" are *y* and *(1-y)*, respectively. In addition, by combining the concepts of the "value of government data assets" (Ren, 2021) and the "value of the whole life cycle of data" (Shanghai Modern Service Industry Federation Data Center & KPMG, 2022), we can see that the economic benefits B_{ei} obtained by enterprises after mining and using government data are positively correlated with the value of data V_i assets and the transformation rate *s* of enterprise data value. Therefore, we assume that $B_{ei} = S * V_i (i=1,2)$. In summary, we can obtain the benefit matrix of local government and enterprises and construct the evolutionary game model diagram, as shown in Table 2 and Figure 2.

Table 2 Benefit matrix of local governments and enterprises

Game Players	Local Governments	
Enterprises	Positive sharing (x)	Negative sharing (1–x)
Use data (y)	$B_{g2} - C_{g2} - bL_g,\ sV_2 + T - C_e$	$B_{g1} - C_{g1} - aL_g,\ sV_1 - C_e$
Don't use data (1–y)	$-C_{g2} - bL_g, -L_e$	$-C_{g1} - aL_g, -L_e$

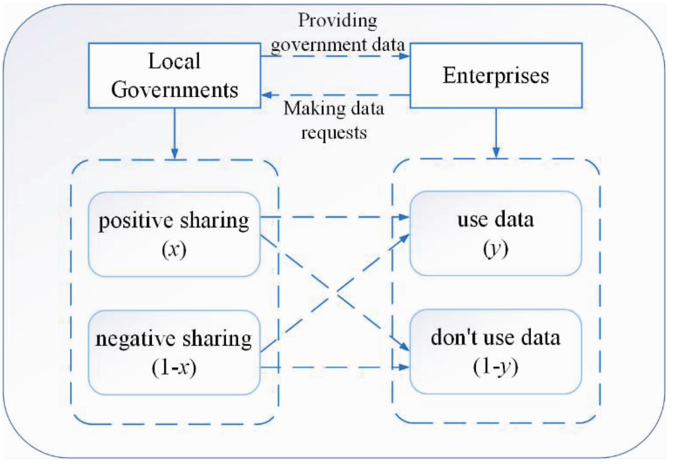

Figure 2 Evolutionary game model of open government data sharing

4 Model Calculation and Stability Analysis

We define the expected benefits of the positive sharing strategy chosen by the local governments as G_1, the expected benefit of the negative sharing strategy as G_2, and the average expected benefit as $\overline{G}$. Then,

$$G_1 = y(B_{g2} - C_{g2} - bL_g) + (1-y)(-C_{g2} - bL_g), \tag{1}$$

$$G_2 = y(B_{g1} - C_{g1} - aL_g) + (1-y)(-C_{g1} - aL_g), \tag{2}$$

$$\overline{G} = xG_1 + (1-x)G_2. \tag{3}$$

Combining Formulas (1)– (3), the replication dynamic equation of the local governments game strategy can be obtained as follows:

$$F(x) = \frac{dx}{dt} = x(G_1 - \overline{G}) = x(1-x)[y(B_{g2} - B_{g1}) + (a-b)L_g + C_{g1} - C_{g2}]. \tag{4}$$

We define the expected benefits of the "use data" strategy chosen by the enterprises as E_1, the expected benefit of the "don't use data" strategy as E_2 , and the average expected benefit as $\bar{E}$. Thus, we have

$$E_1 = x(sV_2 + T - C_e) + (1 - x)(sV_1 - C_e), \tag{5}$$

$$E_2 = x(-L_e) + (1 - x)(-L_e), \tag{6}$$

$$\overline{E} = yE_1 + (1 - y)E_2. \tag{7}$$

Combining Formulas (5)– (7), the replication dynamic equation of the enterprises game strategy can be obtained as follows:

$$F(y) = \frac{dy}{dt} = y(E_1 - \overline{E}) = y(1 - y)[xs(V_2 - V_1) + xT + sV_1 + L_e - C_e]. \tag{8}$$

Combining Formulas (4) and (8), to simplify the calculation, we assume that , $\Delta B_g = B_{g2} - B_{g1}$ $\Delta C_g = C_{g2} - C_{g1}$, and $\Delta L_g = aL_g - bL_g$, from which we can obtain the system of equations for the replication dynamics of local governments and enterprises as follows:

$$\begin{cases} F(x) = x(1 - x)\left(y\Delta B_g + \Delta L_g - \Delta C_g\right) \\ F(y) = y(1 - y)[xs(V_2 - V_1) + xT + sV_1 + L_e - C_e] \end{cases}.$$

Assuming $F(x) = F(y) = 0$, five potential equilibrium points are obtained, namely, H_1 (0,0), H_2 (1,0), H_3 (0,1), H_4 (1,1), and H_5 (x^*, y^*). Among them, we have:

$$x^* = \frac{C_e - (L_e + sV_1)}{s(V_2 - V_1) + T}, y^* = \frac{\Delta C_g - \Delta L_g}{\Delta B_g}.$$

We used the Jacobian matrix in this study to determine the stability of the above potential equilibrium points (Smith, 2012). The analysis proceeds as follows:

$$J_{(x,y)} = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} = \begin{bmatrix} (1 - 2x)\left(y\Delta B_g + \Delta L_g - \Delta C_g\right) & x(1 - x)\Delta B_g \\ y(1 - y)(sV_2 - sV_1 + T) & (1 - 2y)[x(sV_2 - sV_1 + T) + sV_1 + L_e - C_e] \end{bmatrix}.$$

When the Jacobian matrix satisfies Formulas (9)– (10), then the potential equilibrium point of the replicated dynamic equations can be considered as the stable strategy of the evolutionary game, i.e., ESS.

$$detJ = (1 - 2x)\left(y\Delta B_g + \Delta L_g - \Delta C_g\right)(1 - 2y)[x(sV_2 - sV_1 + T) + sV_1 + L_e - C_e] \\ - y(1 - y)(sV_2 - sV_1 + T)\, x(1 - x)\Delta B_g > 0 \tag{9}$$

$$trJ = (1 - 2x)\left(y\Delta B_g + \Delta L_g - \Delta C_g\right)(1 - 2y)[x(sV_2 - sV_1 + T) + sV_1 + L_e - C_e] \\ < 0 \tag{10}$$

We substitute H_1 (0,0), H_2 (1,0), H_3 (0,1), H_4 (1,1), and H_5 (x^*, y^*) into Formulas (9)– (10) to obtain the determinants and traces of the five equilibrium points in the Jacobin matrix, as shown in Table 3. From Table 3, the *trJ* of H_5 (x^*, y^*) is 0. Furthermore, it can be seen that the game process cannot reach stability at H_5. Therefore, we discard H_5 and discuss only the stability of the remaining four potential equilibria.

Table 3 Determinants and traces of the Jacobin matrix

Point	*detJ*	*trJ*
H_1 (0,0)	$(\Delta L_g - \Delta C_g)(sV_1 + L_e - C_e)$	$(\Delta L_g - \Delta C_g) + (sV_1 + L_e - C_e)$
H_2 (1,0)	$(-1)(\Delta L_g - \Delta C_g)(sV_2 + T + L_e - C_e)$	$(-1)(\Delta L_g - \Delta C_g) + (sV_2 + T + L_e - C_e)$
H_3 (0,1)	$(\Delta B_g + \Delta L_g - \Delta C_g)(-1)(sV_1 + L_e - C_e)$	$(\Delta B_g + \Delta L_g - \Delta C_g) + (-1)(sV_1 + L_e - C_e)$
H_4 (1,1)	$(\Delta B_g + \Delta L_g - \Delta C_g)(sV_2 + T + L_e - C_e)$	$(-1)[(\Delta B_g + \Delta L_g - \Delta C_g) + (sV_2 + T + L_e - C_e)]$
H_5 (x^*, y^*)	$y^*(y^* - 1)(sV_2 - sV_1 + T)y^*(1 - x^*)\Delta B_g$	0

This study uses cost-benefit analysis to classify and discuss the stability of the game strategies of both parties when they are in different situations. From the perspective of local governments, when local governments shift from the negative sharing strategy to the positive sharing one, enterprises may choose to "use data" or "don't use data." Thus, local governments will certainly be able to reduce the loss of public privacy and gain credibility, goodwill, and other synergistic benefits from the development of data by enterprises. However, this also means that they must pay higher costs. As can be seen, the sum of costs of the local governments at this point is , i.e., $C_{g2}-C_{g1}$, i.e., $\triangle C_g$. The sum of benefits for the local governments in the worst case and the optimal case are $(a-b)L_g$ and $B_{g2}-B_{g1}+(a-b)L_g$, i.e., $\triangle L_g$ and $\triangle B_g+\triangle L_g$, respectively.

From the perspective of enterprises, when enterprises shift from the "don't use data" strategy to the "use data" strategy, local governments may choose either the positive sharing or negative sharing strategy. This means that enterprises will be able to avoid the loss of their own business caused by the development of data by their peers and the economic benefits of developing and utilizing low-value data assets. As such, they may obtain the economic benefits of developing high-value data assets and the increased trust from local governments; however, they must also pay the costs associated with using government data. At this time, C_e is the total cost of the enterprise, and sV_1+L_e and sV_2+T+L_e are the total revenues of the enterprise in the worst case and optimal case, respectively. In summary, we can obtain the following nine different scenarios, as shown in Table 4.

Table 4 Determination of potential equilibrium points in different scenarios

Scenarios		Conditions	Potential equilibrium points			
			(0,0)	(1,0)	(0,1)	(1,1)
(1)	$\Delta C_g > \Delta B_g + \Delta L_g$ $C_e > sV_2 + T + L_e$	*detJ*	+	−	−	+
		trJ	−	±	±	+
		Stability	ESS	Saddle Point	Saddle Point	Unstable point
(2)	$\Delta C_g > \Delta B_g + \Delta L_g$ $sV_1 + L_e < C_e < sV_2 + T + L_e$	*detJ*	+	+	−	−
		trJ	−	+	±	±
		Stability	ESS	Unstable point	Saddle Point	Saddle Point
(3)	$\Delta C_g > \Delta B_g + \Delta L_g$ $C_e < sV_1 + L_e$	*detJ*	−	+	+	=
		trJ	±	+	−	±
		Stability	Saddle Point	Unstable point	ESS	Saddle Point
(4)	$\Delta L_g < \Delta C_g < \Delta B_g + \Delta L_g$ $C_e > sV_2 + T + L_e$	*detJ*	+	−	+	−
		trJ	−	±	+	±
		Stability	ESS	Saddle Point	Unstable point	Saddle Point
(5)	$\Delta L_g < \Delta C_g < \Delta B_g + \Delta L_g$ $sV_1 + L_e < C_e < sV_2 + T + L_e$	*detJ*	+	+	+	+
		trJ	−	+	+	−
		Stability	ESS	Unstable point	Unstable point	ESS
(6)	$\Delta L_g < \Delta C_g < \Delta B_g + \Delta L_g$ $C_e < sV_1 + L_e$	*detJ*	−	+	−	+
		trJ	±	+	−	−
		Stability	Saddle Point	Unstable point	Unstable point	ESS

Scenarios		Conditions	Potential equilibrium points			
			(0,0)	(1,0)	(0,1)	(1,1)
(7)	$\Delta C_g < \Delta L_g$ $C_e > sV_2 + T + L_e$	*detJ*	−	+	+	−
		trJ	±	−	+	±
		Stability	Saddle Point	ESS	Unstable point	Saddle Point
(8)	$\Delta C_g < \Delta L_g$ $sV_1 + L_e < C_e < sV_2 + T + L_e$	*detJ*	−	−	+	+
		trJ	±	±	+	=
		Stability	Saddle Point	Saddle Point	Unstable point	ESS
(9)	$\Delta C_g < \Delta L_g$ $C_e < sV_1 + L_e$	*detJ*	+	−	−	+
		trJ	+	±	±	−
		Stability	Unstable point	Saddle Point	Saddle Point	ESS

In (1), (0,0) is the ESS. When both sides of the game are in Scenarios 1 and 2, the cost of choosing positive sharing strategy is greater than the benefit in the optimal case for the local government, i.e., $\triangle C_g > \triangle B_g + \triangle L_g$, so the local government will choose negative sharing strategy (x → 0). At the same time, for enterprises, the cost of choosing to use data is greater than the benefit in the worst case, i.e., $C_e > sV_1 + L_e$, and local governments will inevitably tend to choose the negative sharing strategy. Therefore, enterprises will eventually tend to choose the "don't use data" strategy, and the game converges to (0,0), as shown in Figure 3-a. When both sides of the game are in Scenario 4, the cost of "positive sharing" is between the worst-case and the best-case benefits. Therefore, the strategy of the local government will be influenced by the strategy of the enterprise. For enterprises, the cost of using the data is greater than the optimal benefit, i.e., $C_e > sV_2 + T + L_e$, which means they are likely to not use the data (y → 0). In turn, local governments will gradually choose the negative sharing strategy (x → 0), and the game process will eventually converge to (0,0), as shown in Figure 3-a.

In (2), (1,0) is the ESS. When both sides of the game are in Scenario 7, i.e., $\triangle C_g < \triangle L_g$ and $C_e > sV_2 + T + L_e$, the cost for local governments to choose the positive sharing strategy is smaller than the reduced privacy loss after strengthening the data regulation model; therefore, local governments are likely to choose the positive sharing strategy (x → 1). At the same time, the cost of using the data is already greater than the economic benefits and trust gains for enterprises, so they will tend to not use the data (y → 0) for cost reasons. Eventually, the game process will converge at (1,0), as shown in Figure 3-b. Eventually, the game process will converge to (1,0), as shown in Figure 3-b.

In (3), (0,1) is the ESS. When both sides of the game are in Scenario 3, i.e., $\triangle C_g > \triangle B_g + \triangle L_g$ and $C_e < sV_1 + L_e$, the cost of choosing the positive sharing strategy is greater than the benefits of reputation, trust, economic benefits, and privacy risk reduction that the local governments may obtain in the optimal situation. Therefore, local governments will tend to choose the negative sharing strategy (x → 0) . At the same time, even if the value of the data assets provided by the local governments is low, the benefits of developing the data can still compensate for the cost of using the data for the enterprises, so the enterprises will tend to choose the "use data" strategy (y → 1) . Therefore, the game process will eventually converge to (0,1), as shown in Figure 3-c.

In (4), (1,1) is the ESS. When both sides of the game are in Scenario 6, i.e., $\triangle L_g < \triangle G_g <$

$\triangle B_g + \triangle L_g$ and $C_e < sV_1 + L_e$, the cost for local governments for choosing the positive sharing strategy is between the worst-case and the best-case benefits. Therefore, the governments' strategy will be influenced by the enterprises' strategy. Meanwhile, regardless of the value of the data assets provided by the local government, the cost of mining and analyzing the data is still less than the economic benefits for the enterprise. Thus, the enterprise will tend to choose to "use data" (y → 1). Under this influence, local governments will also choose the positive sharing strategy (x → 1). Hence, the game process will eventually converge to (1,1), as shown in Figure 3-d. When both sides of the game are in Scenarios 8 and 9, the improvement of data regulation ability and data quality can effectively reduce the probability of public privacy leakage, and this can induce the local government to choose the positive sharing strategy. Furthermore, the benefits of privacy risk reduction are already greater than the costs; therefore, the local government will choose the positive sharing strategy (x → 1). At the same time, for enterprises, as local governments inevitably choose the positive sharing strategy, as long as the cost of choosing to use the data is lower than the sum of their optimal benefits, i.e., $C_e < sV_2 + T + L_e$, enterprises will tend to choose the "use data" strategy (y → 1). Hence, the game process will eventually converge to (1,1), as shown in Figure 3-d.

In (5), (0,0) and (1,1) are ESS simultaneously. When both sides of the game are in scenario 5, i.e., $\triangle L_g < \triangle C_g < \triangle B_g + \triangle L_g$ and $sV_1 + L_e < C_e < sV_2 + T + L_e$, the cost for the governments to choose the positive sharing strategy is between the worst-case and the best-case benefits. Therefore, some local governments may choose the positive sharing strategy (x → 1), while others may choose the negative sharing strategy (x → 0) . At the same time, the cost of using data is between the worst-case and the best-case benefits for enterprises. If the local governments choose the negative sharing strategy (x → 0), the enterprises only gain the minimum benefit, i.e.,$sV_1 + L_e$, which will encourage them to not use the data (y → 0) due to cost considerations. If the local governments tend to choose the positive sharing strategy (x → 1), the potential benefits that the enterprises can obtain at this time is $sV_2 + T + L_e$, which is already greater than the cost it needs to pay to use the data. Therefore, the enterprises will choose the "use data" strategy (y → 1) . Therefore, as time goes on, the game process will

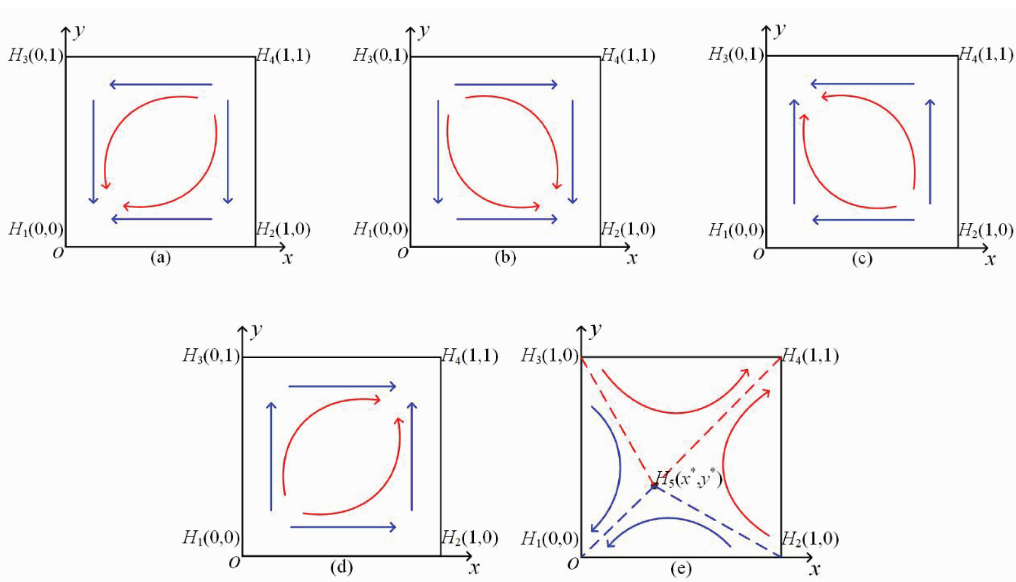

Figure 3 Evolutionary phase diagram

eventually form two ESSs, namely, $H_1(0,0)$ and $H_4(1,1)$, as shown in Figure 3-e. From Figure 3-e, it can be seen that there is uncertainty in the evolutionary outcome between local governments and enterprises, where $H_5(x^*, y^*)$ is the critical value for the evolution of the system, and the proportion between the groups that are in $H_1(0,0)$ and $H_4(1,1)$ is related to the critical value.

5 Numerical Simulation

To analyze more intuitively the effect of each parameter variation on the evolutionary stabilization strategy, this study used MATLAB R2021a for numerical simulation. In particular, we choose Scenario 5 as an example and set the initial values of each parameter as follows: V_2 = 20, V_1 = 10, s=0.5, T=10, $\triangle B_g$=20, $\triangle C_g$=30 , $\triangle L_g$=20 , C_e=20 , and L_e=10. Then, we choose D(x0,y0) = (0.5,0.5) as the initial point. At this point, the critical value H5(x*,y*) = (0.33,0.50), combined with the evolutionary stability analysis can be obtained. The current evolutionary process of the system is shown in Figure 4.

From Figure 4, the system converges to $H_4(1,1)$ with a higher probability than $H_1(0,0)$ under the initial value. At the initial point $D(x_0, y_0)$, local governments are more likely to choose the positive sharing strategy, while the enterprises are more likely to choose the "use data" strategy, as a result of which the system will eventually converge to $H_4(1,1)$. Then, this study took (x_0, y_0) = (0.5,0.5) for numerical simulation, after which the evolutionary trend is obtained, as shown in Figure 5. As can be seen, the evolutionary results are consistent with the calculated results shown in Figure 4.

Combined with realistic scenarios, given that V_1 , $\triangle B_g$, and L_e are difficult to change direction, to further analyze the effects of other parameters on the critical value $H_5(x^*,y^*)$, this study uses sensitivity analysis to change the values of the target parameters. Then, it keeps the other parameters at their initial values to conduct numerical simulations to further discuss the evolution of the system caused when individual parameters are changed.

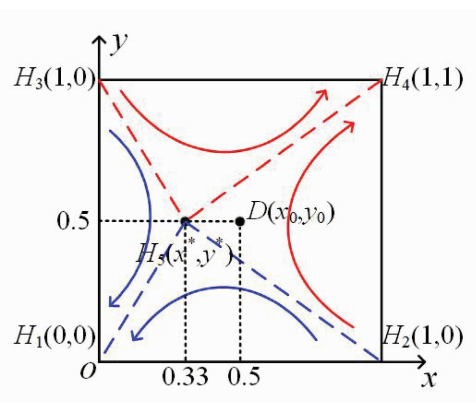

Figure 4 Evolutionary phase diagram for the initial value condition

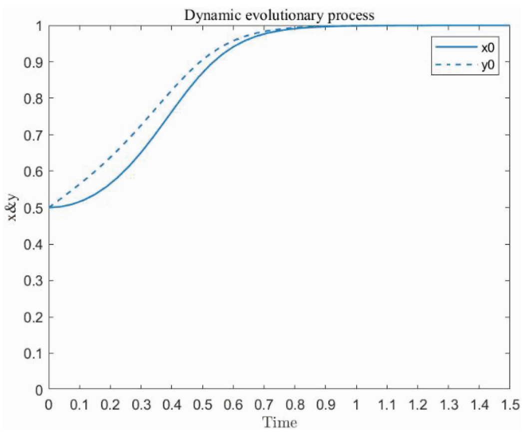

Figure 5 Initial state evolutionary trend diagram

5.1 The cost of the positive sharing strategy selected by the local governments $\triangle C_g$

We conduct numerical simulations while keeping other parameters constant. For this purpose, we set the values of $\triangle C_g$ to 30, 24, 28, 32, and 36 and obtain the evolutionary trend of (x_0,y_0) to (x_4,y_4), as shown in Figure 6. From Figure 6, we can see that the system converges to $H_4(1,1)$ when $\triangle C_g$=30, 24, 28, and 32, while it converges to $H_1(0,0)$ when $\triangle C_g$ is 36. The effect of increasing $\triangle C_g$ is more significant on the enterprises' strategy (y) than the local governments' strategy (x). Combined with Figure 4, it can be seen that as $\triangle C_g$ increases, the value of y^* also increases continuously, and the critical value $H_5(x^*,y^*)$ moves upward vertically, resulting in the increasing area of $\triangle OH_5H_2$ and the decreasing area of $\triangle H_3H_5H_4$. Thus, the probability of the system converging to $H_4(1,1)$ gradually increases, while the probability of the system converging to $H_4(1,1)$ gradually decreases. This evolutionary process is consistent with the numerical simulation results shown in Figure 6.

In practical terms, the increase of $\triangle C_g$ means that the cost of local governments choosing the positive sharing strategy is increasing, and when the cost exceeds the expected benefit, local governments will choose the negative sharing strategy to reduce the cost. When it chooses negative sharing, the benefits of using the data are less than the costs due to the inability to obtain higher-value data assets; thus, the enterprises are likely to choose the "don't use data" strategy. Finally, the system converges to $H_1(0,0)$.

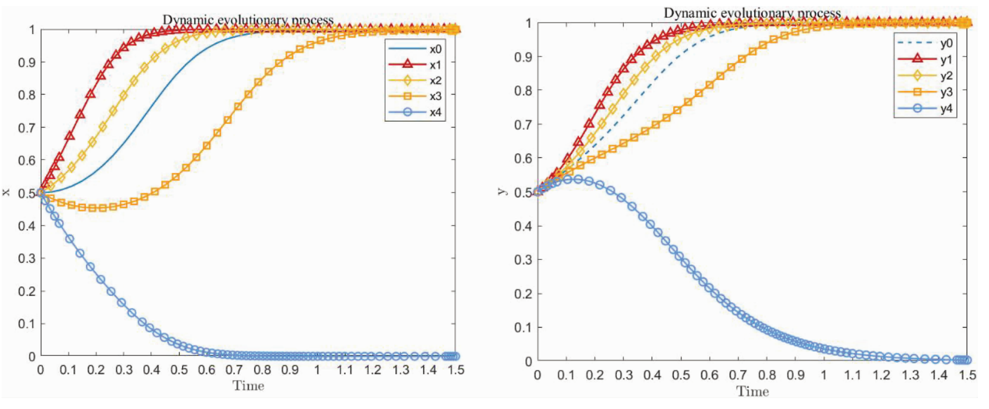

Figure 6 Evolutionary trends of the changes of $\triangle C_g$

5.2 Value of the positive sharing of data assets by local governments V_2

Numerical simulations were performed when the values of V_2 were set to 20, 12, 16, 24, and 28, while keeping the other parameters constant. In doing so, we obtained the evolutionary trend of (x_0,y_0) to (x_4,y_4), as shown in Figure 7. From Figure 7, the game process converges to $H_4(1,1)$ when V_2 =20, 12, 16, 24, and 28, and the effect of increasing V_2 is more significant on the enterprises' strategy (y) than the local governments' strategy (x). Combined with Figure 4, it can be seen that as V_2 increases, the value of x^* also decreases continuously, and the critical value $H_5(x^*,y^*)$ moves horizontally to the left, making the area of $\triangle H_1H_3H_5$ decrease continuously and the area of $\triangle H_2H_4H_5$ increase continuously. Therefore, the probability that the system converges to $H_1(0,0)$ gradually decreases, and the probability that it converges to $H_4(1,1)$ gradually increases. This evolutionary process is consistent with the numerical simulation results shown in Figure 7.

In practical terms, the increase of V_2 means that when the local governments choose the positive sharing strategy, once the enterprises choose to use data, they can obtain higher-value data assets and thus gain higher economic benefits. In other words, the increase of V_2 can enhance the expected benefits brought about by the enterprise choosing to use the data. As a result, the system will converge to $H_4(1,1)$ faster as increases.

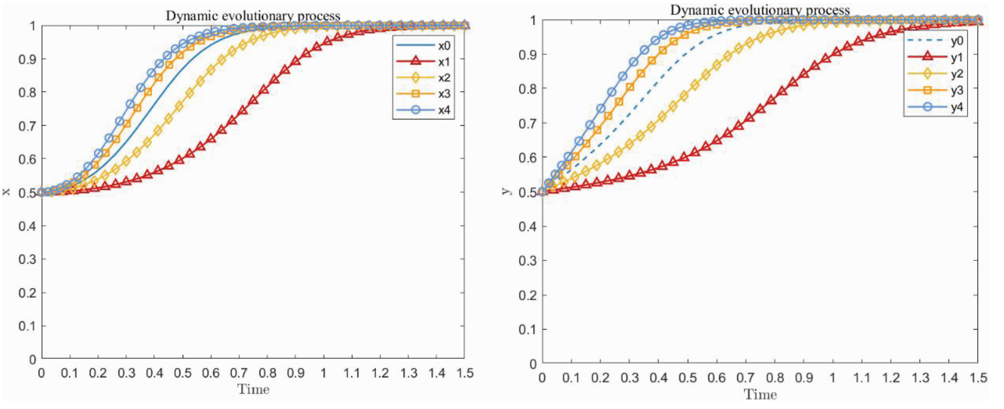

Figure 7 Evolutionary trends of the changes of V_2

5.3 The cost of using data for enterprises C_e

Numerical simulations were performed when the values of C_e were set to 20, 16, 18, 22, and 24, while keeping other parameters constant. In doing so, we obtained the evolutionary trend of (x_0, y_0) to (x_4, y_4), as shown in Figure 8. As seen in the figure, the game process converges to $H_4(1,1)$ when C_e=20, 16, 18, and 22; when C_e=24, the game process converges to $H_1(0,0)$, and the effect of increasing C_e is more significant on the enterprises' strategy (y) than the local governments' strategy (x).

Combined with Figure 4, it can be seen that as C_e increases, the value of x^* also increases continuously, and the critical value $H_5(x^*, y^*)$ moves horizontally to the right, making the area of $\triangle H_1H_3H_5$ increase continuously and the area of $\triangle H_2H_4H_5$ decrease continuously. Therefore, the probability of the system converging to $H_1(0,0)$ gradually increases, while the probability of converging to $H_4(1,1)$ gradually decreases. This evolutionary process is consistent with the numerical simulation results shown in Figure 8.

In practical terms, the increase in C_e means that the cost of using the data will increase, and when the cost exceeds the expected benefit, companies will tend to choose the "don't use data" strategy due to cost considerations. At this point, local governments lack the synergistic benefits of the positive sharing of data and will tend to choose the negative sharing strategy; thus, the game process will eventually converge to $H_1(0,0)$.

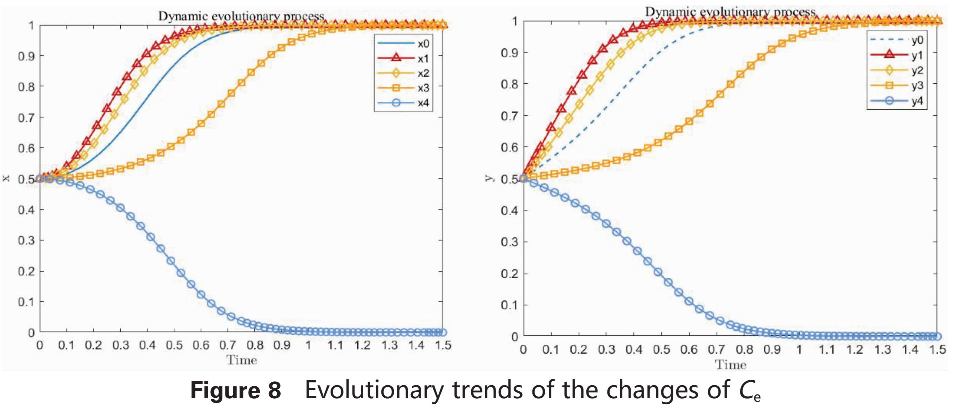

Figure 8 Evolutionary trends of the changes of C_e

5.4 Data value conversion rate *s*

Numerical simulations were conducted when the values of the data value conversion rate *s* of the enterprises were set to 0.5, 0.3, 0.4, 0.6, and 0.7 while keeping other parameters constant. In doing so, the evolutionary trend of (x_0 ,y_0) to (x_4 ,y_4) was obtained, as shown in Figure 9.

From Figure 9, we can see that the game process converges to H_1(0,0) when s=0.3; when s=0.4, 0.5, 0.6, and 0.7, the game process converges to H_4(1,1). Furthermore, the game process converges to H_4(1,1) and gradually accelerates as *s* increases, and the effect of increasing on the enterprises' strategy (*y*) is more significant than that of the local governments' strategy (x).

Combined with Figure 4, we can see that the value of x^* will keep decreasing as increases, and the critical value $H_5(x^*,y^*)$ will move horizontally to the left, making the area of $\triangle H_2H_4H_5$ increase and the area of $\triangle H_1H_3H_5$ decrease. As a result, the probability of the system converging to H_4(1,1) gradually increases, while the probability of converging to H_1(0,0) gradually decreases. This evolutionary process is consistent with the numerical simulation results shown in Figure 9.

In practical terms, the increase of enterprise data value conversion rate can directly improve the expected economic benefits of enterprises when they use data, which makes them more inclined to develop and utilize government data. At the same time, when enterprises choose to use data more clearly, local governments will also tend to choose the positive sharing strategy. Hence, the system will converge to H_4(1,1) faster.

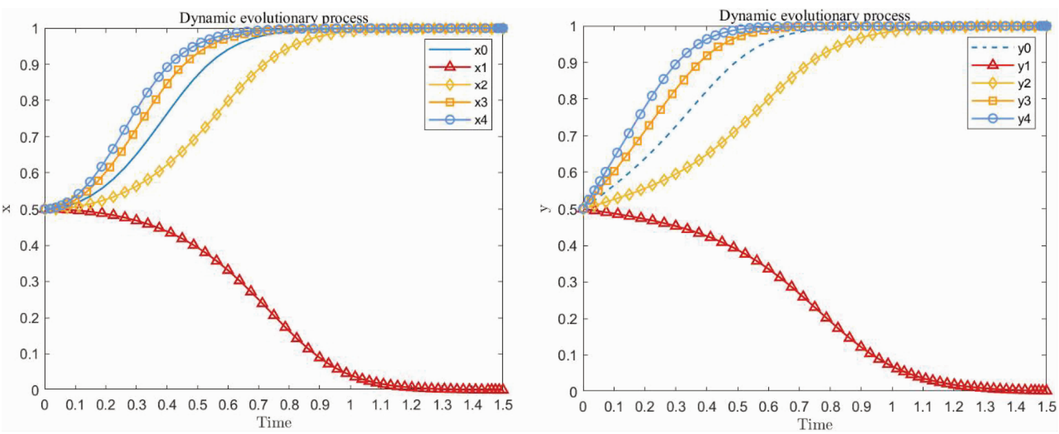

Figure 9 Evolutionary trends of the changes of *s*

5.5 Trust gains *T*

Numerical simulations were conducted when the values of the enterprises' trust gain *T* were set to 10, 6, 8, 12, and 14 while keeping other parameters constant. In doing so, the evolutionary trend of (x_0 ,y_0) to (x_4,y_4) was obtained, as shown in Figure 10.

From Figure 10, we can see that the game process converges to H_4(1,1) when T=10, 6, 8, 12, and 14. Furthermore, the game process converges to H_4(1,1) and gradually accelerates with the increase of *T*. The increase of *T* has a more significant effect on the enterprises' strategy (*y*) than the local governments' strategy (*x*).

Combined with Figure 4, it can be seen that the value of x^* will keep decreasing as *T* increases, and the critical value $H_5(x^*, y^*)$ will move horizontally to the left, making the area of $\triangle H_2H_4H_5$ increase and the area of $\triangle H_1H_3H_5$ decrease. Therefore, the probability that the system converges to $H_4(1,1)$ gradually increases, while the probability that it converges to $H_1(0,0)$ gradually decreases. This evolutionary process is consistent with the numerical simulation results in Figure 10.

In practical terms, a good trust relationship between local governments and enterprises can enhance the expected benefits of enterprises' decision-making, and a good relationship between governments and enterprises can induce enterprises to actively acquire and develop government data, thus leading to a win – win situation between enterprises and local governments.

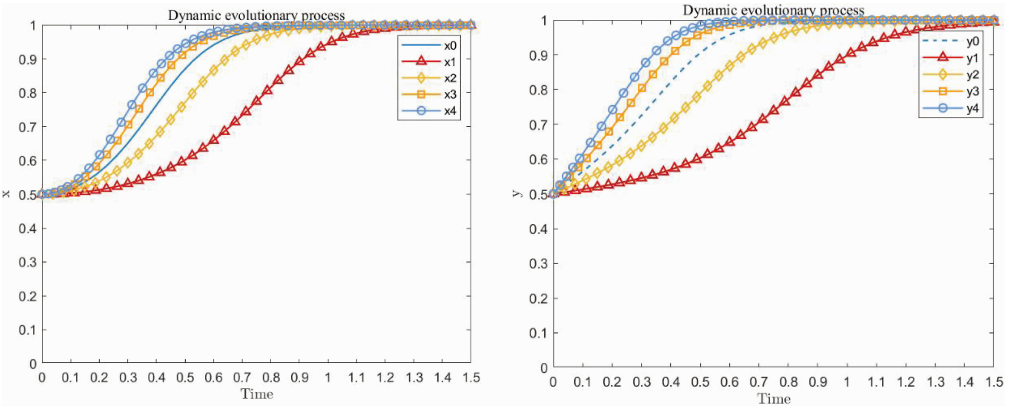

Figure 10 Evolutionary trends of the changes of T

6 Conclusions and Policy Implications

6.1 Conclusions

Based on the above analysis, the evolutionary game model constructed in this study has good accuracy and can well reflect the game strategies and the evolutionary processes of both parties under various scenarios. The main findings are listed below:

(1) Enterprises choose the " use data strategy," while local governments choose the positive sharing strategy as the optimal evolutionary path to promote open government data sharing, in which enterprises' decisions are the internal driving force.

(2) The value of data assets provided by local governments when choosing the positive sharing strategy V_2 , the cost of data use by enterprises C_e , the data value conversion rate of enterprises S, and the trust gain T given by local governments to enterprises are all key factors influencing enterprises' decisions. The additional cost of the positive sharing strategy $\triangle C_g$ is a key factor influencing the decision of local governments.

In this regard, this study proposes the following suggestions to promote the open sharing of government data from the perspective of " independent innovation, asset value, and business environment."

6.2 Policy Implications

6.2.1 Enhance independent innovation capability

For enterprises, the transformation ability of government data assets and the cost of using data will directly affect the economic benefits obtained. Therefore, enterprises should enhance their independent innovation ability, innovate from three aspects (organizational structure, technology level, and internal management), improve the transformation rate of data value, and reduce the cost of using government data to promote their active participation in the development and utilization of government data. Specifically, the following measures can be taken:

(1) Accelerate digital transformation. Enterprises should accelerate the pace of digital transformation, introduce cloud computing, 5G, blockchain, and other cutting-edge digital technologies, and combine them with their business model transformation, thus transforming into data-driven enterprises. In this way, they can make full use of government data to improve their corporate performance and create social value.

(2) Improve the level of data mining technology. Enhancing enterprise data mining technology can directly improve the conversion rate of data value. Therefore, enterprises should not only improve the existing personnel system, set up data development departments, and hire analysts and data scientists (among other positions), but also actively introduce the required technical talents from domestic and foreign universities, research institutes, and major data enterprises.

(3) Optimize supply chain procurement. For information systems or network equipment needed in the transformation process, with clear specific needs, enterprise managers can seek cooperation with other enterprises or entrust specialized agencies to carry out centralized procurement as well as reduce the corresponding procurement costs by optimizing supply chain procurement.

(4) Explore the use of the flat management system. The combination of digital technology and flat management system can effectively reduce the cost of internal communication, coordination and control, and supervision. Therefore, enterprises can try to change the section management mode into a flat management mode following the "workflow as the core" principle, thus reducing administrative costs.

6.2.2 Enhance the value of data assets

From the perspective of enterprises, the value of data assets provided by local governments when they choose the positive sharing strategy has a significant impact on whether they choose to use data. Therefore, to encourage enterprises to use government data and enhance the value of enterprise and government data co-creation, local governments should start from the following aspects to further enhance the value of data assets.

(1) Promote digital government. The factors influencing the value of government data assets mainly include quality, scale, value density, shareability, and timeliness of data (Ren, 2021). However, the current open sharing of government data is still dominated by structured data and has yet to focus on unstructured data, such as images, audio, and text. Therefore, promoting the construction of digital government and accelerating the comprehensive datafication of government information can not only enhance the value of data assets in terms of the scale, quality, and diversity of data, but also develop various types of data clusters that meet the needs of enterprises in a targeted manner.

(2) Sound data opening and sharing mechanism. Due to the rich content of government data, the disclosure of some data may cause the outbreak of network public opinion or, worse, the leakage of public privacy and government secrets. Therefore, local governments should fully investigate the actual local situation and establish and improve laws and regulations and related policies on the open sharing of government data from the aspects of data

standards, data property rights, open authority, operation management, and business processes. In doing so, local governments can reduce the sharing cost of government data and enhance the value of data assets.

(3) Optimize the data regulatory model. Local governments can set up data management departments, such as big data bureaus and big data centers. At the same time, they can also cooperate with big data enterprises, optimize data supervision mode, conduct accurate traceability and integrated management for the whole life cycle of raw data, and realize the improvement of data asset value through the improvement of data quality.

6.2.3 Continuous optimization of business environments

A good business environment not only enhances the trust of enterprises in local governments but also reduces the costs of both enterprises and governments in the process of opening and sharing government data. Therefore, local governments should combine the characteristics of each region, and promote the reform of the "streamline the government, delegate power, and improve government services" policy, while continuously optimizing the business environment. In doing so, they can build a good government – enterprise relationship and promote the active participation of enterprises in the development and utilization of government data. Specifically, they can apply the following measures:

(1) Adhere to the development of a "platform plus ecology" strategy. Although there are numerous government data platforms in China, there are still problems, such as uneven data quality, poor user experience, and low update frequency (Zheng et al., 2019; Meng & Yang, 2020). Therefore, local governments should adhere to the development of the "platform plus ecology" strategy, further optimize the data information and user experience of the platform, as well as build a "platform-centered" government data application ecosystem to reduce the cost of collecting and using government data by enterprises. In doing so, the cost of government data collection and utilization by enterprises can thus be reduced.

(2) Screen and cultivate potential enterprises. Local governments can combine market demand and screen potential enterprises, with government data development and utilization as their core competitiveness to establish an enterprise cultivation pool. They can also provide a series of supporting services, such as incentive subsidies, tax reductions, financing guarantees, and technical training, to help enterprises overcome difficulties related to capital, technology, and talent. Finally, these can improve their technical levels and reduce the cost of data use, as well as promote the development of government data while helping enterprises practice open sharing and value co-creation.

(3) Establish a multi-channel feedback mechanism. Local governments can establish multi-channel feedback mechanisms, such as setting up opinion boxes or message boards, conducting regular questionnaires related to the business environment, and visiting relevant enterprises. In doing so, they can understand the actual needs of enterprises related to business environments and the use of government data, thus achieving the dynamic optimization of the business environment.

Acknowledgement

This study is supported in part by the Major Programs of the National Social Science Foundation of China (No. 19ZDA348).

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