Research on Digital Transformation of Small and Medium-Sized Enterprises Driven by Dual Agent Collaboration

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Abstract. From the perspective of multi-agent collaboration, this paper builds a tripartite evolutionary game model of government-market-enterprise, studies how the government and market cooperate to drive the digital transformation of enterprises, uses MATLAB software to conduct numerical simulation, and analyzes the evolution path. The results show that the choice of an enterprise's digital transformation strategy is affected by both the government and the market. Enterprise profits, competitive profits, transformation costs, relationship losses, cost synergy coefficient, revenue sharing coefficient, and cost reduction coefficient will all affect the formation of the stable equilibrium point of the enterprise. With the gradual decline of the cost synergy coefficient and the gradual increase of the revenue sharing coefficient and the cost reduction coefficient, enterprises have begun to choose digital transformation.

Keywords: Digital Transformation · Government · Market · Evolutionary Game

1 Introduction

As an important force in promoting economic development and enhancing technological innovation in China, small and medium-sized enterprises are often faced with "dare to switch, do not want to switch, will not turn" dilemma. Therefore, how to give full play to the synergistic effect of multiple entities to promote the digital transformation of enterprises has become an important research topic. The government, as the maker of policies and regulations, and the market, as the allocator of scarce resources, play a role in guaranteeing and guiding the digital transformation of enterprises. From an endogenous and long-term perspective, the government pays attention to the connotative development of economic stock, and formulates support policies for the digital transformation of small and medium-sized enterprises in combination with the actual development of local industries, so as to create an intelligent and digital regional environment; it is necessary to build a digital economy and industrial structure transformation Upgrade the communication platform, so as to provide a technical path for the digital transformation of enterprises; it is necessary to clear the channels for the digital transformation and upgrading of the industry, so as to reduce the cost of enterprise transformation and

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upgrading, and provide a guarantee for the digitalization of small and medium-sized enterprises. From the perspective of competitiveness and synergy, the market respects the laws of market operation, pays attention to industrial transformation and upgrading, encourages enterprises to use digital technology to innovate business operation models, and seek their own development; the market creates a healthy competition environment among enterprises, the market optimizes resource allocation; the market respects the development trend of individualized and diversified consumer demand, promotes the digital transformation of enterprises from the demand side, and plays a guiding role in the digital transformation of small and medium-sized enterprises.

Regarding the research on the digital transformation of enterprises, Li and Huang (2022) proposed that the digital economy can promote the consumption expenditure of residents. Yao et al. (2022) pointed out that the key factors for the successful digital transformation of an enterprise are the perception of managers, the strategic positioning of the enterprise, the implementation of the strategy, and the pace of transformation. Wang et al. (2022) proposed that digital finance can promote the digital transformation of enterprises, and this effect is more obvious in state-owned enterprises. Liu (2020) proposed that the digital transformation of small and medium-sized enterprises should be facilitated from the aspects of ecosystem, financing, benchmarking, and talents. Liu (2022) proposed to use the government platform model to accelerate the establishment of an information sharing mechanism. Wang et al. (2022) proposed that indirect political connections have a positive impact on the digital transformation of SMEs. Qing et al. (2021) pointed out that the digital transformation of enterprises has a significant upward convergence effect, which is more obvious in the competitive environment. The existing literature starts with the utility and specific path of digital reform, but from the perspective of multi-agent collaboration, there are few studies that consider the digital transformation of SMEs.

Based on this, starting from the rational economic man hypothesis, this paper adopts the method of evolutionary game to study the impact of the collaborative driving of the government and market players on the digital transformation of small and medium-sized enterprises. Provide suggestions for promoting the digital transformation of small and medium-sized enterprises in coordination.

2 Three-Party Evolutionary Game Model

In order to study the impact of multi-agent collaborative driving on the digital transformation of small and medium-sized enterprises, from the perspective of government guarantee and market orientation, this paper takes the government departments and two small and medium-sized enterprises in the market as the research subjects. The government departments are the guiding managers of the digital transformation of enterprises, the enterprise is the main body of digital transformation, and enterprise A and enterprise B form a competitive relationship in the industry. Since the market drive is mostly reflected by the competitive relationship between enterprises, this paper describes the market competition environment by constructing two companies with competitive relationship. Government departments are responsible for the supervision and management of the digital transformation of enterprises, and provide a reference basis for the digital

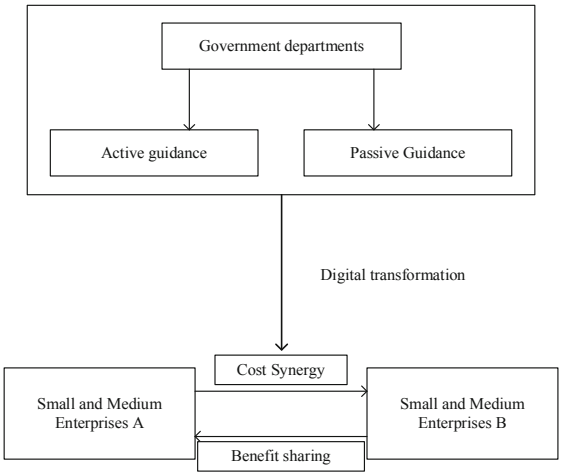

Fig. 1. Enterprise digital transformation model

transformation of enterprises through measures such as system design, infrastructure construction, and platform construction. When performing functions, the cost of performing duties and the effectiveness of performing duties will be considered. As the subject of bounded rational decision-making, enterprises take maximizing their own interests as the basis for decision-making. When making digital transformation decisions, they take into account their own needs to keep up with the development of industry trends and the driving factors of government departments and competing companies in the market. Considering the high cost of transformation and transformation failure losses. The digital transformation model of the enterprise is shown in Fig. 1.

2.1 Basic Assumptions

Hypothesis 1: Considering the role of government guidance and guarantees, government departments have two strategies to choose from: (actively guiding, not actively guiding). If the government department chooses not to actively guide, the social welfare W will remain unchanged; if the government department chooses to actively guide, it needs to pay the transformation cost Cg. When the enterprise implements digital transformation, the government department will receive the industry digital transformation bonus Fj (J represents the number of transformed enterprises, $j = 0, 1, 2$ and $F0 < F1 < F2$). In the long run, the credibility of government departments T will also increase.
Hypothesis 2: Considering the role of market orientation, companies have two options: (implementing digital transformation, not implementing digital transformation). The net profit of enterprise A is Pa, and the net profit of enterprise B is Pb.
Hypothesis 3: Enterprises implementing digital transformation should invest a certain cost Cd to transform and upgrade existing production lines, hardware equipment, software equipment, etc. Due to digital transformation, internal operational efficiency has been improved and additional benefits Ri.

Hypothesis 4: If only one enterprise implements digital transformation, the transformed enterprise will gain competitive profits due to its high degree of digitalization, while the non-transformed enterprises will reduce profits due to competitive disadvantages, expressed by Ei.
Hypothesis 5: If two companies choose to implement digital transformation, there will be a synergy between the companies, such as jointly finding a transformation path and jointly solving the problems encountered in the transformation, thereby reducing the transformation cost, α is the cost synergy coefficient, the new cost is $\alpha Cd, 0 < \alpha < 1$. Similarly, the spillover effect of the other party's digital transformation results will also be obtained, β is the profit spillover coefficient, and the new income is $\beta Ri, \beta > 1$.
Hypothesis 6: If the two companies do not implement digital transformation, the company will continue to operate according to the existing situation, but it will affect the overall development of the industry and the transformation of the internal structure, resulting in a decline in the competitiveness of the industry, denoted by K.
Hypothesis 7: When the government department actively guides the digital transformation of enterprises, the cost of enterprise transformation will be reduced due to the guidance and management of the government department, λ is the cost reduction coefficient, and the new cost is $(1 - \lambda)Cd, 0 < \lambda < 1$; Digital transformation will affect the relationship between enterprises and government departments, resulting in the loss of government-enterprise relations, denoted by L.

2.2 Model Building

The probability of enterprise A/B implementing digital transformation is X/Y, and the probability of not implementing transformation is 1 − x/1 − Y; the probability of government departments actively guiding management is z, and the probability of not actively guiding management is 1 − z. Based on the above assumptions, the return matrix is shown in Table 1.

3 Model Evolution Game Analysis

3.1 Construction of Dynamic Replication Equations

The expected return and average return of the two strategies of firm A are:

$$\pi_{11} = zy(P_a - (1-\lambda)\alpha C_d + \beta R_a) + z(1-y)(P_b - E_b - L) + (1-z)y(P_a - \alpha C_d + \beta R_a) + (1-z)(1-y)(P_a - C_d + R_a + E_a) \tag{1}$$

$$\pi_{12} = zy(P_a - E_a - L) + z(1-y)(P_a - L) + (1-z)y(P_a - E_a) + (1-z)(1-y)P_a \tag{2}$$

$$\overline{\pi_1} = x\pi_{11} + (1-x)\pi_{12} \tag{3}$$

Table 1. Evolution game payment matrix of enterprise digital transformation

Strategy selection		Enterprise A	Enterprise B	
			Transformation y	No transformation 1 − y
Government department	Gguide Z	Transformation x	$W - Cg + T + F2$	$W - Cg + T + F1$
			$Pa - (1 - \lambda)\alpha Cd + \beta Ra$	$Pa - (1 - \lambda)Cd + Ra + Ea$
			$Pb - (1 - \lambda)\alpha Cd + \beta Rb$	$Pb - Eb - L$
		No transformation 1 − x	$W - Cg + T + F1$	$W - Cg + T - K$
			$Pa - Ea - L$	$Ra - L$
			$Pb - (1 - \lambda)Cd + Rb + Eb$	$Rb - L$
	Not guide 1 − z	Transformation x	$W + F2$	$W + F1$
			$Pa - \alpha Cd + \beta Ra$	$Pa - Cd + Ra + Ea$
			$Pb - \alpha Cd + \beta Rb$	$Pb - Eb$
		No transformation 1 − x	$W + F1$	$W - K$
			$Pa - Ea$ $Pb - Cd + Rb + Eb$	Pa Pb

The expected return and average return of the two strategies of firm B are:

$$\begin{aligned}\pi_{21} &= zx(P_b - (1 - \lambda)\alpha C_d + \beta R_b) + z(1 - x)(P_b - (1 - \lambda)C_d + Rb + Eb) \\ &+(1 - z)x(P_b - \alpha C_d + \beta R_b) + (1 - z)(1 - x)(P_b - C_d + R_b + E_b)\end{aligned} \tag{4}$$

$$\pi_{22} = zx(P_b - Eb - L) + z(1 - x)(P_b - L) + (1 - z)x(P_b - Eb) + (1 - z)(1 - x)P_b \tag{5}$$

$$\overline{\pi_2} = \mathrm{y}\pi_{21} + (1 - \mathrm{y})\pi_{22} \tag{6}$$

The expected returns and average returns of the two strategies of the government sector are:

$$\begin{aligned}\pi_{31} &= \mathrm{xy}(W - C_{\mathrm{g}} + T + F_2) + x(1 - y)(W - C_g + T + F_1) \\ &+(1 - x)y(W - C_g + T + F_1) + (1 - x)(1 - y)(W - C_g + T - K)\end{aligned} \tag{7}$$

$$\begin{aligned}\pi_{32} &= \mathrm{xy}(W + F_2) + x(1 - y)(W + F_1) + (1 - x)y(W + F_1) \\ &+(1 - x)(1 - y)(W - K)\end{aligned} \tag{8}$$

$$\overline{\pi_3} = z\pi_{31} + (1 - z)\pi_{32} \tag{9}$$

The replication dynamic equation of government department, enterprise A, and enterprise B is:

$$U_1(x) = \frac{dx}{dt} = x(1-x)((\alpha\lambda Cd - \lambda Cd)yz + (Cd - Ra - \alpha Cd + \beta Ra)y + (L + \lambda Cd)z + Ea - Cd + Ra) \tag{10}$$

$$U_2(\mathrm{y}) = \frac{dy}{dt} = y(1-y)((\alpha\lambda Cd - \lambda Cd)xz + (Cd - Rb - \alpha Cd + \beta Rb)x + (L + \lambda Cd)z + Eb - Cd + Rb) \tag{11}$$

$$G_3(z) = \frac{dz}{dt} = z(1-z)(T - C_g) \tag{12}$$

3.2 System Stability Judgment

The author simultaneously replicates the dynamic equations and sets them to 0 to obtain the local equilibrium point of the game model. The Jacobian matrix is as follows. According to Ritzberger and Weibull (1995), we only need to consider the pure-strategy equilibrium points in the stability analysis. The pure-strategy equilibrium points are respectively brought into the Jacobian matrix, and the eigenvalues of each equilibrium point can be obtained after sorting, and the results are shown in Table 2. Combined with the model setting, from a long-term consideration, it is believed that the guidance cost of government departments is less than the increase of government credibility, that is, $Cg < T$. Due to the large number of parameters set in this paper and the complex eigenvalues, in order to facilitate the determination of the sign of the equilibrium point, the evolutionary stabilization strategy is discussed in three cases, as shown in Table 3:

$$J1 = \begin{bmatrix} \frac{\partial U_1 x}{\partial x} & \frac{\partial U_1 x}{\partial y} & \frac{\partial U_1 x}{\partial z} \\ \frac{\partial U_2 y}{\partial x} & \frac{\partial U_2 y}{\partial y} & \frac{\partial U_2 y}{\partial z} \\ \frac{\partial G_3 z}{\partial x} & \frac{\partial G_3 z}{\partial y} & \frac{\partial G_3 z}{\partial z} \end{bmatrix}$$

$$= \begin{bmatrix} (1-2x)((\alpha-1)yz\lambda Cd + (1-\alpha)yCd - (\beta-1)yRa + zL + z\lambda Cd + Ea - Cd + Ra & x(1-x)((1-\alpha)(1-z\lambda)Cd + (\beta-1)Ra) & x(1-x)(L + (1-y+\alpha y)\lambda Cd) \\ y(1-y)((1-\alpha)(1-z\lambda)Cd - (\beta-1)Rb) & (1-2y)((\alpha-1)xz\lambda Cd + (1-\alpha)xCd - (\beta-1)xRa + zL + z\lambda Cd + Eb - Cd + Rb & y(1-y)(L + (1-x+\alpha x)\lambda Cd) \\ 0 & 0 & (2z-1)(Cg - T) \end{bmatrix} \tag{13}$$

Scenario 1: When $Eb-(1-\lambda)\alpha Cd+L+\beta Rb < 0$, if $Ea-(1-\lambda)Cd+L+Ra < 0$, $E_4(0, 0, 1)$ is ESS stable; if $Ea - (1 - \lambda)Cd + L + Ra > 0$, $E_6(1, 0, 1)$ is ESS stable.

Scenario 2: When $Eb-(1-\lambda)\alpha Cd+L+\beta Rb > 0$ and $Eb-(1-\lambda)Cd+L+Rb < 0$, if $Ea-(1-\lambda)\alpha Cd-L-\beta Ra > 0$, $E_8(1, 1, 1)$ is ESS stable; if $Ea-(1-\lambda)Cd+L+Ra < 0$, $E_4(0, 0, 1)$ is ESS stable.

Scenario 3: When $Eb-(1-\lambda)Cd+L+Rb > 0$, if $Ea-(1-\lambda)\alpha Cd+L+\beta Ra < 0$, $E_7(0, 1, 1)$ is ESS stable; if $Ea - (1-\lambda)\alpha Cd + L + \beta Ra < 0$, $E_8(1, 1, 1)$ is ESS stable.

Table 2. Eigenvalue of Jacobian matrix corresponding to each equilibrium point

Equilibrium	λ_1	λ_2	λ_3
$E_1(0,0,0)$	$Ea - Cd + Ra$	$Eb - Cd + Rb$	$T - Cg$
$E_2(1,0,0)$	$Cd - Ea - Ra$	$Eb - \alpha Cd + \beta Rb$	$T - Cg$
$E_3(0,1,0)$	$Ea - \alpha Cd + \beta Ra$	$Cd - Eb - Rb$	$T - Cg$
$E_4(0,0,1)$	$Ea - Cd + L + Ra + \lambda * Cd$	$Eb - Cd + L + Rb + \lambda Cd$	$Cg - T$
$E_5(1,1,0)$	$\alpha Cd - Ea - \beta Ra$	$\alpha Cd - Eb - \beta Rb$	$T - Cg$
$E_6(1,0,1)$	$Cd - Ea - L - Ra - \lambda Cd$	$Eb + L - \alpha Cd + \beta RB + \alpha\lambda Cd$	$Cg - T$
$E_7(0,1,1)$	$Ea + L - \alpha Cd + \beta Ra + \alpha\lambda Cd$	$Cd - Eb - L - Rb - \lambda Cd$	$Cg - T$
$E_8(1,1,1)$	$\alpha Cd - L - Ea - \beta Ra - \alpha\lambda Cd$	$\alpha Cd - L - Eb - \beta Rb - \alpha\lambda Cd$	$Cg - T$

Table 3. Stability analysis of system equilibrium point

Equilibrium	Scenario 1				Scenario 2				Scenario 3			
	Eigenvalues			stability	Eigenvalues			Stability	Eigenvalues			stability
$E_1(0,0,0)$	−	−	+	unstable	+	+	+	saddle point	±	±	+	saddle point
$E_2(1,0,0)$	+	−	+	unstable	−	±	+	unstable	−	±	+	unstable
$E_3(0,1,0)$	−	+	+	unstable	±	−	+	unstable	±	±	+	saddle point
$E_4(0,0,1)$	−	−	−	ESS	−	−	−	ESS	+	+	−	unstable
$E_5(1,1,0)$	+	+	+	saddle point	±	±	+	saddle point	±	±	+	saddle point
$E_6(1,0,1)$	−	−	−	ESS	±	+	−	unstable	−	+	−	unstable
$E_7(0,1,1)$	−	+	−	unstable	+	±	−	unstable	−	−	−	ESS
$E_8(1,1,1)$	+	+	−	unstable	−	−	−	ESS	−	−	−	ESS

In this model, the degree of government guidance and the competition order of the market determine the cost reduction coefficient, cost coefficient and revenue sharing coefficient. Enterprise profit, competitive profit, transformation cost, relationship loss, cost synergy coefficient, revenue sharing coefficient, and cost reduction coefficient will all affect the formation of the stable equilibrium point of the enterprise. With the gradual decline of the cost synergy coefficient α, the gradual increase of the revenue sharing coefficient β and the cost reduction coefficient λ, enterprises begin to choose digital transformation. Assuming that Eb,Cd,Rb and L in the model are fixed values, when α decreases and β and λ increase, the strategy choice of the government department remains unchanged and always chooses to guide, while the enterprise changes its original strategy and chooses digital transformation, that is, the enterprise's strategy. The evolution strategy is jointly influenced by the other two subjects.

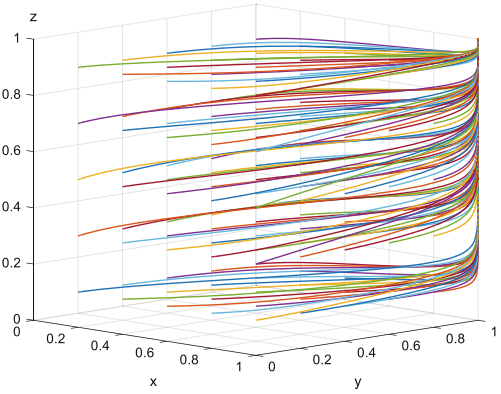

Fig. 2. Dynamic evolution process of enterprise digital transformation

4 Simulation Analysis

According to the above-mentioned enterprise digital transformation model, MATLAB software is used to simulate and analyze it, and the parameters are set as follows: $W = 50$, $Cg = 3$, $T = 4$, $F_1 = 4$, $F_2 = 6$, $Pa/Pb = 10$, $Cd = 4$, $Ra/Rb = 6$, $Ea/Eb = 2$, $\alpha = 0.8$, $\beta = 1.2$, $\lambda = 0.1$, $L = 1$, $K = 8$. According to the parameters, this simulation is applicable to the above situation 3. The dynamic evolution process is shown in Fig. 2.

It can be seen from Fig. 2 that when the probabilities of the three parties in the game take different initial values, the final evolution results tend to be at the same point (1, 1, 1), that is, the government chooses to actively guide, and enterprises A and B choose to digitize transformation. The simulation results show that in the first round of the game, if the government department chooses to actively guide management, it will find that its profit is at a high level, and in the next round of the game, repeat the above choice; if the government department chooses not to actively guide management, it will find its profit In the low position, in the next round of the game, change the choice. The selection process of the enterprise is the same as above. However, it is worth noting that the parameter setting also has a certain impact on the final evolution result of the game subject; and when considering the government guidance management cost and credibility benefits, this paper takes a long-term perspective, and has a long-term perspective on the problems encountered in the government's short-term practice. Practical issues such as funds, time, and energy are not considered carefully, which will also have a certain impact on the final evolution result.

5 Conclusion and Suggestion

The results show that the choice of an enterprise's digital transformation strategy is affected by both the government and the market. Enterprise profit, competitive profit, transformation cost, relationship loss, cost synergy coefficient, revenue sharing coefficient, and cost reduction coefficient will all affect the formation of the stable equilibrium point of the enterprise. With the gradual decline of the cost synergy coefficient and the

gradual increase of the revenue sharing coefficient and the cost reduction coefficient, enterprises have begun to choose digital transformation. Based on the above findings, the following recommendations are made:

(1) Give full play to the government's guiding management and demonstration role to reduce the cost of digital transformation of enterprises. First of all, the government, as the promoter of the digital transformation of enterprises, should combine the actual development of the industry to introduce practical, high-quality and effective support policies in terms of corporate social financing, capital use, and project management, and increase support and guidance for digital transformation of enterprises. Secondly, the government, as a participant in the digital transformation of enterprises, plays a pioneering and demonstration role, and timely summarizes its own successful experience in the process of modernization and transformation for reference in the transformation of enterprises.
(2) Guide the healthy market competition relationship and ensure the competitive profit of the enterprise. First of all, it is necessary to encourage the innovative spirit of entrepreneurs, actively explore new business models and business operation models, solve their own business problems, seek the blue ocean of goals, and find new momentum for enterprise development from the perspective of corporate strategy driving. Secondly, from the terminal demand to force the industry to progress, due to the changes in the social and economic environment, starting from the diversified needs of consumers, it helps enterprises to find new production methods and transformation directions, and uses demand terminals to feed back the adjustment of industrial structure. Finally, it is essential to maintain the cooperative and competitive relationship between enterprises, maintain the competition order, build a new digital ecology, and avoid illegal competition hindering the development of the industry.
(3) Build a digital sharing platform to empower the digital transformation of enterprises from the perspective of cost synergy and revenue sharing. First, make efforts from digital technology, integrate various ICT technologies, realize technology sharing on the platform, and reduce technical barriers; enrich the possibility of enterprise technology choices, effectively solve practical business problems, and increase the success rate of digital transformation of enterprises. Secondly, we will deeply cultivate data exchange, achieve data exchange and sharing, update the latest industry trends in a timely manner, tap the inherent laws of business, and provide rich data support for enterprises. Finally, on the basis of integration, services are provided to enrich application scenarios, so that platform resources can be quickly connected with enterprises, thereby providing enterprises with a good experience.

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