

# Research on platform empowerment strategies for the digital transformation of SMEs from the perspective of tripartite games

Zifu Fan, Dongyun Hu\*, Leifan Wu

School of Economics and Management, Chongqing University of Posts and Telecommunications,  
Chongqing 400065, China

\* Corresponding author. E-mail: 277173847@qq.com

**Abstract.** With the current deep integration and development of the digital economy and the real economy, the industrial internet has become the key form of support for seizing the opportunities of the times and promoting the high-quality development of the real economy. The Ministry of Industry and Information Technology considers the integration of "two industries" the main line; takes the acceleration of the construction of industrial internet platforms as the starting point; and coordinates the promotion of platform system construction, benchmarking, and application promotion. Leading industries in China, as well as third-party internet companies, have successively created multiple industrial internet platforms. However, currently, most platforms offer standardized services that cannot meet the transformation needs of small and medium-sized enterprises (SMEs) at different stages. In addition, the willingness of SMEs to join these platforms is not strong, and ultimately, the desired effect has not been achieved. This article constructs an asymmetric evolutionary game model among three entities—platforms, SMEs, and the government—analyzes the evolutionary paths of the strategic evolution of each game entity and the influencing factors using the stability theorem of differential equations, and explores the evolutionary stable strategies of the system through the Jacobian matrix. Through numerical simulation, the impacts of government subsidy intensity and the platform cost-sharing ratio on the evolutionary stable strategies of the system are analyzed to explore how to promote the high-quality development of industrial internet platforms and attract a larger number of SMEs to use cloud services.

**Keywords:** Industrial internet, empowerment, SMEs, tripartite game.

## 1. Introduction

In recent years, the industrial internet has gradually emerged as a crucial form of support for the innovative development of the digital economy, propelling its further integration into various industries and scenarios within the real economy [1]. In 2020, the National Development and Reform Commission, in conjunction with the Cyberspace Administration of China, issued a joint initiative, the "Action Plan for Promoting the 'Move to the Cloud, Use Data, Empower Intelligence' and Cultivating the Implementation Scheme for New Economic Development" initiative. This initiative emphasizes six key areas, namely, building foundations, establishing platforms, promoting transformation, constructing ecosystems, stimulating business models, and strengthening services, with the aim of accelerating the industrialization of digital technologies and the digitization of industries. In 2022, the General Office of the Ministry of Industry and Information Technology issued the "Guidelines for the Digital Transformation of SMEs," directing large enterprises to drive the digital transformation of small and medium-sized enterprises (SMEs) by either applying or constructing industrial internet platforms.

The relevant competent authorities and local governments have responded successively by introducing a series of measures to support the digital transformation of SMEs. Many internet platforms and industry leaders have also launched assistance programs for SMEs, leveraging their own advantages in application services and core technologies. Examples include the following platforms: Alibaba's Rising Star Plan, JD's New Power, and Tencent's Digital Ark. Industry leaders such as Haier's H-CHI and Shenyang Machine Tool's i5 platform, as well as Sany Heavy Industry's Cloud Platform, have also launched industrial internet platforms. Through the combined efforts of



the government and enterprises via these platforms, SMEs have become empowered to undergo digital transformation.

At present, large-scale internet enterprises and industry leaders have successively established industrial internet platforms to be used by SMEs. Due to early emphasis placed on efficiency and the neglect of personalized demands, most platforms offer only standardized services at the Infrastructure-as-a-Service (IaaS) level. However, SMEs face varying needs at different stages, and their demand for platform services is transitioning from the IaaS level to the Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS) levels. Traditional standardized services struggle to meet this upgraded demand. Moreover, SMEs consider cost and benefit issues, adopting a cautious stance on joining platforms. The supportive policies introduced by the government also impact the decisions of both platforms and SMEs. As observed [2], leveraging industrial internet platforms to empower SMEs' digital transformation is a long-term systematic undertaking that requires the active participation of multiple entities. Considering this situation, this article constructs an asymmetric tripartite evolutionary game among platforms, SMEs, and the government, delving primarily into the decision-making behaviors among these entities and the significant factors influencing their decisions.

## 2. Literature Review

The issue of empowering SMEs with digital transformation through platforms has received increasing attention from theoretical researchers. Such research focuses mainly on the aspects presented below. (1) The demand for platform empowerment by SMEs. Wang Junfeng [3], in conjunction with the actual situation of SME development in China, proposed that public technology service platforms for SMEs in China should be based on the transformation of research institutes. Moreover, Yin Chao [4] and others established a framework for the common key technology system of platforms; analyzed the characteristics of cloud manufacturing service platforms for SMEs; and laid the foundation for the further in-depth and systematic research, development, implementation, and application of cloud manufacturing service platforms for SMEs. Additionally, Wang Fang [5] and others suggested that SMEs need open innovation platforms to fully utilize the resources of large enterprises, obtain innovation resources at lower cost, and promote the participation or lead of SMEs in larger-scale innovation activities. (2) Mechanism analysis of platform empowerment for SMEs. Gunjan Soni [6] and others found, through case analysis, that platforms can integrate the supply chain resources of SMEs, connect resource providers with SMEs, reduce the transaction costs for SMEs to obtain supply chain finance, and promote their digital transformation process. Emil Blixt Hansen [7] and others suggested that platforms can provide new production insights and support real-time decision-making for SMEs through their big data analysis capabilities. The data generated by SMEs can be fully utilized through big data analysis and artificial intelligence (AI) methods, which helps SMEs improve their industrial performance. Li Honglei [8] and others proposed that the knowledge empowerment of the industrial internet platform can help integrate knowledge on the supply side, promote cross-domain knowledge sharing, and form a knowledge-driven supply chain system, thereby promoting the digital transformation of SMEs from the perspective of knowledge management theory. (3) Strategy analysis of platform empowerment for SMEs. Tariq Masood [9] and others pointed out that SMEs should integrate advantageous resources through platform resource sharing, network cooperation, external service support, and technological joint research and development to assist in the realization of digital upgrading and the improvement of industry competitiveness. Dóra Horváth [10] and others, through analyzing the different understandings of platforms by SMEs, sought to strengthen the synergy of technology and management and enhance the internal and external consensus on change, cross-domain talent training, and cooperation in education projects with universities, which can help promote the successful implementation of industrial internet platforms among SMEs. Dong Zhiyong [11] and others suggested that platform construction be strengthened, establishing and improving public service demonstration platforms to leverage their ability to gather resources such as funds, talent, technology, and data and to make good use of platform effects.

In conclusion, current research in the academic community on the empowerment of SMEs by platforms focuses mainly on three aspects: the study of SMEs' needs, the analysis of empowerment mechanisms, and the analysis of strategies. Although existing research has also focused on the game relationships in the process of the platform empowerment of SMEs, most studies have emphasized the game between platforms and SMEs, focusing on the mutual influence between the two. However, this approach overlooks the important impact that the government, as a relevant public policy maker, may have. In reality, in 2021, the Ministry of Finance issued the "Administrative Measures for Special Funds for SME Development," which explicitly supports public service platforms for SMEs. In 2022, the Ministry of Industry and Information Technology also conducted pilot work in terms of fiscal support for the digital transformation of SMEs, which fully demonstrates that the government, through the introduction of relevant support policies, is essentially involved in and influencing the distribution of game interests in the process of the platform empowerment of SMEs. To address the limitations of the existing research perspective, this study proposes the use of a multiagent game theory framework and introduces the government into the analysis. Furthermore, existing research analyzes mainly how to attract more SMEs to join platforms from the perspective of cost sharing but pays less attention to the important impact of the platform service types themselves in attracting enterprises. The reality is that due to the heterogeneity of SMEs in their operational development stages and digital transformation processes, their levels of demand for platform empowerment services also vary. Simply providing generic standardized services makes it difficult for platforms to meet all the personalized needs of enterprises. In fact, research has found that the demand for customized services is increasingly apparent among SMEs. In the future, if platforms can develop differentiated customized solutions based on enterprise types and stage characteristics, then it would be beneficial for platforms to maintain long-term user stickiness and engagement, which complements the traditional research perspective.

Based on existing research, the marginal contribution of this study is reflected in the below aspects. (1) The construction of a tripartite evolutionary game model involving platforms, SMEs, and the government is performed. Through this model, the simulation of the payoff matrix of each subject is used to analyze the strategy choices of each party under different conditions. (2) By fully considering the important role of the government in empowering the transformation of SMEs on the platform, government subsidy is included as a parameter in the game model to explore the impact of its behavior on the strategy choices of each party. (3) In addressing the differentiation in the levels of demand of SMEs at different stages, the type of platform services is introduced into the game model to explore which factors ultimately influence platforms to provide customized services or standardized services.

### **3. Model Establishment**

#### **3.1. Problem Description**

This article uses the method of evolutionary game theory, considering that the three game entities—platforms, SMEs, and the government—are limited rational entities with the goal of maximizing their own interests and continuously adjust and optimize their strategy choices according to their own benefits during the game. It is assumed that the strategy choice of platforms is to provide customized or standardized services, where customized services refer to those services offered by platforms after analyzing the specific needs of SMEs at different stages of digital transformation, and standardized services refer to those services provided by platforms that are the same for all SMEs. The strategy choice for SMEs is whether or not to join the platform, and the government's strategy is whether or not to subsidize. The relationships among game entities are shown in Figure 1.

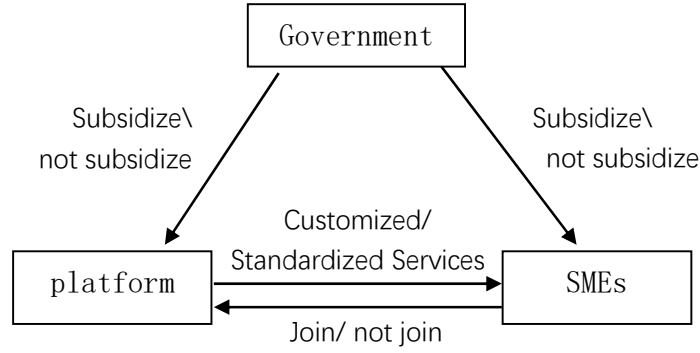


Figure 1. The relationships among game entities

### 3.2. Model Assumptions and Symbol Definitions

To construct the research model in a rational manner, the below assumptions are made.

**H1:** The evolutionary game in this paper involves three participants, namely, platforms, SMEs, and the government [12]. Among them, the probability of platforms choosing to provide customized services is  $x$  ( $0 \leq x \leq 1$ ) and that of them choosing to provide standardized services is  $1-x$ . Moreover, the probability of SMEs choosing to join platforms is  $y$  ( $0 \leq y \leq 1$ ), and that of them choosing not to join platforms is  $1-y$ . Furthermore, the probability of the government choosing the subsidy strategy is  $z$  ( $0 \leq z \leq 1$ ), and that of it choosing not to subsidize is  $1-z$ .

**H2:** The original benefits of platforms, SMEs, and the government are  $R_0^i$  ( $i=M, R, G$ ).

**H3:** The total revenue of the platform system is distributed among the various entities in proportion, with platforms receiving a proportion of  $\theta \in (0,1)$  and SMEs receiving a proportion of  $1-\theta \in (0,1)$ . If platforms provide customized services and SMEs choose to join these platforms, then the total revenue of the platform system is  $n_1$ ; if platforms choose to provide standardized services and SMEs join these platforms, then the system's total revenue is  $n_2$ .

**H4:** When platforms choose customized services, they incur cost  $C_1$  and receive internal benefits  $R_1$ . At this point, SMEs choose to join platforms and incur access costs  $C_3$ . If platforms provide only standardized services, then they incur cost  $C_2$  and receive internal benefits  $R_2$ . In this case, the joining cost for SMEs is  $C_4$ . In addition, platforms share the access costs  $\varphi C_j$  ( $j=3,4$ ) with SMEs.

**H5:** When platforms choose to provide customized services, if the government chooses to subsidize, then the reputation gain is  $F_M^G$ ; when SMEs choose to join platforms, the government's choice of subsidizing strategy gains reputational benefits  $F_R^G$ . In addition, when the government chooses a subsidizing strategy, in addition to needing to bear subsidy costs  $\alpha S_M$  and  $\beta S_R$ , it also has to bear management costs  $C_5$  associated with formulating the subsidy policy.

The symbols and their meanings related to the model are explained in Table 1.

Table 1 Table of relevant symbols and their meanings

Symbol	Meaning
$R_0^M$	Platforms' basic income
$R_0^R$	SMEs' basic income
$R_0^G$	Government's basic income
$R_1$	Internal benefits of platform customization services
$R_2$	Internal returns from platform standardized services
$\theta$	Platform system profit distribution ratio, $\theta \in [0,1]$
$n_1$	Total revenue of the system for platform customization services and SMEs joining
$n_2$	Total revenue of the system with standardized services and SMEs joining
$\alpha$	Extent of government subsidies to platforms, $\alpha \in [0,1]$
$S_M$	Maximum amount of government subsidies for platforms
$\beta$	Extent of government subsidies for SMEs, $\beta \in [0,1]$
$S_R$	Maximum amount of government subsidies for SMEs
$\varphi$	Cost sharing ratio, $\varphi \in [0,1]$
$C_1$	Customization cost of platform services
$C_2$	Platform standardized service costs
$C_3$	Access cost for SMEs to join customized service platforms
$C_4$	Access cost for SMEs to join standardization service platforms
$F_M^G$	Reputation benefits obtained when the government subsidizes platforms
$F_R^G$	Reputation benefits obtained when the government subsidizes SMEs
$C_5$	Management costs generated by government subsidies

The mixed strategy game matrix of the three players is shown in Table 2.

Table 2 Mixed strategy game matrix

x,y,z	Platforms	SMEs	Government
Customization, inclusion, subsidy	$R_0^M + R_1 + \theta n_1 - C_1 + \alpha S_M - \varphi C_3$	$R_0^R + (1 - \theta)n_1 + \beta S_R - (1 - \varphi)C_3$	$R_0^G + F_M^G + F_R^G - \alpha S_M - \beta S_R - C_5$
Customization, inclusion, no subsidy	$R_0^M + R_1 + \theta n_1 - C_1 - \varphi C_3$	$R_0^R + (1 - \theta)n_1 - (1 - \varphi)C_3$	$R_0^G$
Customization, no inclusion, subsidy	$R_0^M + R_1 - C_1 + \alpha S_M$	$R_0^R$	$R_0^G + F_M^G - \alpha S_M - C_5$
Customization, no inclusion, no subsidy	$R_0^M + R_1 - C_1$	$R_0^R$	$R_0^G$
Standardization, inclusion, subsidy	$R_0^M + R_2 + \theta n_2 - C_2 - \varphi C_4$	$R_0^R + (1 - \theta)n_2 + \beta S_R - (1 - \varphi)C_4$	$R_0^G + F_R^G - \beta S_R - C_5$
Standardization, inclusion, no subsidy	$R_0^M + R_2 + \theta n_2 - C_2 - \varphi C_4$	$R_0^R + (1 - \theta)n_2 - (1 - \varphi)C_4$	$R_0^G$
Standardization, no inclusion, subsidy	$R_0^M + R_2 - C_2$	$R_0^R$	$R_0^G - C_5$
Standardization, no inclusion, no subsidy	$R_0^M + R_2 - C_2$	$R_0^R$	$R_0^G$

#### 4. Analysis of the Strategy Stability and Evolutionary Paths of Each Game Entity

##### 4.1. Platform

##### 4.1.1. Equilibrium Analysis of the Platform

From the return matrix, it can be seen that the expected return  $U_{11}$  of platforms choosing to provide customized services, the expected return  $U_{12}$  and the average expected return  $U_1$  of platforms choosing to provide standardized services are, respectively, as follows:

$$U_{11}=yz(R_1-C_1+R_0^M-\varphi C_3+\alpha S_M+\theta n_1)-z(y-1)(R_1-C_1+R_0^M+\alpha S_M)-y(z-1)(R_0^M+R_1+\theta n_1-C_1-\varphi C_3)+(y-1)(z-1)(R_0^M+R_1-C_1) \quad (1)$$

$$U_{12}=yz(R_2-C_2+R_0^M-\varphi C_4+\theta n_2)-z(y-1)(R_0^M+R_2-C_2)-y(z-1)(R_0^M+R_2+\theta n_2-C_2-\varphi C_4)+(y-1)(z-1)(R_0^M+R_2-C_2) \quad (2)$$

$$U_1=R_2-C_2+R_0^M-xC_1+xC_2+xR_1-xR_2-\varphi yC_4+\theta yn_2-\varphi xyC_3+\varphi xyC_4+\alpha xzS_M+\theta xyn_1-\theta xyn_2 \quad (3)$$

#### 4.1.2. Platform's Replication Dynamic Analysis

$$f(x)=x(1-x)(C_2-C_1+R_1-R_2-\varphi C_3y+\varphi C_4y+\alpha S_Mz+\theta n_1y-\theta n_2y) \quad (4)$$

To obtain the partial derivative of  $f(x)$  with respect to  $x$ , we have the following:

$$\frac{df(x)}{dx}=(1-2x)(C_2-C_1+R_1-R_2+\alpha S_Mz-\varphi C_3y+\varphi C_4y+\theta n_1y-\theta n_2y) \quad (5)$$

$$\text{Let } W(z)=C_2-C_1+R_1-R_2+\alpha S_Mz-\varphi C_3y+\varphi C_4y+\theta n_1y-\theta n_2y$$

$$z_0 = \frac{C_1-C_2+R_2-R_1-A}{SM*\alpha}, \text{ where } A=(-\varphi C_3+\varphi C_4+\theta n_1-\theta n_2)y.$$

**Proposition 1:** When  $0 < z_0 < z < 1$ ,  $x^*=1$  is an evolutionarily stable point. When  $0 < z < z_0 < 1$ ,  $x^*=0$  is an evolutionarily stable point.

**Proof:**  $W(z)$  is an increasing function. When  $z=z_0$ ,  $W(z)=0$ , which means that  $f(x)=0$ , indicating that under this condition, all  $x$  values are in a stable state. When  $0 < z_0 < z < 1$ ,  $W(z) > 0$ ,  $\frac{df(x)}{dx}|_{x=0} > 0$ , and  $\frac{df(x)}{dx}|_{x=1} < 0$ . In this case,  $x^*=1$  is an evolutionarily stable point. When  $0 < z < z_0 < 1$ ,  $W(z) < 0$ , and  $\frac{df(x)}{dx}|_{x=0} < 0$ ,  $\frac{df(x)}{dx}|_{x=1} > 0$ . In this case,  $x^*=0$  is an evolutionarily stable point.

The evolution trend of the platform strategy is depicted in Figure 2.

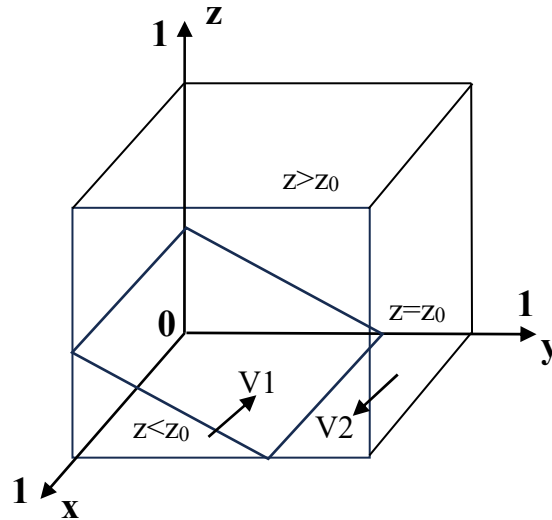


Figure 2 Platform Strategy Evolution Trend

**Proposition 2** states that under other unchanged conditions [13], as  $\alpha$ ,  $C_2$  and  $R_1$  increase, platforms are more likely to prefer providing customized services than providing standardized services [14]; as  $C_1$  and  $R_2$  increase, platforms are more likely to choose to offer standardized services than to offer customized services. This finding suggests that the probability of a platform selecting customized or

standardized services is positively correlated with government subsidies, the cost of providing standardized services, and the internal benefits of customized services. In contrast, this probability is inversely related to the cost of customized platforms and the internal benefits of standardized services.

**Proof:** As  $z_0 = \frac{C_1 - C_2 + R_2 - R_1 - A}{SM * \alpha}$ , when  $\alpha$ ,  $C_2$  and  $R_1$  increase gradually, the value of  $z_0$  decreases gradually. At this time, the volume of  $V_2$  increases, and the probability of platforms choosing a customized service strategy increases. Similarly, when  $C_1$  and  $R_2$  increase, the value of  $z_0$  gradually increases, and the volume of  $V_2$  decreases, indicating a decrease in the probability of platforms choosing a customized service strategy.

## 4.2 SMEs

### 4.2.1. Equilibrium Analysis of SMEs

The expected return  $U_{21}$  of SMEs choosing to joining platforms, the expected return  $U_{22}$  of SMEs choosing not to join platforms, and the average expected return  $U_2$  of SMEs choosing not to joining platforms are, respectively,

$$U_{21} = xz(R_0^R + S_R\beta + C_3(\varphi - 1) - n_1(\theta - 1)) - x(z - 1)(R_0^R + C_3(\varphi - 1) - n_1(\theta - 1)) - z(x - 1)(R_0^R + S_R\beta + C_4(\varphi - 1) - n_2(\theta - 1)) + (x - 1)(z - 1)(R_0^R + C_4(\varphi - 1) - n_2(\theta - 1)) \quad (6)$$

$$U_{22} = R_0^R(x - 1)(z - 1) - R_0^R z(x - 1) - R_0^R x(z - 1) + R_0^R xz \quad (7)$$

$$U_2 = R_0^R - C_4y + n_2y + C_4\varphi y - C_3xy + C_4xy - \theta n_2y + n_1xy - n_2xy + C_3\varphi xy - C_4\varphi xy + S_R\beta yz - \theta n_1xy + \theta n_2xy \quad (8)$$

### 4.2.2 SME Replication Dynamic Analysis

$$f(y) = y(1 - y)(n_2 - C_4 + C_4\varphi - C_3x + C_4x - \theta n_2 + n_1x - n_2x + C_3\varphi x - C_4\varphi x + S_R\beta z - \theta n_1x + \theta n_2x) \quad (9)$$

Taking the partial derivative of  $f(y)$  with respect to  $y$  yields the following:

$$\frac{df(y)}{dy} = (1 - 2y)(n_2 - C_4 + C_4\varphi - C_3x + C_4x - \theta n_2 + n_1x - n_2x + C_3\varphi x - C_4\varphi x + S_R\beta z - \theta n_1x + \theta n_2x) \quad (10)$$

Let  $W(x) = (n_2 - C_4 + C_4\varphi - C_3x + C_4x - \theta n_2 + n_1x - n_2x + C_3\varphi x - C_4\varphi x + S_R\beta z - \theta n_1x + \theta n_2x)$ .

$$x_0 = \frac{C_4(1 - \varphi) - n_2(1 - \theta) - S_R\beta z}{(n_1 - n_2)(1 - \theta) + (C_4 - C_3)(1 - \varphi)}$$

**Proposition 3:** When  $0 < x_0 < x < 1$ ,  $y^* = 1$  is an evolutionarily stable point. When  $0 < x < x_0 < 1$ ,  $y^* = 0$  is an evolutionarily stable point.

**Proof:**  $W(x)$  is an increasing function. When  $x = x_0$ ,  $W(x) = 0$ , which implies that  $f(y) = 0$ , indicating that under this condition, all  $y$  values are in a stable state, meaning that regardless of the probability of SMEs choosing to join or not, their strategy choices do not change over time. When  $0 < x_0 < x < 1$ ,  $W(x) > 0$ ,  $\frac{df(y)}{dy}|_{y=0} > 0$ , and  $\frac{df(y)}{dy}|_{y=1} < 0$ . In this case,  $y^* = 1$  is an evolutionarily stable point. When  $0 < x < x_0 < 1$ ,  $W(x) < 0$ ,  $\frac{df(y)}{dy}|_{y=0} < 0$ , and  $\frac{df(y)}{dy}|_{y=1} > 0$ . In this case,  $y^* = 0$  is an evolutionarily stable point.

The evolution trend of the SME strategy is depicted in Figure 3.

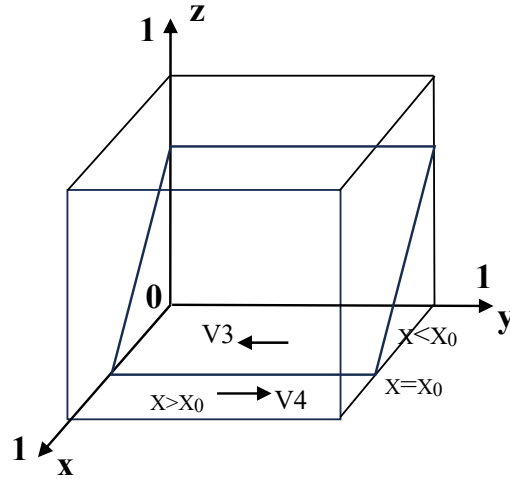


Figure 3 SME Strategy Evolution Trend

**Proposition 4:** Under the condition of the other parameter conditions remaining unchanged, as  $n_1$  increases, SMEs tend to choose to join platforms; however, as  $\theta$  and  $C_3$  increase, SMEs tend to choose not to join platforms. This situation also indicates that the probability of SMEs choosing to join or not join platforms is directly proportional to the platforms' customization and the overall benefits gained by SMEs joining and inversely proportional to the distribution proportion of system benefits and the access cost of joining customized platforms.

**Proof:** Since  $x_0 = \frac{c_4(1-\varphi) - n_2(1-\theta) - S_R\beta z}{(n_1 - n_2)(1-\theta) + (c_4 - c_3)(1-\varphi)}$ , when  $n_1$  gradually increases, the value of  $x_0$  gradually decreases, the volume of  $V_4$  increases, and the probability of SMEs choosing to join platforms increases. In the same way, when  $\theta$  and  $C_3$  increase, the value of  $x_0$  gradually increases, the volume of  $V_4$  decreases, and the probability of SMEs choosing to join platforms decreases.

### 4.3. Government

#### 4.3.1. Equilibrium Analysis of the Government

The expected return of the government choosing the subsidy strategy is  $U_{31}$ , the expected return of the government choosing the no subsidy strategy is  $U_{32}$ , and the average return  $U_3$  are, respectively, as follows: [15]

$$U_{31} = x(y-1)(C_5 - F_M^G - R_0^G + \alpha S_M) - (C_5 - R_0^G)(x-1)(y-1) - xy(C_5 - F_M^G - F_R^G - R_0^G + S_M\alpha + S_R\beta) + y(x-1)(C_5 - F_R^G - R_0^G + S_R\beta) \quad (11)$$

$$U_{32} = R_0^G(x-1)(y-1) - R_0^G y(x-1) - R_0^G x(y-1) + R_0^G xy \quad (12)$$

$$U_3 = R_0^G C_5 z + F_M^G xz + F_R^G yz - \alpha S_M xz - \beta S_R yz \quad (13)$$

#### 4.3.2. Government's Replication Dynamic Analysis

$$f(z) = z(z-1)(C_5 - F_M^G x - F_R^G y + S_M\alpha x + S_R\beta y) \quad (14)$$

Finding the first-order partial derivative for  $f(z)$  with respect to  $z$  yields the following:

$$\frac{df(z)}{dz} = (2z-1)(C_5 - F_M^G x - F_R^G y + S_M\alpha x + S_R\beta y) \quad (15)$$

Let  $W(y) = C_5 - F_M^G x - F_R^G y + S_M \alpha x + S_R \beta y$

$$y_0 = \frac{-C_5 + F_M^G x - S_M \alpha x}{S_R \beta - F_R^G}$$

**Proposition 5:** When  $0 < y_0 < y < 1$ ,  $z^* = 0$  is an evolutionarily stable point. When  $0 < y < y_0 < 1$ ,  $z^* = 1$  is an evolutionarily stable point.

**Proof:**  $W(y)$  is a decreasing function. When  $y = y_0$ ,  $W(y) = 0$ , indicating that  $f(z) = 0$ , meaning that under this condition, all  $z$  values are stable states; that is, the government's strategy does not change over time. When  $0 < y_0 < y < 1$ ,  $W(y) > 0$ ,  $\frac{df(z)}{dz}|_{z=0} < 0$ , and  $\frac{df(z)}{dz}|_{z=1} > 0$ . The equilibrium point  $z^* = 0$  is evolutionarily stable in this case. When  $0 < y < y_0 < 1$ ,  $W(y) < 0$ ,  $\frac{df(z)}{dz}|_{z=0} > 0$ , and  $\frac{df(z)}{dz}|_{z=1} < 0$ , indicating that the equilibrium point  $z^* = 1$  is evolutionarily stable in this case.

The evolution trend of the government strategy is depicted in Figure 4.

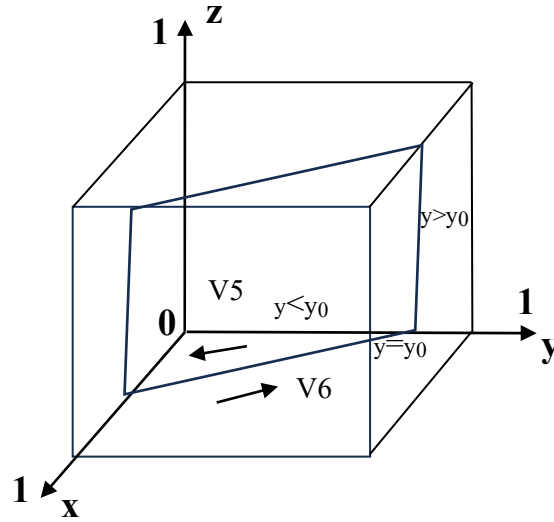


Figure 4 Government Strategy Evolution Trend

**Proposition 6:** When the other parameters remain constant, the government is more willing to subsidize as  $F_R^G$  increases and is less willing to subsidize as  $S_R$ ,  $\beta$  and  $C_5$  increase. This finding indicates that the probability of government subsidy selection is directly proportional to the reputational benefits obtained by the government when it subsidizes SMEs and inversely proportional to the amount of government subsidies to SMEs and the management costs incurred when government subsidies are generated.

**Proof:** Since  $y_0 = \frac{-C_5 + F_M^G x - S_M \alpha x}{S_R \beta - F_R^G}$ , as  $F_R^G$  gradually increases, the value of  $y_0$  also increases. At this point, the volume of  $V_5$  increases, and the probability of the government choosing a subsidy strategy also increases. Similarly, when  $S_R$ ,  $\beta$ , and  $C_5$  increase, the value of  $y_0$  gradually decreases, the volume of  $V_5$  decreases, and the probability of the government choosing a subsidy strategy decreases.

## 5. Analysis of the Stability of System Evolution Strategies

The above text starts from the perspective of an individual game player, analyzing the evolutionary process of strategy selection for individual game players and the important factors influencing their strategy selection. However, the empowerment of SMEs' digital transformation and development through the industrial internet platform requires the joint efforts of platform creators, SMEs, and the

government. Therefore, a comprehensive analysis of the three parties is of significant importance. According to previous studies, analyses using the Jacobian matrix can obtain the evolutionary stable strategies of the dynamic system constituted by differential equations.

In the dynamic system constituted by these three strategic entities, setting  $F(x)=0$ ,  $F(y)=0$ , and  $F(z)=0$  yields eight pure strategy Nash equilibrium points for the system. These points are denoted as  $E_1(0,0,0)$ ,  $E_2(0,0,1)$ ,  $E_3(0,1,0)$ ,  $E_4(0,1,1)$ ,  $E_5(1,0,0)$ ,  $E_6(1,0,1)$ ,  $E_7(1,1,0)$ , and  $E_8(1,1,1)$ . According to the replicated dynamic equations, the system's Jacobian matrix is determined as follows:

$$J = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} = \begin{bmatrix} F_{11} & F_{12} & F_{13} \\ F_{21} & F_{22} & F_{23} \\ F_{31} & F_{32} & F_{33} \end{bmatrix} \quad (16)$$

where

$$F_{11} = (1-2x)(C_2 - C_1 + R_1 - R_2 + S_M \alpha z - C_3 \varphi y + C_4 \varphi y + \theta n_1 y - \theta n_2 y)$$

$$F_{12} = [\theta n_2 - \theta n_1 + (C_3 - C_4) \varphi] x^2 + [-\theta n_2 + \theta n_1 + (C_4 - C_3) \varphi] x$$

$$F_{13} = S_M \alpha x - S_M \alpha x^2$$

$$F_{21} = [(1-\theta)n_2 + (\theta-1)n_1 + (C_4 - C_3) \varphi - C_4 + C_3] y^2 + [(\theta-1)n_2 + (1-\theta)n_1 + (C_3 - C_4) \varphi + C_4 - C_3] y$$

$$F_{22} = (1-2y)(n_2 - C_4 + C_4 \varphi - C_3 x + C_4 x - \theta n_2 + n_1 x - n_2 x + C_3 \varphi x - C_4 \varphi x + S_R \beta z - \theta n_1 x + \theta n_2 x)$$

$$F_{23} = S_R \beta y - S_R \beta y^2$$

$$F_{31} = (S_M \alpha - F_M^G) z^2 + (F_M^G - S_M \alpha) z$$

$$F_{32} = (S_R \beta - F_R^G) z^2 + (F_R^G - S_R \beta) z$$

$$F_{33} = (2z-1)(C_5 - F_M^G x - F_R^G y + S_M \alpha x + S_R \beta y)$$

According to Lyapunov's first law, when all eigenvalues of the Jacobian matrix are negative, the equilibrium point is a stable point of the system. Therefore, by substituting the above 8 pure strategy equilibrium points into the Jacobian matrix of the system, we can obtain the eigenvalues of the Jacobian matrix of the equilibrium points, as shown in Table 3.

Table 3 Eigenvalues

Equilibrium	Eigenvalue	Plus-Minus	Stability Conclusion
[0,0,0]	$-C_5$	-	unstable point
	$C_2 - C_1 + R_1 - R_2$	+	
	$n_2 - C_4 + C_4 \varphi - \theta n_2$	+	
[1,0,0]	$F_M^G - C_5 - S_M \alpha$	uncertain	unstable point
	$C_1 - C_2 - R_1 + R_2$	-	
	$n_1 - C_3 + C_3 \varphi - \theta n_1$	+	
[0,1,0]	$F_R^G - C_5 - S_R \beta$	uncertain	unstable point
	$C_4 - n_2 - C_4 \varphi + \theta n_2$	-	
	$C_2 - C_1 + R_1 - R_2 - C_3 \varphi + C_4 \varphi + \theta n_1 - \theta n_2$	+	
[0,0,1]	$C_5$	+	unstable point
	$C_2 - C_1 + R_1 - R_2 + S_M \alpha$	+	
	$n_2 - C_4 + C_4 \varphi + S_R \beta - \theta n_2$	+	
[1,1,0]	$F_M^G - C_5 + F_R^G - S_M \alpha - S_R \beta$	uncertain	possibly stable
	$C_1 - C_2 - R_1 + R_2 + C_3 \varphi - C_4 \varphi - \theta n_1 + \theta n_2$	-	
	$C_3 - n_1 - C_3 \varphi + \theta n_1$	-	
[1,0,1]	$C_5 - F_M^G + S_M \alpha$	uncertain	unstable point
	$C_1 - C_2 - R_1 + R_2 - S_M \alpha$	-	
	$n_1 - C_3 + C_3 \varphi + S_R \beta - \theta n_1$	+	
[0,1,1]	$C_5 - F_R^G + S_R \beta$	uncertain	unstable point
	$C_4 - n_2 - C_4 \varphi - S_R \beta + \theta n_2$	-	
	$C_2 - C_1 + R_1 - R_2 - C_3 \varphi + C_4 \varphi + S_M \alpha + \theta n_1 - \theta n_2$	+	
[1,1,1]	$C_5 - F_M^G - F_R^G + S_M \alpha + S_R \beta$	uncertain	possibly stable
	$C_3 - n_1 - C_3 \varphi - S_R \beta + \theta n_1$	-	
	$C_1 - C_2 - R_1 + R_2 + C_3 \varphi - C_4 \varphi - S_M \alpha - \theta n_1 + \theta n_2$	-	

The following is a discussion of the stability of the system for different conditions.

Condition 1 When  $R_1-C_1>R_2-C_2$ ,  $(1-\theta)n_2-(1-\varphi)C_4>(1-\theta)n_1-(1-\varphi)C_3$  and  $\theta n_1-C_3\varphi>\theta n_2-C_4\varphi$ , the system has and only has the evolutionary stability point  $E_8(1,1,1)$ , and the corresponding tripartite strategy is selected as (customized service, joining platform, subsidy).

Condition 2 When  $F_M^G-C_5+F_R^G-S_M\alpha-S_R\beta<0$ , that is, when the final income of the government is negative, the system has and only has the evolutionary stability point  $E_5(1,1,0)$ , and its corresponding evolutionary stability strategy is (customized services, joining the platform, not subsidy).

## 6. Simulation Analysis

Based on the replication dynamic equations and the stability analysis of evolutionary strategies, an ideal stability state is selected to assign values to the parameters in the game system. Assuming that  $R_0^M=50$ ,  $R_0^R=18$ ,  $R_0^G=10$ ,  $R_1=75$ ,  $R_2=72$ ,  $\theta=0.8$ ,  $n_1=100$ ,  $n_2=80$ ,  $\alpha=0.3$ ,  $S_M=40$ ,  $\beta=0.4$ ,  $S_R=15$ ,  $\varphi=0.3$ ,  $C_1=40$ ,  $C_2=30$ ,  $C_3=13$ ,  $C_4=10$ ,  $F_M^G=20$ ,  $F_R^G=20$ , and  $C_5=5.5$ . By setting the initial values, this paper uses MATLAB to simulate the dynamic evolution process of strategy selection for different initial states of platforms, SMEs, and the government. Based on the simulation analysis results, the subsidy intensity of participating entities and the coefficient of cost sharing are discussed.

### 6.1. Model Verification

The assigned array is simulated in the model to verify the effectiveness of the system evolution stability analysis. The simulation results are shown in Figure 5. Under the given conditions, the system eventually evolves to  $(1,1,1)$ , which is consistent with the conclusion obtained from the abovementioned system evolution stability analysis. This finding supports the validity of the model and indicates practical implications for platform, SMEs, and the government.

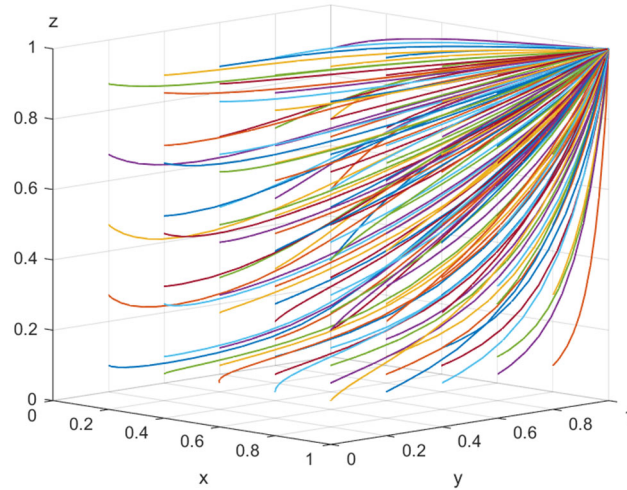


Figure 5 System Evolution Game Simulation

### 6.2. Government Subsidy Intensity $\alpha$ for Platforms

Under certain conditions for the other parameters, let the values of  $\alpha$  be 0.2, 0.4, 0.6, and 0.8; the simulation results are shown in Figure 6.

From Figure 6, it can be observed that the critical value of the government's subsidy intensity to platforms lies between 0.6 and 0.8. When the government's subsidy intensity to platforms exceeds the critical value, the stable point of the system evolution is  $(1, 1, 0)$  because the government considers high degrees of subsidy intensity and excessive costs, ultimately choosing no subsidy. When the government provides subsidy intensity to platforms that is less than the critical value, platforms, SMEs, and the government choose customized services, to join the platform, and subsidies,

respectively. At this point, the stable point of the system evolution becomes (1, 1, 1). Furthermore, increasing the degree of subsidy intensity from 0.2 to 0.6 only accelerates the rate at which the system evolves to (1, 1, 1) and does not affect the final strategy choices of the three entities. In conclusion, as a bounded-rational actor, the government chooses to provide a certain amount of subsidies to platforms. These policy subsidies also encourage platforms to make decisions to provide customized services for SMEs.

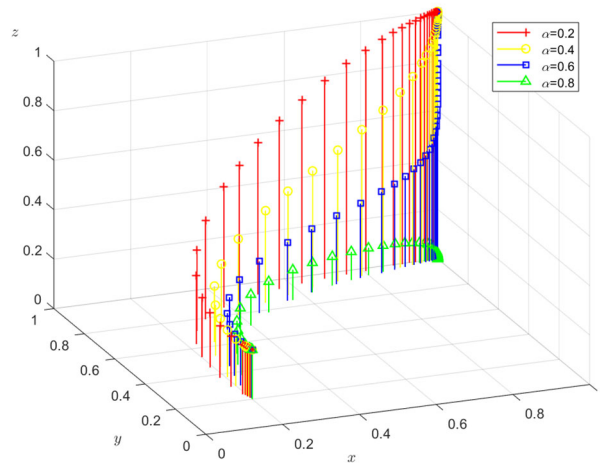


Figure 6 Impact of the Variation in  $\alpha$  on the Evolution of the System

### 6.3. Government Subsidy Intensity $\alpha$ for SMEs

Keeping the other parameters constant, let  $\beta$  take the values of 0.2, 0.4, 0.6, and 0.8; the impact of government subsidies to SMEs on the stability of the system is discussed. The simulation results are shown in Figure 7.

Figure 7 shows that the magnitude of government subsidies to SMEs does not affect the evolutionary stability point of the system. Regardless of whether the subsidy strength  $\beta$  is high or low, the evolution stability point of the system always remains at (1,1,1) because, even if the government does not provide subsidies to SMEs, the benefits of SMEs joining platforms are large enough, and thus, government subsidies do not affect the strategic choices of SMEs. In addition, as the government subsidies to SMEs  $\beta$  increase from 0.2 to 0.8, the rate at which the system evolves to (1,1,1) also gradually increases.

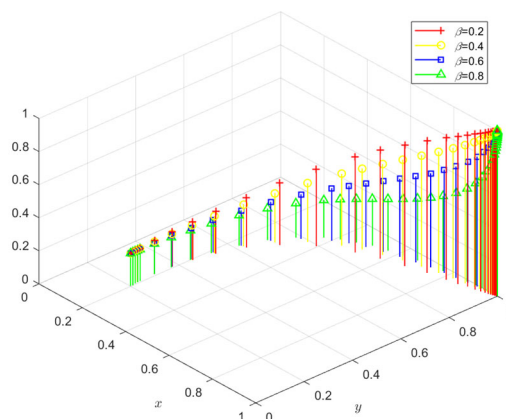


Figure 7 Impact of the Variation in  $\beta$  on the Evolution of the System

## 6.4. Cost-Sharing Coefficient $\varphi$

Under the condition that the other parameters remain unchanged, the cost-sharing coefficient  $\varphi$  takes the values of 0.2, 0.4, 0.6 and 0.8. The simulation results are shown in Figure 8.

As seen from Figure 8, the magnitude of the cost-sharing coefficient  $\varphi$  is independent of the final evolution state of the system. The cost-sharing coefficient  $\varphi$  is either larger or smaller, and the final system steady state is (1,1,1), i.e., (customized services, joining the platform, subsidies). The reason for this is also that cost sharing by platforms for SMEs is not a necessary condition for SMEs to enter the cloud; even if costs are not shared, the benefits obtained by SMEs after entering the cloud are greater than are the costs, and rational SMEs thus eventually choose to enter and use the cloud to maximize their benefits. In addition, the larger the  $\varphi$  value of the cost-sharing coefficient, the faster the system reaches the evolutionary stability point (1,1,1), which indicates that if platforms share the costs of SMEs joining them, then SMEs are more motivated to join at an earlier time.

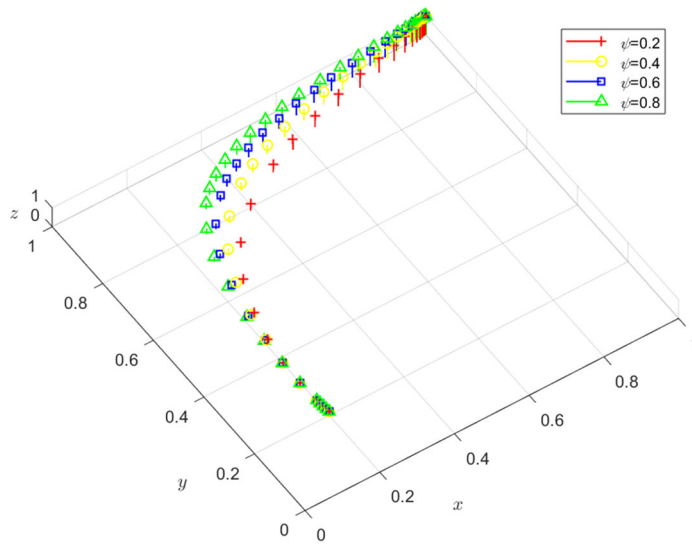


Figure 8 Impact of the Variation in  $\varphi$  on the Evolution of the System

## 7. Conclusions and Recommendations

### 7.1. Research Conclusions

Based on the current situation in which SMEs urgently need to rely on industrial internet platforms for digital transformation, this article constructs an evolutionary game model among platforms, SMEs, and the government as three stakeholders. The below conclusions can be drawn.

- 1) The strategy selection of the three game players is influenced by multiple factors. The decision of the platform creator is related mainly to the government subsidy intensity ( $\alpha$  and  $\beta$ ), the cost of providing services on platforms ( $C_1$  and  $C_2$ ), and the internal revenue after service ( $R_1$  and  $R_2$ ); SMEs are influenced mainly by the total platform system revenue ( $n_1$  and  $n_2$ ), the platform revenue distribution ratio ( $\theta$ ), and the access costs ( $C_3$  and  $C_4$ ) required to join platforms; the government's strategy selection is related to subsidy intensity ( $\alpha$  and  $\beta$ ) and is also influenced by the reputation benefits obtained from subsidies ( $F_M^G$  and  $F_R^G$ ) and the management costs ( $C_5$ ) generated when formulating subsidy policies.
- 2) In the process of conducting simulation analysis, the subsidy intensity provided by the government to different platforms alters the final stability state of the system. When the government's subsidy intensity is excessively high, the stable point of the system becomes (1,1,0), leading the government to ultimately choose no subsidy. In all other cases, the stable point of system evolution is (1,1,1), indicating a scenario of customized services, platform participation, and subsidies. The reason for this is that when the government subsidy reaches a certain level, the government faces increasing cost pressure, where the cost exceeds the benefits, resulting in a decrease

in the probability of it choosing a subsidy strategy.

- 3) The proportion of cost sharing and the extent of government subsidies to enterprises can influence the decision-making of platforms and SMEs. An increase in these parameters enhances platforms' ability to provide customized services and the willingness of SMEs to join platforms. Therefore, platform creators and the government can promote the participation of SMEs in platforms and optimize platforms by adjusting the proportion of cost sharing and the extent of subsidies to enterprises [17].

## **7.2. Insights and Recommendations**

1) The utilization of industrial internet platforms for digital transformation is an inevitable result of technological changes and market demand fluctuations [18]. Platform creators (industry leaders or internet enterprises) need to thoroughly analyze the characteristics of the internal and external environment, combining them with their own industry features and resource conditions to establish a digital transformation plan that aligns with the long-term development strategy of SMEs [19].

2) Considering the actual needs of SMEs in different stages of development, providing customized and differentiated services is currently more desirable. However, most platforms still offer only standardized services, severely impacting the pace of digital transformation for SMEs. Governments should therefore set a reasonable level of subsidies to reduce platform construction costs and encourage and promote the high-quality digital transformation of SMEs. In addition, embracing the use of platforms is a crucial step toward successful digital transformation. To improve the efficiency of platform utilization and encourage more SMEs to join platforms, the distribution of interests between platform systems should be fair and reasonable, reducing the cost pressure placed on SMEs.

3) The process of digital transformation in SMEs neither is merely the application of a single digital technology in enterprise management innovation nor is it achieved through solitary efforts, but rather through breakthroughs, developments, integrations of multiple technologies and the convergence of large enterprises and SMEs. [20] In the process of digital transformation, SMEs need to not only fully utilize platforms to integrate innovative resources and solve common technological problems but also combine enterprise talent reserves, management system innovation, and other factors to better leverage the enabling effects of platforms, enhance data quality, and improve the ability to make intelligent decisions, thus providing technical support for the digitization of operational management in SMEs [21].

This study takes into account the scenario where platforms are built by industry leaders or internet enterprises and examines the interests and strategies of platforms, SMEs, and the government under various conditions, such as cost sharing and government subsidies. This work provides theoretical references for the government and SMEs that are willing to undergo digital transformation.

Notably, this article is a study of the simplified platform-SME-government tripartite model. However, in reality, the decision-making of the three parties is much more complex. Factors such as data security breaches, information asymmetry between platforms and SMEs, and changes in national policies significantly increase the degree of difficulty of decision-making. Thus, further research can be conducted in the future to address these complexities.

## **8. Data availability statement**

Data sharing does not apply to this article.

## **9. CRediT authorship contribution statement**

Dongyun Hu: Writing – original draft. Zifu Fan: Formal analysis, Methodology. Leifan Wu: Conceptualization, Data curation.

## 10. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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