

Research on Online Industrial Cluster Model of SMEs Based on Complex Network Evolutionary Game

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ABSTRACT

Online industry cluster, emerging as a novel business model facilitated by the digital economy, present new opportunities for the development of Small and Medium Enterprises (SMEs). Based on evolutionary game theory, this paper analyzes the realization conditions of SME online industrial cluster model. It also investigates the diffusion mechanism of SMEs' participation in online industrial cluster decision-making under various influences combined with complex networks. Subsequently, the dynamic evolution process of the cluster model is analyzed using numerical simulation. Theoretically, this paper breaks through the limitations of traditional industrial cluster and reflects the new characteristics and models of industrial cluster in the digital economy era. Practically, online industrial clusters based on digital platform services can enable SMEs to integrate into the digital revolution and enhance resilience and competitiveness. The findings indicate that an increase in online business opportunities and transaction efficiency augments SMEs' propensity to engage with online industrial clusters. Digital governance is found to alleviate the adverse effects of platform monopolies and data security threats, thereby facilitating the spread of decision-making. Furthermore, the study reveals that the number of SMEs participating in online clusters has a more significant influence on successful decision dissemination than product homogeneity. Both elements affect SMEs' strategic choices by altering the competitive landscape within the clusters. Additionally, robust relational and institutional trust serves as an intrinsic motivator for SMEs' participation in online clusters. Lastly, the coordination provided by industry associations acts as an external incentive, reducing trust-related risks within the clusters and encouraging active SME involvement.

Keywords: Small and medium-sized enterprises; online industrial clusters; platform; evolutionary game of complex networks

Mathematics Subject Classification: 91D30, 91A22, 68Q25

Journal of Economic Literature (JEL) Classification : L25, C73

1. INTRODUCTION

Small and medium-sized enterprises (SMEs) are the foundation of the global economy, accounting for 90% of the world's enterprises, providing 70% of the world's jobs, and contributing 50% of the world's GDP of the digital economy (WTO, 2023), the development and popularization of digital technologies

have brought unprecedented opportunities and unique challenges to SMEs. The survival and development of SMEs have attracted much attention in the face of uncertainties in the global economy. According to the World Economic Forum, 70% of the newly created value in the next decade will be based on digital technology (World Economic Forum, 2023). In the digitalization wave, SMEs need not only to be responsive to the needs of the environment with basic digital knowledge and IT architecture, but also need to focus on how to improve enterprise resilience and competitiveness, and better achieve sustainable development and value growth. The International Trade Center suggests that governments should create a business ecosystem for SMEs so that they can not only survive but also thrive (International Trade Centre, 2023). Online industrial clusters, as a new business model formed by upstream and downstream SMEs in the industry chain relying on virtual agglomeration of platform services under digitalization changes, bring new opportunities for SMEs' development. This helps SMEs to improve their risk-resistant ability, enhance their market competitiveness, and realize efficiency growth. Meanwhile, the emergence of the platform service model has changed the digital service paradigm, so that more SMEs can enjoy the digital benefits. Its short cycle, low cost, more efficient, and agile services are more compatible with the development needs of SMEs (CASME, 2023). In recent years, numerous countries have successively introduced relevant policies to optimize the business environment and promote the integration of the digital economy with the real economy, thereby creating new business models and fostering innovative development among SMEs. For example, Malaysia mentioned in "National Science, Technology and Innovation Policy 2021-2030" that the application of digital technology is an important factor in enhancing the resilience and sustainability of SMEs' development, and that in the future, more SMEs will sell their products and services on digital platforms, gaining access to broader markets and development space (MOSTI, 2022). In the "14th Five-Year Plan for Promoting the Development of SMEs", China proposes to support the development of new business models and accelerate the cultivation of SMEs' characteristic industrial clusters. Consequently, leveraging digital platform services to construct a symbiotic model of online industrial clusters for SMEs is not only a new opportunity for them to realize value innovation and growth, but also a crucial strategy to bolster their resilience and promote their sustainable development.

In the context of a new wave of scientific and technological revolution driven by digital technology, digital transformation has emerged as an inevitable trend in the evolution of SMEs (Yang et al., 2023). However, compared with large enterprises, SMEs face greater challenges in digital transformation due to constraints in capital, technology, talent, and other resources. Owing to a lack of advanced expertise and limited applicable solutions, most SMEs find themselves in a digital predicament (Del Giudice et al., 2021). Concurrently, the focus of SMEs is different from that of large enterprises at this stage. Large enterprises often need to address the issue of internal information system silos first, aiming to tackle digital transformation through the design and planning of information system architecture. Conversely, SMEs are primarily concerned with survival, focusing on digital solutions that foster business model innovation and channel growth.

The construction of online industrial clusters ecosphere is an important practical exploration under the background of digital transformation. This model not only helps SMEs break through the bottleneck of

traditional development and enhance market competitiveness, but also expands upstream and downstream through platform services, and obtains more customers and orders. Some studies define online industrial clusters as the virtual agglomeration of interrelated enterprises in the network platform space (Taura & Radicic, 2019; Zhou et al., 2023). This makes it reasonable to think that, unlike traditional industrial clusters, which are often confined to the agglomeration mode formed in a specific geographical space, online industrial clusters break through the limitations of geographical space and distance, and closely connect enterprises in all links of the industrial chain through digital platform services, making it possible for enterprises to trade and collaborate across geographical distances (Chen, 2017).

This paper aims to analyze the conditions for the formation of the SMEs online clusters industry model, as well as the dynamic evolution of SMEs' participation in online clusters under different factors. The combination of complex network and evolutionary game can effectively depict the diffusion of strategies and the evolution process of interactive learning behavior among the subjects in the network structure. It also elucidates the influencing factors and mechanisms that drive these processes (Zhang et al., 2024). Based on this, this paper firstly explores the influence of different subjects' behaviors on the stability of SMEs' online industrial clusters by constructing an evolutionary game model with the government, platforms, and SMEs as the main subjects. It then combines with the complex network and constructs the SMEs' complex network game model to explore the influence and diffusion effect of platform behaviors, online competition, and trust on the decision-making of SMEs' participation in the online industrial clusters. It provides theoretical support and practical guidance for promoting the development of online industrial clusters model of SMEs.

The innovations of this paper are mainly reflected in the following three aspects:

- (1). From a system stability perspective, constructing a tripartite evolutionary game model of the government, platforms and SMEs. This allows for the analysis of the target behaviors of different subjects in SMEs' industrial clusters, revealing the stability conditions for the formation of SMEs' online industrial clusters, which enriching the research perspectives of SMEs' online industrial clusters.
- (2). By constructing a complex network evolutionary game model, the influence of online transaction efficiency, platform violation tendency, online competition, and trust risk on SMEs' decision-making is explored. This further investigates the influence mechanism affecting SMEs' online industrial clusters. The dynamic evolution process of SMEs' participation in the decision-making of online industrial clusters is analyzed using numerical simulation. This represents a departure from previous literature that studies online industrial clusters from static viewpoints.
- (3). As a new clusters model in the digital era, online industrial clusters break through the time and space limitations of traditional industrial clusters. This paper explores the stable conditions for the formation of SMEs' online industrial clusters under the influence of various subjects' behaviors and analyzes the impact of different factors on SMEs' participation in online industrial clusters. This provides practical guidance and theoretical support for the promotion of SMEs' business model innovation.

2. LITERATURE REVIEW

In recent years, relevant researches have been conducted on the implementation methods, mechanisms, and influencing factors of online industry clusters.

2.1. Implementation methods

On the one hand, the development of digital technology has given birth to new forms of online industrial clusters. Fernandez-Escobedo et al. (2024) noted that digital platform technology has revolutionized traditional interaction modes between enterprises, enabling virtual space for cross-geographical interactions. Digital platforms can relate many SMEs, transitioning from a “one-to-one model” to a “one-to-many model”, and from “single service” to “ecological service” (CASME, 2023). Based on the characteristics of low cost and high efficiency of platform services, Tan and Xia (2022) posited that SMEs across different regions would rely on online platforms to penetrate online markets, gradually forming online clustering in the process. On the other hand, the digital transformation of enterprises furnishes practical conditions for the emergence of online industrial clusters. Jiao et al. (2024), Jasinska & Jasinski (2019) all concurred that digital transformation equips most SMEs with the capability to utilize digital tools, facilitating digital information exchange and fostering enterprise agglomeration in cyberspace. Moreover, some scholars highlighted that governmental and societal sectors have created favorable conditions for the development of SMEs online industrial clusters. For example, governmental policies provide a conducive environment for SMEs; industry associations promote inter-SMEs exchanges and collaborations through organized activities and coordinated member engagements.

2.2. Mechanism of action

Firstly, relying on the technology and services of digital platforms, the digital transformation of SMEs has been accelerated. Mann et al. (2022) discovered that the platform ecological model offers technical and service support beneficial for SMEs to actualize digital transformation in business model injecting fresh impetus into their development. Secondly, the online industrial clusters ecological model can improve the efficiency of the industrial chain and reduce transaction costs. Al Mashalah et al. (2022) argued that platform services transcend geographical barriers and streamline communication and resource transmission among enterprises, which mitigates information asymmetry and transactional expenses while augmenting supply chain cooperation efficacy. Finally, online industrial clusters have expanded the market scale and provided more development opportunities for the development of SMEs. Steinhoff et al. (2019) found that the platform service can expand enterprise market channels, enabling enterprises to interact with a wider array of potential customers online. Marzi et al. (2023) pointed out that in B2B platform, SMEs can not only quickly connect with the market to achieve cost reduction and efficiency enhancement, but also adapt swiftly to supply-demand fluctuations to capture timely opportunities, thereby bolstering market competitiveness.

2.3. Influencing factors

Firstly, platform services and efficiency directly impact online industrial clusters. Li (2023) found through empirical research that the improvement of platform service quality significantly propels the expansion

of platform user bases, encompassing ease of platform tool usage, diversity, and inherent information matching efficiency. Secondly, trust and competition among enterprises affect the stability of online industrial clusters. Jiao et al. (2024) emphasized that trust among multiple agents is pivotal for realizing value co-creation in digital industrial clusters. Regarding the competition in online industrial clusters, Zhu et al. (2022) noted that in homogeneous product markets, B2B platform emergence can trigger price wars among merchants. Therefore, establishing a reasonable competition system and multi-dimensional trust relationship within the cluster can motivate more enterprises to join the online industrial cluster and better realize multi-agent value creation. Finally, platform abuse of market dominance and security concerns pose potential detriments to online industrial clusters. Tan and Xia (2022) identified that strong network externalities may hinder enterprise exit from platforms, leading to potential monopolistic tendencies, such as the platform leveraging traffic, data, and service advantages to extract various “rentals” from network cluster enterprises. Concurrently, online congregation elevates enterprise information security risks, including data damage, loss, attacks, and tampering on platforms. These issues have somewhat compromised enterprise interests, reducing their willingness to aggregate online.

2.4. Application of complex network evolution game

Enterprises often have a special game in market activities, forming a network of relationships due to factors such as supply chain division of labor and cooperation (Bengtsson et al., 1999). According to social learning theory, enterprises enhance their market competitiveness by improving the effectiveness of their decision-making through imitation and learning from successful strategies of other entities in the same industry (Bandura, 2018). And this decision will spread through the enterprise relationship network. The complex network provides a new perspective and method for studying the interactions between enterprises and the evolution of systemic decision-making. By utilizing complex networks, we can explore the evolutionary dynamic behaviors such as game and diffusion on the enterprise network. For example, Xu et al. (2023) investigated the dynamic decision-making process and critical factors of value co-creation behavior of focal companies and non-focal subjects based on a complex network evolutionary game model. Based on the evolutionary game model of complex networks, Hu et al. (2023) by established a complex network evolution game model between different heat supply enterprises, and explored the evolution of enterprise behavior under the implementation of heat metering and charging situation.

2.5. Review

The existing literatures mostly focused on qualitative analysis, and discussed the online industrial clusters of SMEs from the perspectives of implementation methods, action mechanism and influencing factors. However, there is limited research on the dynamic evolution process of online industry clusters of SMEs. Moreover, the factors influencing these clusters and their micro-mechanism require further investigation. This is particularly pertinent given the accelerating digital transformation of SMEs, which blurs organizational boundaries due to extensive digital technology and network usage. The relationship between SMEs presents the characteristics of systematic and network structure, leading to mutual imitation behaviors and co-evolution in the competitive market. What are the factors influencing the

formation of online industrial clusters for SMEs? What are the stabilizing conditions for the formation of SMEs online clusters? Additionally, what are the prerequisites for SMEs to actively participate in online clusters and the dynamic diffusion process of decision-making? These interrelated questions all require further research.

3. EVOLUTIONARY GAME ANALYSIS OF SMES ONLINE INDUSTRIAL CLUSTER MODEL

3.1. Analysis of cluster subject relationships and their objectives

Industrial cluster is a complex system involving multiple subjects (Camuffo & Grandinetti, 2011). How to fully tap the enthusiasm of the participants, establish an online industrial cluster model of SMEs (as shown in Figure 1) and form a multi-agent value creation mechanism, it is necessary to first delineate the relationships among participants and their behavioral objectives. On the one hand, industrial online clusters cannot do without external support. The government can create a good environment and conditions for the development of online industrial cluster of SMEs by improving the digital economic governance system and strengthening the supervision of platform behavior. On the other hand, the theory of complex adaptive system holds that the internal subjects within a system exhibit adaptability and are capable of proactively selecting suitable behaviors in different environments (Holland, 1992). This is actually a kind of gaming behavior of the subject to maximize its own interests in the process of cooperation or competition with other subjects. SMEs and platform, as the pivotal subjects in the online industrial cluster, have different behaviors and goals in the process of interactive competition and cooperation.

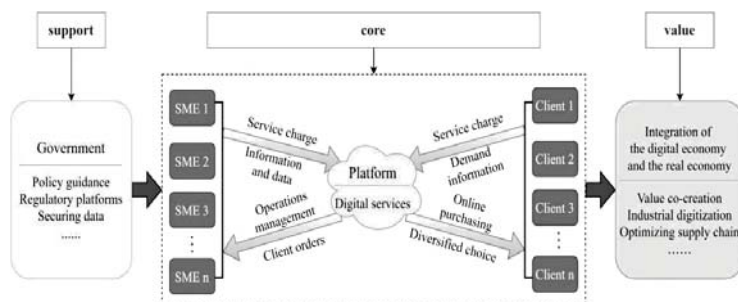


Figure 1. Online Industrial Cluster Model of SMEs

Firstly, there is a competing relationship between SMEs. On the one hand, leveraging the platform's powerful connectivity, SMEs can form a tighter supply-demand cooperation relationship. The internet facilitates the convergence and sharing of supply and demand information. With the platform's efficient information matching, SMEs can quickly and accurately find the target customers. They can then harness the network effect to establish collaborations that were previously unattainable through bilateral relationships. On the other hand, the open services of platform have lowered the barriers for SMEs to enter the online market, thereby intensified the competition among enterprises. Given that SMEs often have similar market positioning and common needs, with the expansion of online cluster makes it increasingly challenging for them to compete for customers and resources. This scenario may lead to

low-end competition such as price war, and thus reduce the profit margins of SMEs. Moreover, the trust relationship between enterprises in online industrial cluster is more complicated. Since activities in online cluster are primarily conducted through platform, this virtual interaction impedes the transfer of non-verbal cues. As a result, enterprises are compelled to rely more on limited information sources, such as text and online reviews, during the trust-building process. This reliance heightens the difficulty of establishing mutual trust and may even introduce the risk of online transactional fraud.

Secondly, the relationship between SMEs and platforms is intricate. On the one hand, SMEs and platforms share a mutually beneficial relationship in the online industrial cluster model. SMEs require platform services to access market information and customer resources, thereby facilitating their own value growth. This also propels the development of the platform economy. Conversely, there may be conflicts of interest between SMEs and platforms. As the scale of online clusters expands, platforms may exploit SMEs' reliance on them and abuse their dominant market position to gain more benefits. For instance, by altering the terms of service, fee structure, and other methods of charging "rents", which may conflict with the interests of SMEs. Furthermore, while providing services to SMEs, platforms need to collect and analyze enterprise data, which could involve data security issues. Data breaches could not only result in the loss of sensitive information from enterprises but could also lead to financial and reputational damage.

Therefore, facing the new development opportunity of online industrial clusters, SMEs must contemplate not only the associated costs and potential benefits but also consider competitive pressures, trust risks, and data security issues. To mitigate decision-making risks, SMEs often adopt a strategy of imitation and learning from their competitors, aligning their choices with the objective of maximizing their own interests. Although there is a symbiotic and win-win cooperation relationship between the platform and SMEs, concerns over platform dominance and potential harm to online enterprise interests significantly influence SME decisions regarding joining online industrial clusters.

3.2. Basic assumptions and game model construction

Considering that the government's behavioral decisions are committed to promoting and optimizing social value, this study takes SMEs, platforms, and the government as the game players in the construction of SMEs' online industrial cluster. Under the situation of information asymmetry, the players in the game are all bounded rational (Liu & Sun, 2020). In the process of the game, the strategies of the players will influence each other and eventually evolve to dynamic equilibrium.

Assumption 1: The strategic choices of SMEs facing online cluster include {participation, non-participation}, with the probability of participation is denoted as x and the probability of non-participation is $1-x$. The strategic choices of platforms are {legitimate operation, illegitimate operation}, with the probability of choosing legitimate operation is y and the probability of illegitimate operation is $1-y$. Similarly, the government also has two strategic choices of {improvement, non-improvement}, and the probability of choosing to improve the governance system of digital economy is z , and the probability of not improving is $1-z$.

Assumption 2: SMEs participating in online cluster can expand their market channels and gain revenue (Ron), which is greater than the revenue (Roff) gained from traditional offline operations. At the same time, SMEs participating in online cluster need to purchase or subscribe to platform services to pay a certain amount of costs (Con), fierce competition in the online marketplace may generate loss of profits (Lp), and data risks such as privacy leakage may cause losses (Ld) to online enterprises. Traditional offline enterprises tend to have lower operational and transaction efficiency, and need to invest more time, human resources and other costs (Coff), and $Coff > Con$, and compared with enterprises in online cluster, it may be difficult for them to obtain more customer resources due to limited market channels, leading to a decline in competitiveness, and incurring losses (Lc). However, unlike online communication in the virtual space, the offline transaction mode can increase the trust between both parties through physical face-to-face communication, thus gaining customer loyalty and generating sticky earnings (Eoff). In addition, online cluster not only bring new opportunities for SMEs to create value, but also bring economic benefits (G1) to the society.

Assumption 3: Platforms need to invest certain costs (Cp) in the process of operation and can gain revenue (Rp) by providing digital services to SMEs. If platforms choose to comply with laws and regulations, they are able to maintain value co-creative relationships with SMEs and gain user stickiness benefits (Ep). However, under the strong network effect, platforms can exploit market dominance, charging excessive fees for higher profits (Pm), where $Pm > Ep$, resulting in the SMEs profits loss (Lm). As the government refines the digital economy governance system, platform behavior becomes regulated. The government enforces antitrust measures, imposing penalties (Gf) for illegitimate operation, and $Gf > Rm$.

Assumption 4: The new economic growth theory points out the positive intervention role of the government in economic development. When the government improves the digital economy governance system, the cost of governance is (Cg), which can promote the development of digital economy generating societal economic benefits (G2). Conversely, if the government chooses not to improve the digital economy governance system, issues such as platform violations and data leakage could emerge, leading to loss (Lg) of reputation. The loss would be more than the cost of improving the digital economy governance system, where $Lg > Cg$.

Based on the above three-party game relationship and assumptions, this paper constructs an evolutionary game revenue matrix of SME, platform and government stakeholders to promote the development of online industrial cluster of SMEs, as shown in Table 1.

Table 1: Revenue matrix of the three-party game

Strategic choices		Government	
SME	Platform	Improvement (z)	Non-improvement (1-z)
Participation (x)	Legitimate operation (y)	$R_{on} - C_{on} - L_p - L_d$	$R_{on} - C_{on} - L_p - L_d$
		$R_p - C_p + E_p$	$R_p - C_p + E_p$
		$G_1 + G_2 - C_g$	G_1
		$R_{on} - C_{on} - L_p - L_d - L_m$	$R_{on} - C_{on} - L_p - L_d - L_m$

Non-participation (1-x)	Illegitimate operation (1-y)	$R_p + P_m - C_p - G_f$	$R_p + P_m - C_p$
		$G_1 + G_2 - C_g + G_f$	$G_1 - L_g$
	Legitimate operation (y)	$R_{off} - C_{off} - L_c + E_{off}$	$R_{off} - C_{off} - L_c + E_{off}$
		$-C_p$	$-C_p$
	Illegitimate operation (1-y)	$G_2 - C_g$	0
		$R_{off} - C_{off} - L_c + E_{off}$	$R_{off} - C_{off} - L_c + E_{off}$

3.3. Game model analysis

3.3.1. SMEs strategy stability analysis

The expected revenue A_{11} for SME choosing the “participation” strategy and the expected revenue A_{12} for SME choosing the “non-participation” strategy are computed to obtain the average expected revenue A_1 and replicator dynamic equation $F(x)$:

$$\begin{aligned}
 A_{11} &= yz(R_{on} - C_{on} - L_p - L_d) + y(1-z)(R_{on} - C_{on} - L_p - L_d) \\
 &\quad + z(1-y)(R_{on} - C_{on} - L_p - L_d - L_m) + (1-y)(1-z)(R_{on} - C_{on} - L_p - L_d - L_m) \\
 A_{12} &= yz(R_{off} - C_{off} - L_c + E_{off}) + y(1-z)(R_{off} - C_{off} - L_c + E_{off}) \\
 &\quad + z(1-y)(R_{off} - C_{off} - L_c + E_{off}) + (1-y)(1-z)(R_{off} - C_{off} - L_c + E_{off}) \\
 A_1 &= xA_{11} + (1-x)A_{12}
 \end{aligned}$$

$$\begin{aligned}
 F(x) &= \frac{dx}{dt} = x(1-x)(A_{11} - A_{12}) \\
 &= x(1-x)(R_{on} - C_{on} - L_p - L_d - L_m + yL_m - R_{off} + C_{off} + L_c - E_{off})
 \end{aligned}$$

Let $W(y) = R_{on} - C_{on} - L_p - L_d - L_m + yL_m - R_{off} + C_{off} + L_c - E_{off}$, when $y = y^*$, $W(y) = 0$, the stable state cannot be determined at this time. According to the principle of stability of differential equations, the evolutionary stabilization strategy needs to satisfy $F(x) = 0$, and $\frac{dF(x)}{dx} < 0$. Since $\frac{\partial W(y)}{\partial y} > 0$, so $W(y)$ is an increasing function. Therefore, when $y < y^*$, $W(y) < 0$, and $\left. \frac{dF(x)}{dx} \right|_{x=0} < 0$, at this time $x = 0$ for the stable strategy point, SME will choose not to participate in online cluster; Similarly, when $y > y^*$, $W(y) > 0$, and $\left. \frac{dF(x)}{dx} \right|_{x=1} < 0$, at this time $x = 1$ for the stable strategy point, SME will choose to participate in online cluster. In order to explore the influence factors of SME participate in online industrial cluster, the first-order partial derivatives of each variable are obtained separately for y^* , which can be obtained as $\frac{\partial y^*}{\partial R_{on}} < 0$, $\frac{\partial y^*}{\partial C_{on}} > 0$, $\frac{\partial y^*}{\partial L_p} > 0$, $\frac{\partial y^*}{\partial L_d} > 0$, $\frac{\partial y^*}{\partial L_m} > 0$, $\frac{\partial y^*}{\partial R_{off}} > 0$, $\frac{\partial y^*}{\partial C_{off}} < 0$, $\frac{\partial y^*}{\partial L_c} < 0$, $\frac{\partial y^*}{\partial E_{off}} > 0$, therefore, when R_{on} , C_{off} , L_c is larger or C_{on} , L_p , L_d , L_m , R_{off} is smaller, and at this time, the y^* is smaller, $y > y^*$ is easier to meet, the higher the enthusiasm of SME to participate in online industrial cluster, and Inference 1 can be obtained from the above analysis.

Inference 1: The probability of SMEs participating in online cluster increases with the probability of platforms adopting compliant operational strategies. SMEs' motivation to participate in online cluster is

positively related to online revenues, offline operating costs, and potential losses from not participating in online cluster, and negatively related to the costs of participating in online cluster, traditional offline operating revenues, platform profit-seeking behavior, online competition, and data risks.

3.3.2. Platform strategy stability analysis

The expected revenue A_{21} of platform selects "legitimate operation" strategy and the expected revenue A_{22} of the platform choosing the "illegitimate operation" strategy are calculated to obtain the average expected revenue A_2 and replicator dynamic equation $F(y)$:

$$A_{21} = xz(R_p - C_p + E_p) + x(1-z)(R_p - C_p + E_p) \\ + z(1-x)(-C_p) + (1-x)(1-z)(-C_p)$$

$$A_{22} = xz(R_p + P_m - C_p - G_f) + x(1-z)(R_p + P_m - C_p) \\ + z(1-x)(-C_p - G_f) + (1-x)(1-z)(-C_p)$$

$$A_2 = yA_{21} + (1-y)A_{22}$$

$$F(y) = \frac{dy}{dt} = y(1-y)(A_{21} - A_{22}) = y(1-y)(xE_p - xP_m + zG_f)$$

Let $W(x) = xE_p - xP_m + zG_f$, when $x = x^* = \frac{zG_f}{P_m - E_p}$, $W(x) = 0$, at this point the stable state cannot be determined. According to the principle of stability of differential equations, the evolutionary stabilization strategy needs to satisfy $F(y) = 0$, and $\frac{dF(y)}{dy} < 0$. Since $\frac{\partial W(x)}{\partial x} < 0$, at this time $W(x)$ is a decreasing function. Therefore, when $x < x^*$, $W(x) > 0$, and $\left. \frac{dF(y)}{dy} \right|_{y=1} < 0$, at this time $y = 1$ for the stable strategy point, the platform will choose to comply with the laws and regulations; Similarly, $x > x^*$, $W(x) < 0$, and $\left. \frac{dF(y)}{dy} \right|_{y=0} < 0$, at this time $y = 0$ for the stable strategy point, the platform will choose not to comply with the laws and regulations. In order to explore the influencing factors of platform comply with the laws and regulations, the first order partial derivatives of each variable of x^* can be obtained as $\frac{\partial x^*}{\partial G_f} > 0$, $\frac{\partial x^*}{\partial P_m} < 0$, $\frac{\partial x^*}{\partial E_p} > 0$, therefore, when G_f , E_p is larger or P_m is smaller, x^* is larger, $x < x^*$ is easier to meet, and platform are more inclined to choose legitimate operation strategy. Similarly, make $z = z^* = \frac{xP_m - xE_p}{G_f}$, can get similar conclusion, from the above analysis can get Inference 2.

Inference 2: The probability of platforms comply with laws and regulations increases with the increase in the probability of SMEs participate in online cluster or the decrease in the probability of the government improving the governance system of the digital economy. The incentive for platforms to comply with the laws and regulations is positively associated with government penalties and SMEs stickiness gains, and negatively associated with profits gained from abusing market dominance to operate in violations.

3.3.3. Stability analysis of government strategy

The government's expected revenue A_{31} for choosing the "improvement" strategy and the expected revenue A_{32} for choosing the "non-improvement" strategy are computed to obtain the average expected revenue A_3 and the replicator dynamic equation $F(z)$:

$$\begin{aligned} A_{31} &= xy(G_1 + G_2 - C_g) + x(1-y)(G_1 + G_2 - C_g + G_f) \\ &\quad + y(1-x)(G_2 - C_g) + (1-x)(1-y)(G_2 - C_g + G_f) \\ A_{32} &= xyG_1 + x(1-y)(G_1 - L_g) + (1-x)(1-y)(-L_g) \\ A_3 &= zA_{31} + (1-z)A_{32} \end{aligned}$$

$$F(z) = \frac{dz}{dt} = z(1-z)(A_{31} - A_{32}) = y(1-y)(G_2 - C_g + G_f + L_g - yL_g - yG_f)$$

Let $M(y) = G_2 - C_g + G_f + L_g - yL_g - yG_f$, when $y = y^* = \frac{G_2 - C_g + G_f + L_g}{L_g + G_f}$, $M(y) = 0$, the stable state cannot be determined at this time. According to the principle of stability of differential equations, the evolutionary stabilization strategy needs to satisfy $F(z) = 0$, and $\frac{dF(z)}{dz} < 0$. Since $\frac{\partial M(y)}{\partial y} < 0$, at this time $M(y)$ is a decreasing function. Therefore, when $y < y^*$, $M(y) > 0$, and $\left. \frac{dF(z)}{dz} \right|_{z=1} < 0$, at this time $z = 1$ for the stability strategy point, the government will choose to improve the digital economy governance system; Similarly, when $y > y^*$, $M(y) < 0$, and $\left. \frac{dF(z)}{dz} \right|_{z=0} < 0$, at this time $z = 0$ for the stability strategy point, the government will not to improve the digital economy system. In order to explore the influence factors of the government to improve the digital economic governance system, the first order partial derivatives of each variable of y^* , respectively, can be obtained $\frac{\partial y^*}{\partial G_2} > 0$, $\frac{\partial y^*}{\partial C_g} < 0$, $\frac{\partial y^*}{\partial G_f} > 0$, $\frac{\partial y^*}{\partial L_g} > 0$, so when G_2 , L_g , G_f the larger or C_g the smaller, at this time y^* is larger, $y < y^*$ is easier to meet, the more the government tends to improve the digital economic governance system, by the above analysis can be derived from Inference 3.

Inference 3: The probability of the government improving the digital economy governance system increases with the probability of platforms non-compliant operation. The government's motivation to improve the digital economy governance system is positively related to the economic benefits brought by SMEs' online cluster, the government's reputational loss, and the penalties for platforms' non-compliant operations, and negatively related to the governance costs.

3.4. Strategic stability analysis of equilibrium point of three-party evolutionary game system

Since mixed strategies in asymmetric information games must not be evolutionarily stable strategies (Weinstein, 1986), therefore only the evolutionary stability of pure strategies is discussed. Let $F(x)=0$, $F(y)=0$, $F(z)=0$, we can get 8 pure strategies of "SME", "platform" and "government" in the game process. Equilibrium points E1 (0,0,0), E2 (0,0,1), E3 (0,1,0), E4 (0,1,1), E5 (1,0,0), E6 (1,0,1), E7 (1,1,0), E8

(1,1,1). The Jacobi matrices are obtained by taking the partial derivatives of x , y and z in formulas $F(x)$, $F(y)$ and $F(z)$, respectively:

$$J = \begin{bmatrix} \partial F(x) / \partial x & \partial F(x) / \partial y & \partial F(x) / \partial z \\ \partial F(y) / \partial x & \partial F(y) / \partial y & \partial F(y) / \partial z \\ \partial F(z) / \partial x & \partial F(z) / \partial y & \partial F(z) / \partial z \end{bmatrix}$$

The online industrial cluster model SMEs requires multi-party participation to form a joint force. Therefore, this paper focuses on the analysis of the stable point of $E8(1,1,1)$, which is the ideal stable state in which SME, platform and the government are actively promoting the development of SME online industrial cluster. According to Lyapunov criterion (Lyapunov, 1992), when all the eigenvalues of Jacobi matrix are less than 0, the equilibrium point is the evolutionary stability point of the system. The eigenvalues of $E8(1,1,1)$ stable point are calculated as follows:

$$J = \begin{bmatrix} R_{off} - R_{on} + C_{on} + L_p + L_d - C_{off} - L_c + E_{off} & & \\ & P_m - E_p - G_f & \\ & & C_g - G_2 \end{bmatrix}$$

The conditions under which $E8(1,1,1)$ is a stable equilibrium are $R_{off} - R_{on} + C_{on} + L_p + L_d - C_{off} - L_c + E_{off} < 0$, $P_m - E_p - G_f < 0$, $C_g - G_2 < 0$, which inference 4 can be drawn.

Inference 4: When $R_{off} - C_{off} - L_c + E_{off} < R_{on} - C_{on} - L_p - L_d$, $P_m - E_p < G_f$, $C_g < G_2$, the three-party evolutionary game is in an ideal stable state.

Inference 4 shows that under certain conditions, SMEs, platforms and the government can collaboratively achieve a system equilibrium strategy. Among them, the strategic choice of SMEs will not only be directly affected by the costs and benefits of different operating modes, but also be closely related to the loss of competitiveness caused by traditional operation, the intensification of online competition and data risks. If the platforms comply with the laws and regulations yield low sticky revenue, the motivation of platforms violations will be increased, and the government's punishment mechanism will play a crucial role in regulating platforms behavior. However, the cost of digital economic governance and its associated social benefits are critical factors for the government to improve the digital economic governance system. Consequently, the government should prioritize the long-term value of the digital economy to socio-economic development and address potential challenges. On the one hand, the government should guide the platform to create a common value with the enterprises through policies. On one hand, the government should encourage platforms to co-create value with enterprises through policy initiatives. On the other hand, continuous improvements to the digital economic governance system are essential, including strengthening supervision of platforms' behaviors, enhancing data security, and fostering an optimal environment for the development of SMEs industrial online cluster.

4. EVOLUTIONARY GAMES OF SMES IN COMPLEX NETWORK

This paper regards the relationship between SMEs as a complex network. Utilizing the dynamic evolution mechanism of evolutionary game theory, the analysis focuses on how online industrial cluster decision-making among SMEs is influenced by the interplay of various factors such as government digital economic governance system, platform violations, data security risks, competition, and trust risks.

4.1. Research assumptions

Facing the online cluster business model, each SME has two pure strategies: {participation, non-participation}. It should be noted that when SMEs choose to participate in online industry clusters, they can still participate in some offline market activities; on the contrary, firms that choose not to participate in online industry clusters direct their entire focus towards offline markets. The government is able to regulate the behavior of platforms and reduce data security risks in digital economy governance, and G denotes the level of governance policy refinement, $G \in [0, 1]$. A higher value of G indicates a more refined governance system. The platform as a stakeholder in the online industry cluster, its violation will affect the willingness of SMEs to engage with the online industry cluster. The propensity of the platform to exploit market dominance for profit is denoted by M , $M \in [0, 1]$, the larger the value, signifying that a larger value suggests an increased possibility of platform violations. Within this network, there exist n SMEs, within the initial proportion of SMEs choosing to participate in the online industrial cluster strategy is λ . During the game, all SMEs are boundedly rational subjects that update their strategies by comparing revenue with neighboring enterprises. To more accurately elucidate the interests of SMEs in the decision-making process, the following hypotheses are proposed:

Assumption 1: SMEs need to pay a certain cost to participate in online industrial clusters, but they can increase efficiency and reduce costs and obtain more business opportunities.

In online industrial clusters, there is a value co-creation relationship between the platform and SMEs. On the one hand, platform support its development by providing technical support and personalized services to SMEs such as brand promotion, data analysis, inventory management, and other tools while charging a certain amount of service fees or transaction commissions. On the other hand, with the help of these digital tools, SMEs can not only optimize their business processes and achieve efficiency improvement and cost reduction, but also quickly link the supply chain, match client demand and obtain more orders. Therefore, assuming that SMEs choose to participate in the online industrial cluster strategy, they need to pay a cost (l) to purchase or subscribe to the platform services, which can improve their transaction efficiency (θ), $\theta > 1$. At this time, the transaction cost is $B_{on} = \delta B_{off} + B_{off} / \theta$, where δ is the percentage of offline business, the percentage of δB_{off} and B_{off} / θ are respectively their offline and online transaction costs. At the same time, the online industry cluster expands the market scale, with the help of the platform information matching service SMEs can obtain more business opportunities, and the revenue increases from R to SR , where $S > 1$, indicating the platform's ability to match business opportunities, and R indicates the revenue of SMEs that did not participate in the online industry cluster before.

Assumption 2: Risks such as platform violations, increased competition, lack of trust and data privacy disclosure in online industrial clusters may cause damage to the interests of online SMEs.

Firstly, the emergence of the platform service model enables more SMEs to enjoy the digital welfare and promotes the online agglomeration of SMEs. However, as the number of SMEs in the platform increases and the network externalities become more prominent, the platform may exploit the stickiness of enterprises to impose unreasonable “rents”, which is detrimental to their interests. Secondly, on the one hand, SMEs in industrial clusters often face similar product positioning and target clients, which exacerbates competition among them, potentially leading to a “price war” dilemma. On the other hand, it is difficult to verify the credibility and reliability of the other party through face-to-face interaction in online transactions, complicating the trust relationship between enterprises. According to social capital theory (Coleman, 1992), trust is an important form of social capital and the basis of interaction between organizations. In market activities, trust between subjects depends on the assessment of interests and risks. Therefore, trust between enterprises can be regarded as “expected cooperation”. Furthermore, platforms require access to enterprise data to provide personalized services, which may involve sensitive information about the enterprises. In the event of data leakage or other risks, this could result in significant losses for online SMEs.

Therefore, (1) Assuming that the probability (M) of platform violation is directly related to the number of SMEs z in the platform, but negatively correlated with the strength (G) of government regulation and governance, violations cause SMEs to lose MF , where $M = z(1 - G)$, denotes the tendency of platform violations, and F denotes the unreasonable “rent” charged by the platform. (2) Assuming that SMEs in online clusters may loss CP due to competition, where $C = zD$, denotes the degree of competition, P is the maximum damaged profit of SMEs, and the degree of competition is affected by proportion (z) of cluster SMEs and product similarity (D). (3) Assuming that the trust risk T in online transactions affects the cooperation expectations of SMEs, referring to the concepts of institutional trust and relational trust in the study of Jin et al. (2023), constructing the trust risk function $T = 1 / (1 + e^{-(1+a)(i+r)})$, where $i \in [0, 1]$, denotes the level of institutional trust among SMEs in online transactions, including the rules of platform transactions, trust evaluation and dispute resolution mechanism, etc.; $r \in [0, 1]$, denotes the level of relational trust among SMEs in the cluster, for example, assessing the credibility and reliability of the other party by looking at the other party’s transaction records and evaluations; and $a \in [0, 1]$, denotes the coordinating service capacity of the industry association. The industry association can play the role of coordinating the relationship between SMEs and solving the symbiotic problems in the online activities of SMEs, so as to promote the communication and cooperation between SMEs. (4) In addition, it is assumed that the data security risk in the platform will bring loss GL to SMEs, where L denotes the maximum loss that enterprises may incur, and G denotes the level of refinement of the digital economy governance system, and the more refinement the system is, the lower the possibility of events such as data leakage and misuse occurring in platform.

Assumption 3: The offline traditional SMEs have higher transaction costs, but can obtain certain sticky revenues.

According to the resource-based view (Wernerfelt, 1995), traditional SMEs may face insufficient resources in competing with SMEs in online clusters, which leads to decreased competitiveness. Moreover, compared with efficient online platform transactions, offline transactions are more difficult to match supply and demand of both parties due to fragmented market. Moreover, the transaction process is complicated and the information transmission efficiency is low. The offline SMEs often need to invest more manpower and time to complete transactions, resulting in higher transaction costs. However, in online industrial clusters, clients can easily transfer from one enterprise to another with low transfer costs, which may lead to a decrease in client loyalty of online enterprise. On the contrary, offline direct entity communication and service can help enterprises to establish closer trust relationship with clients, thus enhancing client satisfaction and loyalty (Cropanzano & Mitchell, 2005). According to the theory of customer relationship management (Chen & Popovich, 2003), the enterprise can establish long-term close customer relationship to obtain continuous revenue. Therefore, suppose that when the neighbors of offline SMEs are in the online industrial cluster, it will lose Q due to the decline in competitiveness, and its transaction cost is B_{off} , but it can obtain sticky income (E) through higher client loyalty.

4.2. Model construction

4.2.1. Game model

SMEs' decisions are affected by their neighbors' strategies, according to assumptions 1-3, take SME i as an example and construct the game payoff matrix among SMEs, as shown in Table 2.

When SME i chooses to participate in the online industry cluster and neighbor j chooses the traditional offline business strategy, SME i 's revenue is directly related to the platform's business opportunity matching ability, online transaction efficiency, and the platform's service fee, while trust risk, competition risk, and data security risk indirectly affect the online SMEs' revenue, and thus SME i 's final revenue is $STR - I - B_{on} - MF - GL - CP$. Neighbor j 's revenue is related to transaction costs, stickiness gains, and losses Q due to declining competitiveness, and its final revenue is $R - B_{off} + E - Q$. When both SME i and neighbor j choose to participate in the online cluster, both gains are $STR - I - B_{on} - MF - GL - CP$ and vice versa, both gains are $R - B_{off} + E$.

Table 2: The game profit matrix of SMEs

SME i	Neighbor SME j	
	Online	Offline
Online	$STR - I - B_{on} - MF - GL - CP$	$STR - I - B_{on} - MF - GL - CP$
	$STR - I - B_{on} - MF - GL - CP$	$R - B_{off} + E - Q$
Offline	$R - B_{off} + E - Q$	$R - B_{off} + E$
	$STR - I - B_{on} - MF - GL - CP$	$R - B_{off} + E$

4.2.2. Network structure

Complex systems theory posits that market agents are interconnected and engage in both competitive and cooperative interactions, forming a symbiotic relationship (Arthur, 2021). This intricate interplay is

characterized by the small-world phenomenon within networks (Zhong & Nof, 2015). Therefore, this paper takes the NW small-world network as a framework, wherein SMEs are conceptualized as nodes. The competitive dynamics between firms are represented by edges, thus constructing a complex network model to investigate the diffusion of online industrial cluster decision-making of SMEs within a game-theoretic context. Specifically, the NW small-world network model facilitates the creation of a nearest-neighbor coupling network comprising n nodes, which is established by randomly introducing edges with a probability of p . Each SME is distinct from itself, and there exists a singular undirected connecting edge between any two SMEs at most. The variable d signifies the count of connecting edges (neighbors) each SME possesses within the network, while x represents the fraction of all its neighbors that partake in the online industrial clustering strategy.

Therefore, the expected revenue of SME i adopting the online industrial cluster strategy is:

$$U_i^{on} = (x \quad 1-x) \times \begin{pmatrix} STR - I - B_{on} - MF - GL - CP \\ STR - I - B_{on} - MF - GL - CP \end{pmatrix}$$

The expected revenue of SME i adopting a traditional offline business strategy is:

$$U_i^{off} = (x \quad 1-x) \times \begin{pmatrix} R - B_{off} + E - Q \\ R - B_{off} + E \end{pmatrix}$$

4.2.3. Strategy update rule

Under the theoretical framework of complex network evolutionary game, each SME is finite rational, and will seek the optimal strategy through continuous learning and adjustment in the process of competitive game. In this paper, it is assumed that each SME adopts the Fermi rule when updating its strategy (Traulsen et al., 2006). In this paper, we assume that each SME adopts the Fermi rule when updating its strategy, that in each game in the network, SME i randomly selects a neighbor j for revenue comparison, and if the neighbor's revenue is higher than its own, it will update and adjust its own strategy in the next round of the game with a certain probability. The probability of Fermi strategy update is:

$$W_{S_i \rightarrow S_j} = \frac{1}{1 + e^{\frac{-(U_i - U_j)}{k}}}$$

Where U_i denotes the benefit of SME i adopting strategy S_i , and U_j denotes the benefit of neighbor j adopting strategy S_j . Since the SMEs are all limited rational subjects, the uncontrollable factors in the environment may interfere with their irrational decision-making, and the degree of this irrationality is measured by the noise intensity k . When the value of k tends to infinity, the decision-making subject will be difficult to make a rational choice of strategy, and will randomly update its own strategy in the next round. After a finite number of games, the degree of diffusion of online industrial cluster decision-making in the network will evolve to a stable level.

5. NUMERICAL SIMULATION ANALYSIS ON EVOLUTIONARY GAME OF SMES IN COMPLEX NETWORK

5.1. Case study and parameters setting

In order to make the model simulation results closer to the actual situation, parameter settings are made by referring to real cases, so as to improve the interpretability and reliability of the model simulation results. In this paper, the electronic components industry in China is selected to be analyzed (Tencent Research Institute, 2023). In Shenzhen, China, tens of thousands of small and medium-sized electronic component enterprises constitute a huge electronic component industry cluster. For a long time, business transactions between enterprises have relied on information and resource sharing generated by face-to-face communication. While this has improved the value creation ability of enterprises in the cluster, geographic proximity does not solve all problems. In the context of electronic component transactions, the vast array of product types and quantities makes it difficult for enterprises to capture comprehensive market transaction data through solely face-to-face communication. This limitation leads to information asymmetry between supply and demand, low transaction efficiency, and often, the transaction can only rely on the relationship between the buyer-seller network relationships and chance. Tengcai Technology, recognizing the potential of digital tools to transcend geospatial limitations, collaborated with Tencent to develop Tengcaitong, a B2B transactional platform tailored for the electronics industry. This platform aims to enhance operational efficiency by attracting traffic. Tengcaitong has served more than 20,000 sellers, covering more than 320,000 buyers, basically SMEs. Tengcaitong is dedicated to offering user-friendly and efficient services. By applying natural language processing and deep learning capabilities to B2B trading scenarios for the first time, it can help sellers automatically subscribe to business opportunities 24 hours a day, quickly and accurately match inventories, automatically provide quotes, automatically record customer labels, and accurately acquire customers through multi-channel marketing, and increase the exposure rate by up to 10 times; and buyers can realize direct and independent orders through Tengcaitong, and the service robot automatically retains the quote history and transaction records. In this online industry cluster model, the industry chain's transaction efficiency and upstream and downstream supply and demand matching efficiency can be increased by more than 10 times, reducing what used to take days or weeks to mere minutes and significantly boosting transactional efficiency in the electronics sector.

The Shenzhen electronics industry boasts 60,000 existing business enterprises. In 2022 and 2023, the overall gross profit rates for the electronics industry were 18.9% and 15.7%, respectively. Upon reviewing the annual report of Huaqiang electronics enterprises for 2023, it is evident that its physical electronic components authorized distribution division had a gross profit rate of 6.61%, while the electronic components industry Internet division reported a gross profit rate of 21.01%. Moreover, the service tools available in Tengcaitong command an annual fee ranging from 7,000 to 15,000 RMB, contingent upon the functionality offered. With respect to data leakage risks, IBM highlighted in their report "The Cost of Data Leakage" that the global average cost of a data breach amounted to \$4.45 million in 2023, marking a 15% increase over three years.

Based on the above actual situation and relevant policy reports, the initial parameters in the model assumptions are set as shown in Table 3. Referring to the existing literature (Tan et al., 2022), the

parameters in the complex network are assigned values: $d = 4$, $p = 0.1$, and the environmental noise k in the policy update is set to 0.1.

Table 3:Parameters setting

parameter	R	B_{off}	B_{on}	I	Q	G	L	T	S	C	P
evaluation	10	8.5	6.8	1.3	0.3	0.06	10	0.93	1.5	0.23	1.5
parameter	D	M	F	E	n	a	i	r	δ	θ	λ
evaluation	0.7	0.066	1.5	2	6000	0.7	0.8	0.7	0.7	10	0.33

* $R, B_{off}, B_{on}, I, Q, L, P, F, E$ are on the order of 10,000

In order to better analyze the evolutionary game process among SMEs, numerical simulation is carried out using MATLAB to explore the influence of different parameter variations on the diffusion of decision-making of online industrial cluster in the network. Considering that the environmental noise may cause the game player to make irrational choices, leading to the randomness and chance of the game results, 20 repetitions of independent experiments are carried out for each round of the game and the results are averaged, so as to make the simulation results more accurate and reliable.

5.2. Simulation analysis

(1) Impact of platform opportunity matching capability on strategy evolution

Online industrial clusters transcend geographical barriers, offering SMEs access to a wider market and enabling the diversification of sales channels. This allows them to engage with a larger pool of potential customers, thus improving their revenue. To examine the influence of business opportunities generated by online industrial cluster on SMEs decision-making, with S taking values of 1.3, 1.4, 1.5, 1.6 and 1.7 respectively, and keeping other parameters constant. The evolution results are shown in Figure 2. Initially, at $S=1.5$, the percentage of SMEs within the network opting for online industrial cluster steadily increases, stabilizing at approximately 75% diffusion rate. As S increases, the proportion of enterprises within the network adopting online industrial cluster surges, ultimately achieving 100% diffusion. Conversely, as S decreases, the number of SMEs participating in online industrial cluster diminishes rapidly, resulting in the failure of this decision's diffusion within the network.

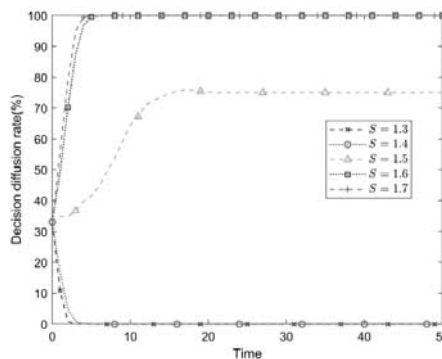


Figure 2. The effect of platform business opportunity matching capability S on the decision diffusion

This result reflects that the matching ability of platform business opportunities will directly affect the success of online industrial cluster decision diffusion of SMEs. In a competitive market, such opportunities represent potential demand and profitability, which are crucial for enterprises to gain market share and improve their revenue and profits. SMEs might perceive high risks associated with participating in online cluster, considering that the potential returns may not offset their costs. This perception could lead them to abstain from joining or remain uninvolved in online clusters, resulting in the failure of decision diffusion. Conversely, larger business opportunities typically signify more market prospects and profit margins, prompting enterprises to continuously refine their strategies in pursuit of maximized profits. As some SMEs within the network benefit from engaging in online clusters, traditional SMEs might experience intensified competitive pressures, thereby becoming more proactive in joining online clusters to secure a competitive edge. This engagement fosters a virtuous cycle through imitation and learning among networked enterprises, enhancing the successful propagation of SMEs' online industrial clustering decisions.

(2) Impact of online transaction efficiency on strategy evolution

Online industrial clusters are characterized by a high degree of informatization and networking. In this virtual agglomeration space, SMEs can rely on platform services to achieve rapid transmission and sharing of information, improve operational efficiency and reduce transaction costs. Fixing other parameter values unchanged, and θ takes the values 8, 9, 10, 11 and 12 respectively, analyzing the impact of changes in online transaction efficiency on the decision-making of SMEs. The evolution results are shown in Figure 3. When $\theta > 10$, the diffusion rate of online industry cluster decision-making in the network is 100%, and the larger θ is, the faster the diffusion rate is; while when $\theta < 10$, the diffusion of online industry cluster decision-making cannot be realized in the network.

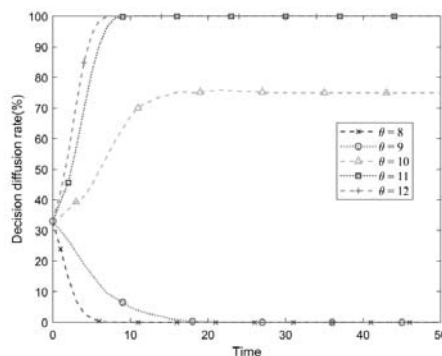


Figure 3. The effect of online transaction efficiency θ on the decision diffusion

From the evolution results, it can be seen that the transaction efficiency in online industry cluster affects the cluster willingness of SMEs. With the efficient information search and matching service of the platform in online industrial clusters, SMEs can quickly find customers in demand and reduce the time and cost of searching for trading objects. Moreover, online industrial clusters simplify the traditional offline trading process, and the information between supply and demand is more transparent, which

helps enterprises to reduce the transaction costs due to asymmetric information. Therefore, higher online transaction efficiency can help SMEs better realize cost reduction and revenue increase, and promote the proliferation of SMEs in the network of online industrial clustering decisions. However, when the online transaction efficiency is low, although SMEs can still reduce transaction costs and obtain revenues sufficient to offset the cost of using the platform services, SMEs may choose not to participate in online cluster out of risk aversion, considering the risks of competition, trust and data security in online cluster, which ultimately leads to the failure of decision diffusion by influencing other firms through the network effect.

(3) Impact of competitive risks in online industrial cluster on strategy evolution

Although online industrial clusters can expand the market scale and bring more business opportunities for SMEs, the platform service model's attributes of affordability, convenience, and user-friendliness notably lower the barrier to enter the online marketplace. Consequently, SMEs find it simpler to engage in online market endeavors and vie for market share. Moreover, products in the SMEs industry are often homogeneous, compounded by the rising quantity of online industrial clusters among SMEs, may intensify the competitive strain associated with product homogenization among enterprises. To secure a competitive edge, SMEs might resort to price reductions to lure customers, thereby instigating a price war. Such actions could diminish not only the SMEs' profit margins but also imperil the sustainable growth of the entire industry chain. In this context, to assess the influence of competitive risk in online clusters on the propagation of SMEs' decisions to cluster online within networks, an analysis is conducted on the proportion of SMEs joining online clusters and the extent of product homogenization.

1) Proportion of SMEs in online cluster

In order to investigate the influence of the proportion of SMEs participating in online industrial cluster on the diffusion of decisions in the network, so that λ takes the values of 0.1, 0.2, 0.33, 0.4, and 0.5, respectively, and the other parameters take the same value, and the evolution results are shown in Figure 4. It can be found that when $\lambda < 0.33$, 100% diffusion of cluster decisions can be realized in the network, while when $\lambda > 0.33$, effective diffusion cannot be realized, and the speed of evolution to 0 is accelerated as λ increases.

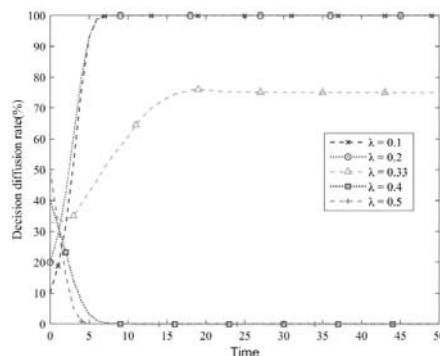


Figure 4. Impact of the proportion of SMEs in online cluster λ on the diffusion of decision

This reflects that the stability of SMEs' online industrial cluster is affected by the number of SMEs in the cluster when competitive risk is considered. This finding is basically consistent with Li et al.'s (2013) argument that an excessive number of firms producing products with a high degree of homogenization tends to exacerbate intra-cluster competition and affects the development of cluster innovation. Additionally, it partially corroborates the findings of Chen & Zhang (2013) regarding the diseconomies of scale in retail enterprises. Online platforms can expand market channels for merchants and increase product exposure, but they also bring the problem of price and information transparency. Customers can conveniently compare the prices of different merchants' products on the platform and then make transactions, which makes it difficult for merchants to obtain a stable customer flow, and with the increase in the number of merchants, customers have more choices. In order to get more orders, merchants may engage in a price war with each other at any cost and profit, and fall into a "prisoner's dilemma". In addition, the probability of platform violations is to a certain extent proportional to the number of SMEs in the online cluster, which may also jeopardize the interests of online SMEs. Therefore, when the proportion of SMEs in online clusters is high, traditional SMEs in the network will have a negative attitude towards online clusters in the face of high competitive risks, and the competition between online enterprises will destroy the stability of the cluster system, and eventually the online cluster decision-making diffusion fails.

2) Homogeneity of products

In order to investigate the impact of product homogenization of SME industries on decision diffusion in the network, so that D takes the values of 0.5, 0.6, 0.7, 0.8 and 0.9 respectively, and other parameters take the same value, the evolution results are shown in Figure 5. It can be found that when $D < 0.7$, the diffusion rate in the network will gradually increase to 100% diffusion, while when $D > 0.7$, the diffusion rate of this decision will decrease with the increase of D .

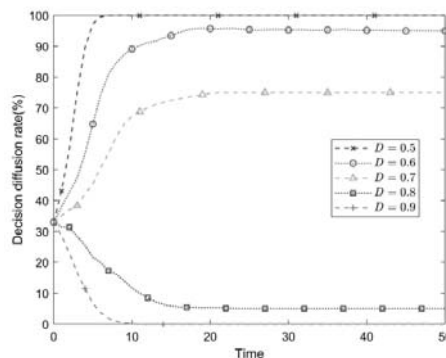


Figure 5. The effect of product homogenization degree D on the decision diffusion

This reflects that product homogenization affects the decision-making of online industrial clusters of SMEs. SMEs tend to have weak R&D and innovation capabilities and generally face financing constraints, making it difficult to convert innovations into competitive and differentiated products (Brancati, 2015). SMEs are often weak in R&D and innovation and generally face financing constraints.

When there is a lack of product differentiation in the market, customers may pay more attention to price when making purchasing decisions, which may lead to lower prices in order to attract customers, thus triggering a “price war” and affecting the profitability of the whole industry. Therefore, when the degree of product homogenization is high, the competition in online clusters will be more intense due to the transparency of information, thus compressing the profits of SMEs, and even incurring losses in order to clear the inventory of products, which will not only discourage traditional SMEs to participate in online clusters, but also affect the stability of the existing online cluster system, leading to the failure of decision-making diffusion in the network. When the degree of product homogenization is low, the competitive pressure in the online market is relatively small, and SMEs participating in online industrial clusters can obtain more market opportunities, therefore, successful diffusion of cluster decisions in the network can be achieved.

In addition, comparing Figure 4 with Figure 5, it becomes evident that the proportion of SMEs in online industrial cluster has a greater impact on the successful diffusion of decisions than the degree of product homogeneity. This could be attributed to the fact that when there are fewer enterprises in a cluster, despite similar product functions, enterprises can still attract customers through their unique brands and marketing strategies, thereby enhancing competitiveness. However, as the number of enterprises increases, not only does the competitive pressure due to product homogenization heighten, but the increase in customer choices also leads to instability in the flow of business, which in turn damages the profits of the enterprises. This affects the decision-making process of the enterprise. Moreover, an increase in network nodes can accelerate the dissemination of information, leading to a faster failure in the diffusion of cluster decision-making within the network. On the other hand, as SMEs’ participation in online cluster increases, the tendency for platform profiteering also rises. Under the dual risk of ‘platform profiteering + enterprise competition’, SMEs are likely to opt out of entering online clusters at a quicker rate.

(4) Impact of trust risk in online industrial cluster on strategy evolution

Compared to traditional offline business models, trust relationships in online clusters are more intricate. Under the online industrial cluster model, it is difficult for SMEs to verify each other’s credibility and reliability through traditional face-to-face interactions, and they can often only make judgments based on information on the platform. This leads to possible trust risks such as fraud and violations with contracts in the process of online trading and cooperation among SMEs. To establish trust relationships in online industry clusters, relational trust among SMEs is the foundation, while trust evaluation and secure transaction mechanisms in the platform are the key for SMEs to gain institutional trust. In addition, industry associations serve as an important force to promote the development of the industry. On the one hand, industry associations can promote communication and interaction among SMEs, thus deepening mutual understanding and trust; on the other hand, industry associations can play a coordinating role to establish and maintain trust relationships within the industry. Therefore, in order to analyze the impact of trust risk on SMEs’ decision-making in online industry clusters, relational trust, institutional trust, and the ability of industry associations to reconcile relationships are explored.

1) Level of relational and institutional trust

In order to explore the influence of relationship trust and institutional trust between SMEs on the decision-making diffusion of online industrial cluster in the network, so that i takes the values of 0.7, 0.75, 0.8, 0.85 and 0.9, r takes the values of 0.6, 0.65, 0.7, 0.75 and 0.8, while keeping other parameters constant. The results are shown in Figure 6. It can be found that when $i > 0.8$ and $r > 0.7$, 100% diffusion of cluster decisions can be achieved in the network. Conversely, as i and r decrease, the diffusion rate plummets to 0. This shows that whether SMEs participate in online industrial cluster will be affected by the level of relationship trust and institutional trust in the cluster.

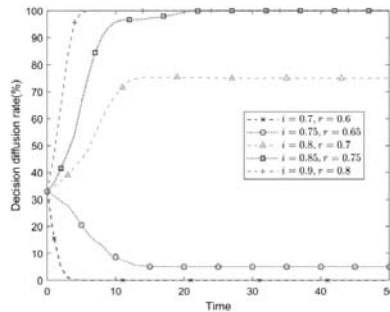


Figure 6. The effect of relational trust r and institutional trust i on the decision diffusion

A robust trust framework facilitates the establishment of stable cooperative relationships among enterprises within online industry cluster, mitigates potential risks stemming from information asymmetry and opportunistic behaviors, and reduces transaction costs. Moreover, an elevated trust environment fosters a positive cluster culture, promoting the development of shared values and behavioral norms among SMEs, thereby enhancing the allure of the cluster and encouraging more SMEs within the network to join the online industrial cluster. Conversely, when trust levels within the cluster are diminished, issues of trust can precipitate disputes over interests among SMEs, undermining the stability of online cluster and inhibiting decision diffusion throughout the network.

2) Organizational and coordinating capacity of industry associations

In order to explore the influence of the coordination relationship ability of industry associations on the diffusion of cluster decision-making in the network, so that a takes the values of 0.5, 0.6, 0.7, 0.8 and 0.9, respectively, and the other parameters take the same value, and the evolution results are shown in Figure 7. It can be found that when $a > 0.7$, the diffusion rate of online industry cluster decisions in the network will gradually increase; while when $a < 0.7$, the decision diffusion rate will rapidly decline and eventually fail to diffuse. This shows that industry associations play an important role in the process of SME online industrial clustering and promote the development of SME online industrial clusters.

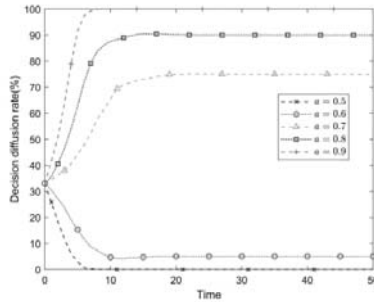


Figure 7. Impact of industry association organizational and coordination capacity a on the decision diffusion

This finding supports Czakonm & Czernek (2016)'s argument that the establishment of trust mechanisms within industrial clusters requires the role of third-party organizations to promote the process. Industry associations are able to provide a common framework for firms within the cluster to follow by setting industry standards and norms. This helps reduce information asymmetry among SMEs and reduces the risk of cooperation, thus enhancing trust among enterprises. And when frictions and disputes occur between enterprises, the industry association can play a coordinating role to maintain the relationship between enterprises and promote the sustainable development of the industry. Therefore, when the industry association has a stronger ability to coordinate the relationship, it can more effectively promote the cooperation and communication between SMEs, promote the construction of good trust relationship within the cluster, reduce the trust risk, and thus attract more SMEs to join the online industry cluster. On the contrary, when the industry association has a lower ability to down-regulate relationships, SMEs may avoid the higher trust risk environment and choose traditional business methods, leading to a lower diffusion rate of online industrial cluster decisions in the network.

(5) Impact of government digital economic governance on strategy evolution

The platform provides an activity space for online industrial clusters of SMEs. The safety of the platform's operation is crucial to both the interests of SMEs and the development of cluster ecology. The government's digital economic governance policy plays a pivotal role in standardizing platform behavior and enhancing data security, thereby safeguarding the rights and interests of SMEs in online clusters and fostering favorable environmental conditions for it. To examine the impact of the government's digital economic governance system on online industrial clusters of SMEs, so that G takes the values of 0.7, 0.75, 0.8, 0.85 and 0.9, and the corresponding M takes the values of 0.099, 0.0825, 0.066, 0.0495 and 0.033, respectively. The results are depicted in Figure 8. When $G > 0.85$, decision-making within online industrial clusters can achieve rapid and successful dissemination; conversely, the decision cannot spread.

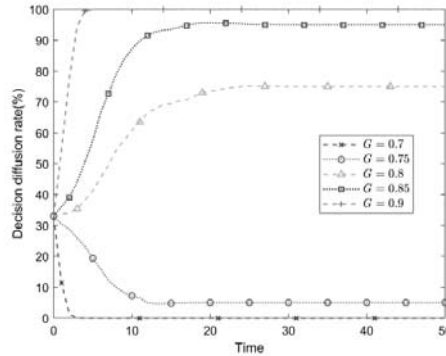


Figure 8. Impact of governmental digital economy governance system G on the decision diffusion

This suggests that platform violations and data security risks adversely affect online industrial cluster of SMEs, and the government can mitigate this negative impact by improving digital economic governance. On one hand, as a stakeholder in the online industrial cluster ecology, the platform may seek higher profits through violations such as “rent”, potentially harming the interests of SMEs. On the other hand, a vast amount of SME data is accumulated on the platform, which may include sensitive and private enterprise information. Data leakage or tampering could result in significant losses for the enterprise and even destabilize the entire online industrial cluster. Therefore, when the government’s digital economic governance system is well-developed, the platform’s behavior will be subject to government oversight and legal constraints, thereby regularizing its own conduct. Moreover, digital economic governance has bolstered data protection on the platform, which helps reduce data leakage and security risks, further encouraging SMEs to participate in online industrial clusters. However, if the government’s digital economic governance system fails to guarantee data security and regulate platform behavior effectively, it may pose substantial risks to online enterprises, undermine the stability of SME online industrial cluster, and foster negative attitudes towards online cluster among SMEs.

6.RESULTS

In the era of digital economy, online industrial clusters of SMEs is an important measure to improve the competitiveness of SMEs and promote the development of “digital-real integration”. Based on the evolutionary game theory, this paper constructs an evolutionary game model of whether SMEs participate in online industrial clusters. Combining with the complex network, it explores the influence of online transaction efficiency and platform business opportunity matching ability, competition risk, trust risk, platform violations behavior and other factors on the decision-making diffusion of online industrial clusters of SMEs. It also analyzes the diffusion effect and micro-mechanism of the decision-making in the network under the change of different factors through numerical simulation. The results show that: (1) The platform’s business opportunity matching capability and online transaction efficiency are directly related to the benefits and costs of SMEs, thus affecting SMEs’ motivation to participate in online industrial clusters. When the platform’s business opportunity matching capacity is large and online

transaction efficiency is high, it can promote more SMEs to participate in online industrial clusters. At the same time, platform violations and data security risks will have a negative impact on SMEs' online clusters, while the government can resolve the risks and promote SMEs' participation in online clusters by improving the governance system of the digital economy.

(2) Competitive risk in online industry clusters is an important factor affecting the willingness of SMEs in online industry clusters, and when the risk in online industry clusters is high, the decision of online industry clusters in the network can not be diffused. And the number of SMEs and the degree of product homogenization both affect the degree of competition in online industrial clusters, and the number of enterprises has a greater impact than product homogenization, when the number of SMEs in online industrial clusters is higher or the level of product homogenization is higher, SMEs will choose the traditional business strategy to avoid the higher competitive risks.

(3) Trust risk in online clusters can negatively affect SMEs' online clusters. SMEs will actively participate in online industrial clusters when the trust risk in the cluster is low. With regard to internal cluster factors, relational trust and institutional trust among SMEs are key, and SMEs will actively participate in online clusters when the level of these two types of trust is high. In terms of external cluster factors, a high level of coordination and promotion by industry associations can effectively improve the trust relationship in online clusters and promote the development of online clusters for SMEs.

Based on the above analysis, the countermeasures and suggestions of this paper are as follows:

(1) Improve the governance system of the digital economy and enhance the service capacity of platforms. The government should, on the one hand, continuously improve the platform economic regulatory mechanism to prevent platforms from abusing their dominant market position and other non-compliant behaviors that harm the rights and interests of SMEs; on the other hand, it should improve the level of data security governance, safeguard the data security of both platforms and SMEs, and create a safe and stable environment for SMEs' online clusters, so as to promote the development of SMEs' online clusters. At the same time, the platform also needs to improve data analysis and algorithmic capabilities, continuously optimize information matching services and digital tools to enhance the efficiency of SMEs' online transactions. The platform needs to focus on user feedback in the service process, optimize platform functions and services, improve user experience and loyalty, and better achieve value co-creation with SMEs.

(2) Strengthening the regulation of competition in online markets and promoting the innovative development of small and medium-sized enterprises. Establish a "government-platform-enterprise" collaborative supervision mechanism, the government and the platform to establish and improve the online market access standards and competition supervision system, strictly supervise the price manipulation behavior of enterprises, and set up a reporting incentive mechanism to encourage small and medium-sized enterprises to report on unfair competition, and jointly create a good competitive environment for small and medium-sized enterprises in online industrial clusters. The competition environment for online industry clusters of SMEs. Guide SMEs to establish a sense of product differentiation, increase support for SMEs' innovation activities, encourage SMEs to upgrade and innovate their products, and support SMEs to carry out customized and personalized production, so

that they can enhance the competitiveness of their products in the marketplace while meeting the diversified and personalized needs of consumers.

(3) Playing the role of industry associations in organizing and coordinating to enhance the level of mutual trust in online industry clusters. Industry associations can hold regular industry exchange activities to enhance the understanding and trust among SMEs, and they can also organize training and educational activities to improve SMEs' understanding of and trust in the operation rules of online industry clusters. In addition, the industry association needs to establish a coordination mechanism in the SME online industry cluster to identify and solve problems such as transaction disputes between enterprises in the cluster in a timely manner, and to maintain the trust relationship between enterprises in the cluster. The platform needs to build a reasonable dynamic credit evaluation system, record and publicize the credit status of online enterprises, strengthen the supervision and punishment of trust-breaking behaviors, enhance the trust in the relationship between enterprises, and reduce the risk of transactions. The platform also needs to improve the online transaction system, ensure the legitimacy and compliance of transactions, and set up a specialized dispute resolution mechanism to strengthen institutional trust in the cluster and create a cluster culture of mutual trust, mutual benefit and value co-creation.

SMEs online industrial cluster, as a new business model, has brought new opportunities for the development of SMEs, but it is also facing many challenges. In this study, through the construction of a complex network evolutionary game model, the influencing factors of online industrial clusters of SMEs are discussed in depth, which theoretically reveals the action path of online industrial clusters of SMEs, and also provides practical guidance for the development of "integration of the digital economy with the real economy" of SMEs. However, there are still some limitations: (1) This paper does not adequately account for the differences and uniqueness of SMEs across various industries. Future research could analyze from diverse industry perspectives, investigate inter-industry differences, and enhance the generalizability of the findings. (2) This paper discusses the evolution of online industrial clusters of SMEs under the NW network structure. It can explore the evolution and development characteristics of online industrial clusters of SMEs under different network structures in the future and further enrich the relevant research conclusions.

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