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Research on Risk Management of Digital Transformation Based on Stochastic Evolutionary Game

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Abstract: *This paper studies the risk cooperation and management problem in the process of digital transformation of Internet enterprises to help small and medium-sized enterprises. First of all, build the payment benefit matrix of both Internet enterprises and small and medium-sized enterprises. Secondly, the stochastic evolution game model between Internet enterprises and small and medium-sized enterprises is constructed based on the stochastic evolution game theory. Finally, we solve the exponential stability condition based on the determination theorem of stochastic differential equations. The research shows that (i) When the proportion of SMEs (small and medium-sized enterprises) choose not to conduct cooperative management is below a certain threshold, the Internet platform will choose the cooperative management strategy. (ii) When the proportion of the Internet enterprises choose not to cooperative management is below a certain threshold, SMEs will choose cooperative management strategy.*

Keywords: *Stochastic differential game, Payment benefit matrix, Internet enterprise, SMEs*

1. Introduction

With the active promotion of 5G, industrial Internet and the rapid integration of big data and cloud computing, China has entered the era of digital economy. Due to the rising cost of labor and materials, SMEs gradually lose their cost advantage. Digital transformation has become an important means to avoid elimination and enhance their competitiveness. In view of their own characteristics, SMEs are relatively lack of human and material resources, financial resources and other aspects, and still face various difficulties on the road of transformation. It is an important way for SMEs to accelerate the process of digital transformation to actively respond to multi-dimensional cross-border integration and cooperate with Internet platform enterprises to obtain key digital information technology or resources. However, in the process of Internet enterprises helping SMEs, the security and recovery of data and the stability of applications are still the key issues in the process of cooperation between the two sides. If the risks of digital transformation are not rationalized, both Internet enterprises and SMEs will face certain risk losses. Therefore, this paper is of great significance to study the main behavior evolution process of the Internet enterprises under the risk of digital transformation, which is of great significance for the Internet enterprises to help the small and medium-sized enterprises' digital transformation smoothly.

On the digital transformation risk problem of Internet enterprises helping small and medium-sized enterprises, the existing literature mainly conducts qualitative research from the perspective of the necessity of risk management and the importance of collaborative risk management. Liu et al. [1] believed that SMEs can not only rely on the policy assistance of the government, but also cooperate with third-party service platforms to develop online business, so as to improve the risk prevention and control ability of SMEs in the context of normalized epidemic prevention and control. Du et al. [2] argued that SMEs can use new technology to promote digital transformation of the fourth industrial revolution, coordinate the relationship between internal and external, build anti-risk system. Bedell-Pearce [3] pointed out that as transformation becomes the agenda of SMEs, digital security of applications and data remains one of the key issues. Luo and Xu [4] pointed out that although digital transformation can help SMEs to achieve stable business growth while avoiding some risks, potential security risks such as data loss and leakage, service stability and lack of trust in cloud service providers make some enterprises afraid to carry out digital transformation. Snieška et al. [5] believed that the implementation of the concept of Industry 4.0 brings risks to SMEs, which are divided into three categories, such as technological preparation, innovation risk and information risk. Yan and Li [6] elaborated the

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significance of strengthening industrial Internet security for accelerating industrial digital transformation from the dimensions of Internet development stage, industrial security evolution trend and practical characteristics of network security, and proposed that responsibilities should be clarified and coordinated in the process of collaborative development.

Literature [1-6] mainly conducted qualitative research on the risk of Internet enterprises helping SMEs digital transformation from the perspective of the necessity of risk management and the importance of collaborative risk management, but lacks quantitative description at the micro level. On this basis, some scholars conducted quantitative research from the perspectives of risk prediction and risk management. For example, Liu [7] predicted the risk factors in the digital transformation process of manufacturing supply chain by constructing back propagation neural network (BPPN). The research results provided insights for the digital transformation of MSC in China.

Literature [7] mainly studied from the perspectives of risk prediction and the role of risk management. Little literature further explored the risk management decision-making in the process of cooperation transformation between SMEs and Internet enterprises. Actually, in the process of small and medium-sized enterprises and the Internet cooperation transformation, participants decision-making behavior is a gradual learning process and the role evolution of repeated game. At the same time considering the participant decision-making is difficult to meet the traditional game completely rational assumption. The limited rational premise of evolutionary game, natural selection and evolution mechanism of reproduction are especially suitable for solving multi-party strategy selection and role evolution problems. For example, Wang and Yu [8] based on the perspective of evolutionary game and risk association, considered the sharing of risk losses and constructed an evolutionary game model for the risk sharing of rail transit PPP (public-private Partnership) projects to solve and analyze the evolutionary stability strategies under different situations.

In summary, based on the random evolution game, this paper constructs the evolution game model of Internet enterprises and small and medium-sized enterprises. Secondly, according to the determinative theorem of stochastic differential equation, the stability condition of evolution of both parties is solved. Finally, relevant policy suggestions are given according to the results.

2. Symbol description and model assumptions

2.1. Symbol description

M_1: Small and medium-sized enterprises and Internet enterprises cooperate with Internet enterprises for digital transformation

M_2: The basic cooperation benefits obtained by SMEs when cooperating with Internet enterprises for digital transformation

k_1: Cost coefficient of risk management efforts of Internet enterprises

k_2: Cost coefficient of SME risk management efforts

g_1: Risk management efforts of Internet enterprises to manage digital transformation risks

g_2: Risk management efforts when SMEs choose to jointly manage digital transformation risks

b: Risk loss factor when either party chooses not to conduct cooperative risk management

F_1: SMEs need to pay compensation to Internet enterprises when they choose not to jointly manage the risk of digital transformation

F_2: The compensation that Internet enterprises should pay to small and medium-sized enterprises when they choose not to jointly manage the digital transformation risks

T_1: Speculation gains obtained when Internet companies choose not to conduct cooperative risk management

T_2: Speculation benefits obtained when SMEs choose not to conduct cooperative risk management

ISSN 2616-5902 Vol. 4, Issue 13: 32-37, DOI: 10.25236/AJBM.2022.041305

2.2. Model assumptions

Hypothesis 1: Due to the role of the subject, ability, interests, information, cognition differences, when facing digital transformation risk and uncertainty, often appear inconsistent judgment, and roughly decision-making behavior, the two subject decision-making behavior can be abstract for cooperative management and not cooperative management, both sides are limited rational, have action decision-making power.

Hypothesis 2: Based on Miao et al.[9] and other assumptions on risk loss, this paper assumes that when any party chooses not to be a cooperative management strategy, the losses brought by digital transformation risks to Internet enterprises and SMEs will be quantified as L_1 and L_2 respectively. When one party chooses not to conduct the cooperative risk management, it will obtain some speculative income. At the same time, it will bear the resulting digital risk loss and pay the corresponding compensation to the party adopting the cooperative risk management strategy.

Hypothesis 3: In the process of digital transformation risk management, the degree of cooperation efforts between Internet enterprises and SMEs is the key factor in risk management. Draw lessons from literature [10] about cooperation income value hypothesis, this paper assume that cooperation management strategy in addition to the basic cooperation income can also get due to the additional benefits of cooperation risk management. The coefficient of income increase of Internet enterprises and SMEs is a function of the degree of cooperation effort, that is, $\alpha_i = f\left(g_i\right),\left(i=1,2\right)$. $0 \le g_i \le 1$ is the risk management efforts. For simplicity, this paper assumes $f\left(g_i\right) = g_i,\left(i=1,2\right)$.

Hypothesis 4: Based on the assumption of the effort cost, this paper assumes that the risk management effort cost is a convex function of the degree of risk management effort. So the risk management effort cost of Internet enterprises and SMEs are $C_1\left(g_1\right) = \frac{1}{2}k_1 g_1^2$ and $C_2\left(g_2\right) = \frac{1}{2}k_2 g_2^2$. Among them, k_1 and k_2 are the cost coefficient of risk management efforts for the Internet enterprises and SMEs respectively. g_1 and g_2 are the cost degree of risk management efforts for the Internet enterprises and SMEs respectively.

3. Model construction and analysis

3.1. Payment Matrix

Table 1: Payment Matrix of the Internet Enterprise and SME

Internet Enterprise	SME	
	Cooperate $1-y$	Not cooperate y
Cooperate $1-x$	$M_1 + g_1 M_1 - \frac{1}{2}k_1 g_1^2$	$M_1 + g_1 M_1 - \frac{1}{2}k_1 g_1^2 - bM_1 + F_1$
	$M_2 + g_2 M_2 - \frac{1}{2}k_2 g_2^2$	$M_2 - bM_2 + T_2 - F_1$
Not cooperate x	$M_1 - bM_1 + T_1 - F_2$	$M_1 - bM_1$
	$M_2 + g_2 M_2 - \frac{1}{2}k_2 g_2^2 - bM_2 + F_2$	$M_2 - bM_2$

3.2. Construction of the basic evolutionary game model

According to Table 1, we can get the expected return of the Internet choosing the "non-cooperative management" strategy E_{11}, the expected return of the Internet choosing the "cooperative management" strategy E_{12} and the average expected return $\overline{E}_1$ as below

$$E_{11} = \left(1-y\right)\left(M_1 + g_1 M_1 - \frac{1}{2}k_1 g_1^2\right) + y\left(M_1 + g_1 M_1 - \frac{1}{2}k_1 g_1^2 - bM_1 + F_1\right),$$

$$E_{12} = \left(1-y\right)\left(M_1 - bM_1 + T_1 - F_2\right) + y\left(M_1 - bM_1\right),$$

ISSN 2616-5902 Vol. 4, Issue 13: 32-37, DOI: 10.25236/AJBM.2022.041305

$$\overline{E}_1 = xE_{11} - (1-x)E_{12}.$$

In the game, we can get the expected return of the SME choosing the "non-cooperative management" strategy E_{21}, the expected return of the Internet choosing the "cooperative management" strategy E_{22} and the average expected return $\overline{E}_2$ as below

$$E_{21} = (1-x)\left(M_2 + g_2M_2 - \frac{1}{2}k_2g_2{}^2\right) + y(M_1 - bM_1 + T_1 - F_2),$$

$$E_{22} = (1-x)(M_2 - bM_2 + T_2 - F_1) + x(M_2 - bM_2),$$

$$\overline{E}_2 = yE_{21} - (1-y)E_{22}.$$

According to the Malthus differential equation, the replication dynamic equation when the Internet enterprise choose the "non-cooperative management" strategy is

$$F(x) = \frac{dx}{dt} = x(1-x)\left[y(-T_1 + bM_1 + F_2 - F_1) + \left(T_1 - bM_1 - F_2 - g_1M_1 + \frac{1}{2}K_1g_1{}^2\right)\right], \quad (1)$$

Similarly, the replication dynamic equations when the SME choose "non-cooperative management" strategy is

$$F(y) = \frac{dy}{dt} = y(1-y)\left[x(-T_2 + bM_2 + F_1 - F_2) + \left(T_2 - bM_2 - F_1 - g_2M_2 + \frac{1}{2}K_2g_2{}^2\right)\right]. \quad (2)$$

3.3. Construction of stochastic evolution game model

Stochastic perturbations exist in the replication dynamical system due to the complexity and high uncertainty of the external environment. However, the digital transformation process of Internet platforms helping SMEs lasts for a long time and involves many factors. The impact of uncertain factors in the external environment cannot be ignored. Therefore, in order to more accurately describe the random interference of uncertainty on the decisions of Internet enterprises and SMEs, this paper, Gaussian white noise is introduced into (1) and (2), as follows

$$dx(t) = x(1-x)\left[y(-T_1 + bM_1 + F_2 - F_1) + \left(M_1 + T_1 - F_2 - bM_1 - M_1 - g_1M_1 + \frac{1}{2}K_1g_1{}^2\right)\right]dt + \sigma x(t)d\omega(t), \quad (3)$$

$$dy(t) = y(1-y)\left[x(-T_2 + bM_2 + F_1 - F_2) + \left(M_2 + T_2 - F_1 - bM_2 - M_2 - g_2M_2 + \frac{1}{2}K_2g_2{}^2\right)\right]dt + \sigma y(t)d\omega(t). \quad (4)$$

(3) and (4) are one-dimensional stochastic differential equations of Itô type. Among them, $\omega(t)$ is a one-dimensional standard Brownian motion, which represents a random fluctuation phenomenon without rules, and can well describe the random disturbance affected by the group in the process of game as time goes by. $d\omega(t)$ is Gaussian white noise, and when $t > 0$ and $h > 0$, its increment $\triangle\omega(t) = \omega(t+h) - \omega(t)$ follows normal distribution. σ denotes random interference intensity and is a normal number. Since $1-x$ and $1-y$ are both non-negative numbers, they have no influence on the result of strategy evolution. To facilitate discussion, (3) and (4) are improved, and the improved replication dynamic equation is obtained as follows

$$dx(t) = x\left[y(-T_1 + bM_1 + F_2 - F_1) + \left(M_1 + T_1 - F_2 - bM_1 - M_1 - g_1M_1 + \frac{1}{2}K_1g_1{}^2\right)\right]dt + \sigma x(t)d\omega(t), \quad (5)$$

$$dy(t) = y\left[x(-T_2 + bM_2 + F_1 - F_2) + \left(M_2 + T_2 - F_1 - bM_2 - M_2 - g_2M_2 + \frac{1}{2}K_2g_2{}^2\right)\right]dt + \sigma y(t)d\omega(t). \quad (6)$$

3.4. Model stability analysis

The lemma is given a stochastic differential equation

ISSN 2616-5902 Vol. 4, Issue 13: 32-37, DOI: 10.25236/AJBM.2022.041305

$$dx(t) = f(t, x(t)) + g(t, x(t))d\omega(t), x(t_0) = x_0. \tag{7}$$

Let exist smooth function $V(t,x)$ and normal number c_1 and c_2, which make $c_1|x|^p \le V(t,x) \le c_2|x|^p$, $t \ge 0$.

(i) If there is a normal number ξ can make $LV(t,x) \le -\xi V(t,x)$, $t \ge 0$. Then the zero solution p moment is exponentially stable and holds $E|x(t,t_0)|^p < (c_1/c_2)|x_0|^p e^{-\xi t}$, $t \ge 0$.

(ii) If there is a normal number ξ can make $LV(t,x) \ge -\xi V(t,x)$, $t \ge 0$. Then the zero solution p moment is exponentially stable and holds $E|x(t,t_0)|^p \ge (c_1/c_2)|x_0|^p e^{-\xi t}$, $t \ge 0$.

According to the above lemma, we can obtain the stability determination basis for (5) and (6).

Proposition 1 When $y \le \dfrac{-\left(M_1 + T_1 - F_2 - bM_1 - M_1 - g_1M_1 + \frac{1}{2}K_1g_1^2\right) - 1}{-T_1 + bM_1 + F_2 - F_1}$ and $-T_1 + bM_1 + F_2 - F_1 > 0$, the zero solution p moment of (5) is exponentially stable.

Proof: For (5), take $V(t,x(t)) = x$, $x(t) \in [0,1]$, $c_1 = c_2 = 1$, $p = 1$ and $\xi = 1$. Then

$$LV(t,x(t)) = f(t,x(t)) = x\left[y(-T_1 + bM_1 + F_2 - F_1) + \left(M_1 + T_1 - F_2 - bM_1 - M_1 - g_1M_1 + \frac{1}{2}K_1g_1^2\right)\right]$$

According to the lemma, (5) the zero solution p moment index stability needs to meet $x\left[y(-T_1 + bM_1 + F_2 - F_1) + \left(M_1 + T_1 - F_2 - bM_1 - M_1 - g_1M_1 + \frac{1}{2}K_1g_1^2\right)\right] \le -x$. Because $0 \le x \le 1$, then the available (5) the zero solution moment index stability condition is $y \le \dfrac{-\left(M_1 + T_1 - F_2 - bM_1 - M_1 - g_1M_1 + \frac{1}{2}K_1g_1^2\right) - 1}{-T_1 + bM_1 + F_2 - F_1}$ and $-T_1 + bM_1 + F_2 - F_1 > 0$.

Proposition 1 shows that when the proportion of SMEs without cooperative management is less than a certain threshold value, the cooperative management strategy is ultimately chosen, even if the decisions of Internet enterprises are affected by random interference factors.

Proposition 2 when $x \le \dfrac{\left(M_2 + T_2 - F_1 - bM_2 - M_2 - g_2M_2 + \frac{1}{2}K_2g_2^2\right) - 1}{-T_2 + bM_2 + F_1 - F_2}$ and $-T_2 + bM_2 + F_1 - F_2 > 0$, the zero-solution p moment of (5) is exponentially stable.

Proof: For (6), take $V(t,y(t)) = y$, $y(t) \in [0,1]$, $c_1 = c_2 = 1$, $p = 1$ and $\xi = 1$. Then

$$LV(t,y(t)) = f(t,y(t)) = y\left[x(-T_2 + bM_2 + F_1 - F_2) + \left(M_2 + T_2 - F_1 - bM_2 - M_2 - g_2M_2 + \frac{1}{2}K_2g_2^2\right)\right]$$

According to the lemma, (6) the zero solution p moment index stability needs to meet $y\left[x(-T_2 + bM_2 + F_1 - F_2) + \left(M_2 + T_2 - F_1 - bM_2 - M_2 - g_2M_2 + \frac{1}{2}K_2g_2^2\right)\right] \le -y$. Because $0 \le y \le 1$, then the available (6) the zero solution P moment index stability condition is $x \le \dfrac{\left(M_2 + T_2 - F_1 - bM_2 - M_2 - g_2M_2 + \frac{1}{2}K_2g_2^2\right) - 1}{-T_2 + bM_2 + F_1 - F_2}$ and $-T_2 + bM_2 + F_1 - F_2 > 0$.

Proposition 2 shows that when the proportion of Internet enterprises not engaged in cooperative management is less than a certain threshold value, the cooperative management strategy will eventually be chosen even if the decisions of small and medium-sized enterprises are affected by random interference factors.

ISSN 2616-5902 Vol. 4, Issue 13: 32-37, DOI: 10.25236/AJBM.2022.041305

4. Conclusion

1) When the proportion of SMEs without cooperative management is less than a certain threshold value, the cooperative management strategy is ultimately chosen, even if the decisions of Internet enterprises are affected by random interference factors.

2) When the proportion of Internet enterprises not engaged in cooperative management is less than a certain threshold value, the cooperative management strategy will eventually be chosen even if the decisions of small and medium-sized enterprises are affected by random interference factors.

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