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The Game Research of Entrepreneur Digital Transformation Decision

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Abstract: *In this paper, an evolutionary game equilibrium model of two-stage digital transformation decision is created. The entrepreneurs in the same situation are regarded as a group, and the individual entrepreneur's decision is placed in the group decision. Then the individual entrepreneur chooses a certain strategy with a certain probability from the perspective of the entrepreneur group. In the face of digital transformation which can bring many benefits, the formation of stable and balanced strategy of entrepreneur evolution not only depends on the characteristics of the enterprise itself, but also depends on the decision of its competitors. The digital transformation of enterprises has positive externalities, and the government should establish an incentive system for digital transformation to encourage and help small and medium-sized enterprises to carry out digital transformation.*

Keywords: *entrepreneur digital transformation; evolutionary game; Balancing strategy*

1. Introduction

With the widespread application of digital technologies such as artificial intelligence, big data, cloud computing, and blockchain, China's digital economy is rapidly developing. The 19th National Congress of the Communist Party of China emphasized the importance of "accelerating the development of the digital economy and promoting deep integration between the digital economy and the real economy." According to a report on China's digital economic development in 2022 released by the China Academy of Information and Communications Technology, China's digital economy reached a scale of 45.5 trillion yuan in 2021, accounting for 39.8% of GDP and growing by 16.2 percentage points year-on-year. Industrial digitization has accounted for over 80% share in the digital economy, increasingly highlighting its position in national economic development. There is no doubt that technologies such as internet, big data, and cloud computing are penetrating various fields at an accelerated pace and driving China's transformation towards digitization as well as global economic transformation. This transformation has had profound impacts on different enterprises, industries, and society with help from digital technology empowerment. Particularly for enterprises, digitization has become an important choice to achieve leapfrog development and obtain sustainable momentum while bringing new opportunities for innovation-driven changes to adapt to a changing environment.

Small and medium-sized enterprises (SMEs) play an important role in China's economic and social development, contributing over 50% of the tax revenue, more than 60% of GDP, over 70% of technological innovation, and over 80% of urban employment. As a large and widely distributed group, SMEs are the mainstay of stable economic and employment markets, as well as a key link in improving industrial chain supply chain stability and competitiveness. However, due to limitations in concepts, technology, management and capital investment among other factors hindering progress towards transformational change for these businesses; they have become a group urgently needing "assistance" in digital transformation. Currently most SMEs in China are still at relatively low levels of digital transformation. Relevant data shows that among these companies only 89% are exploring digital transformation while just 8% are practicing it with only 3% reaching deep application stages. Overall, most SMEs in China remain at the exploration stage. In addition, according to data from the Ministry of Industry and Information Technology (MIIT), only about 25 percent of companies underwent digital transformations by year-end last year with even lower proportions belonging to small- or medium-sized firms.

As one of the main subjects of digital transformation, SMEs are both challenging and crucial. It is

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evident that there still exist issues of "not willing to change, not daring to change, and unable to change." However, blindly following trends for transformation may not necessarily achieve the desired results. Similar to innovative behaviors, digitalization requires significant investment in funds and human resources, but the final outcomes may not necessarily lead to the desired growth in company quality or cost reduction as intended by its founders. Therefore, decision-makers need to carefully weigh the pros and cons when choosing to undergo digital transformation before making a decision.

Currently, the scholarly research predominantly focuses on examining the impact of digital transformation on enterprises, while there is a dearth of studies analyzing the rationales behind entrepreneurs' pursuit of digital transformation. This article presents an innovative analysis that explores how entrepreneurs make decisions regarding digital transformation from a game theory perspective. By considering individual entrepreneurs as a collective group facing similar circumstances and situating their decisions within the context of group decision-making, it becomes apparent that when an individual entrepreneur selects a particular strategy, it can be perceived at the group level as choosing that strategy with a certain probability. Consequently, it becomes evident that enterprises' adoption of digital transformation yields positive externalities, thereby necessitating governments to establish incentive systems aimed at encouraging and supporting SMEs in their endeavors towards digital transformation.

2. Review of literature

Enterprise digital transformation refers to the comprehensive integration of information and data into specific aspects or even the entire process of a company's production and operation, utilizing digital technology to create valuable digital assets. By fully leveraging advanced technologies such as big data and cloud computing, companies are able to efficiently process and apply information, thereby enhancing their business value. Currently, academia is actively researching enterprise digital transformation, with a particular focus on its driving factors, implementation strategies, and resulting impacts.

First of all, in terms of the driving factors for enterprise digital transformation, relevant literature research and corporate management practices mainly characterize the industrialization system and digitalization system from four aspects: key driving factors, resource attributes, information structure, and value realization. They also explore the cross-system nature between the two (Xiao, 2020) [1]. Among them, technological progress, population changes, trade expansion, accumulation of human capital, and institutional reforms are the five main driving factors that constitute the industrialization system; while new generation digital technologies, business models competition patterns, accumulation of new types of human capital and corresponding institutional reforms are key driving factors for enterprise digital transformation. In addition to these factors influencing digital transformation externally include developments and penetration of digital technology (Matt et al., 2015; Li et al., 2016)[2],[19], intensified competitive environment (Kohli & Melville,2019) [3], as well as changing user demands (Abrell et al., 2019)[4].

Secondly, in terms of mechanisms and implementation paths for enterprise digital transformation. Currently, many traditional enterprises are accelerating the pace of digital transformation, attempting to undergo a disruptive internal and external change through digitization (Li,2020)[5]. Digital transformation is a process of evolution for enterprises, involving a complex system engineering that comprehensively transforms the enterprise from all aspects and perspectives. The classification of digital transformation types in manufacturing enterprises can be constructed based on two logical lines: horizontal and vertical. The vertical logical line includes horizontal technological driving forces and vertical technological driving forces; while the horizontal logical line involves customer experience value and process optimization value, constructing the logic framework for digitalization in manufacturing enterprises based on two dimensions: internal and external forces (Zhang & Zhang, 2020)[6]. Scholars believe that there are multiple ways to achieve enterprise digital transformation, such as internal organizational learning and external collaboration (Hu, 2020)[7]; there are also triggering mechanisms such as "leveraging type," "co-driving type," "internally-driven type," "powerless type," etc.; from a perspective of change research, it has been found that under the drive of digital elements, fundamental changes have occurred in enterprise resource attributes and information structures which have led to systematic changes compared to industrial systems within the digitized system including enterprise boundaries, market foundations, organizational structures , market structures ,and value realization aspects (Xiao,2020)[1]. Some scholars have also discovered significant homophily effects during the process of enterprise digital transformation (Chen,2021) [8].

Finally, in terms of the impact and consequences of enterprise digital transformation. In recent years,

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with the further penetration of digital technology in terms of depth and breadth into business operations, the integration of digital technologies such as cloud computing, big data, and artificial intelligence with physical enterprises represents a new economic form and industrial development law driven by data (He & Liu, 2019)[9]. Digitalization helps reduce information asymmetry among transaction parties, lowering costs related to information search, bargaining negotiations, transaction monitoring, and post-conversion (Wang & Feng, 2015)[10]. In the era of digital economy, enterprises rely more on the internet for production, operation, sales etc. (Shen & Yuan, 2020)[11], under the influence of the internet; enterprise digitization can enhance corporate governance by reducing information asymmetry (Qi et al., 2020)[12]. Enterprise digital transformation significantly enhances outward investment levels (Yang & Bi, 2019)[13], reshapes financing channels, thereby achieving improved company performance (He & Liu, 2019)[9], furthermore, the greater the intensity of enterprise digitization transformation is implemented, the better its main business performance will be (Yi et al., 2021)[14]. At the same time, integrating information technology deeply into traditional industries has promoted enhancement in corporate innovation capabilities (Li et al., 2014)[15] and strengthened motivation for companies to engage in new product research and development. (Brynjolfsson & Mcafee, 2014)[16] pointed out that emerging technologies have provided more channels and convenience for listed companies' disclosure of information, and have provided a good informational basis for stakeholders' decision-making, reducing information asymmetry between different interest groups, and thus improving overall market transparency, promoting optimal allocation resources.(Liu 2022)[17] Research has found that enterprise digital transformation can improve total factor productivity through technological aspects as well as corporate governance aspects.

3. Game behavior analysis of digital transformation of entrepreneurs

Given that the successful digital transformation can effectively enhance business performance (Hu, 2020; Yi et al., 2021)[7, 14] and strengthen companies' adaptability to economic uncertainty (Jiang et al., 2022)[18], enterprises in the industry are actively promoting digital transformation. However, similar to innovative behavior, companies that first implement and successfully complete digital transformation will be in a leading position for a considerable period of time and gain more marginal profits from it. Conversely, digital transformation may also face the risk of failure. Therefore, entrepreneurs need to engage in competition with their peers when deciding whether to undergo digital transformation.

Game theory is a theoretical framework that studies how rational individuals make decisions and the equilibrium problems in decision-making when considering the interactions between multiple decision-making entities. Game theory imposes strict requirements on the rationality of game players, and it cannot determine which equilibrium will be reached when there are multiple equilibria in a game, which undoubtedly limits the theory itself. Evolutionary game theory applies the assumption of bounded rationality to explain the strategy choices of game players, replaces individuals with groups as actors within a game, and uses the ratio of individuals choosing different pure strategies within a group to replace mixed strategies for individual actors, achieving a transition from individual actors in traditional game theory to groups in evolutionary game theory. In practice, entrepreneurs may approach digital transformation cautiously. To make the theory more applicable to real situations, an analysis will be conducted using a two-stage digital transformation decision-making evolutionary game model.

Assuming a digital transformation project, entrepreneurs divide their investments into two stages. The initial investment amount is K_1, and the second stage investment amount is K_2. The probability of receiving good information in the first stage investment is P_1 (the actual probability will be influenced by the ratio of entrepreneur's first stage investment, decreasing as the ratio increases). After completing the first stage investment, if good information is revealed, there will be a higher success probability for continuing with further investments (denoted as P_{11}). If bad information is revealed, there will be a lower success probability for continuing with further investments (denoted asP_{01}, where $P_{01}<P_{11}$) (the actual success probabilities in these two scenarios will also be influenced by the entrepreneur's likelihood of proceeding to the second stage digital transformation and decrease as this likelihood increases). Assuming that the opportunity rate of return on entrepreneurial funds is $\hat{r}$ and that successful completion of digital transformation yields a return rate R_1 while failure yields a return rate R_0; If no second-stage investment is made after the first-stage investment, only a partial recovery of the initial capital can be achieved, while the uninvested funds still have the opportunity to earn a return. Assuming that the comprehensive rate of return on funds under good and bad information is r_1 and r_0 respectively, with $R_0 < r_0 < \hat{r} < r_1 < R_1$. Consolidate the returns of various results into the Figure 1.

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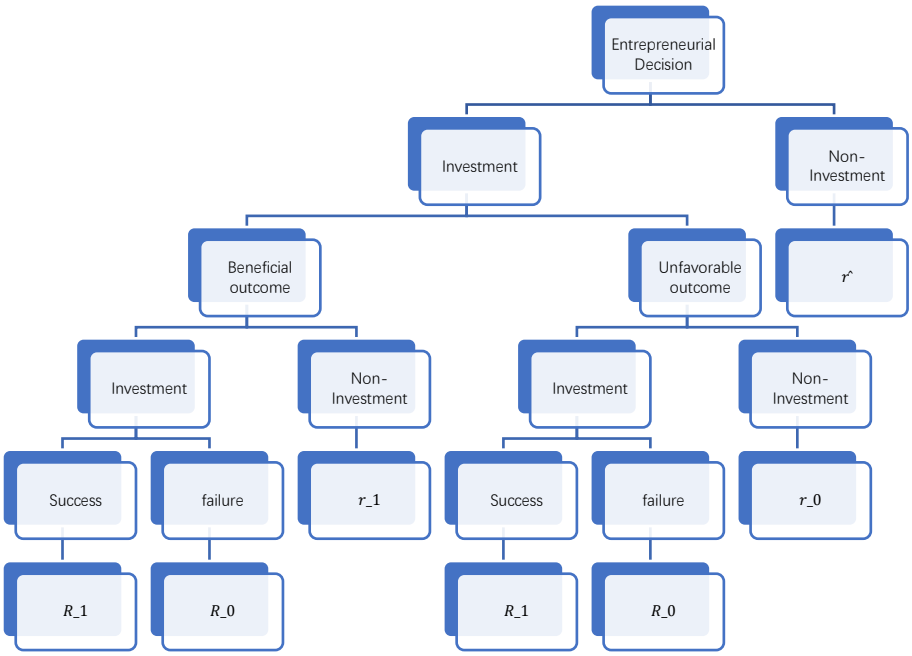

Figure 1: Consolidate the returns of various results

Evolutionary game theory considers individual entrepreneurs as members of the entrepreneur group, so individual decision-making is regarded as a probabilistic event at the group level.

Assumption: The probability that an entrepreneur chooses to invest in the first stage is p_1, and the actual probability of displaying positive information after completing the first stage is $P_1(1-p_1/2)$. When positive information is displayed after completing the first stage, the probability of proceeding with the second stage investment is p_2; whereas when negative information is displayed, the probability of proceeding with the second stage investment is p_3. Therefore, the probability of successfully completing digital transformation for entrepreneurs can be represented as $p_0 = p_1[p_3 + P_1(1-p_1/2)(p_2-p_3)]$

After the completion of the first stage of investment, when positive information is revealed, the actual probability of success is $P_{11}(1-p_2/2)$; while when negative information is revealed, the actual probability of success is $P_{01}(1-p_3/2)$. We can calculate the expected return on various strategic choices for entrepreneurs and conduct corresponding equilibrium analysis. After the completion of the first stage of investment, if the probability of continuing to invest is p_2, then the expected return rate is as follows:

$$ER(1) = R_1P_{11}(1-p_2/2) + R_0[1-P_{11}(1-p_2/2)$$

The expected rate of return, denoted as r_1, is obtained when the entrepreneur decides not to continue investing after receiving favorable information following the initial investment. In an evolutionarily stable equilibrium, there will be no preference for the entrepreneur to either continue or cease investing. We can express this equilibrium by defining $ER(1) = r_1$ and subsequently determining p_2^*.

$$p_2^* = 1, \text{ when } P_{11} \geq 2(r_1 - R_0)/(R_1 - R_0)$$

$$p_2^* = 2\{1-(r_1-R_0)/[(r_1-R_0)P_{11}]\}, \text{ when } P_{11} < 2(r_1-R_0)/(R_1-R_0)$$

The equilibrium probability, p_2^*, of entrepreneurs continuing digital transformation after displaying favorable information is positively correlated with the expected success probability, P_{11}, under favorable information, as well as the return rates of success R_1 and failure R_0 when continuing investment. Conversely, it is negatively correlated with the return rate of retention r_1 under favorable information.

After the completion of the first stage investment, the expected rate of return for continuing to invest with a probability p_3 when bad information is revealed is:

$$ER(0) = R_1P_{01}(1-p_3/2) + R_0[1-P_{01}(p_3/2)]$$

When $p_3 = 0$, we have $ER(0) = R_1P_{01} + R_0(1-p_{01}) > r_0$. This means that if the information displayed after the completion of the first-stage investment is not good and other entrepreneurs do not

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proceed with the second-stage investment, it will be profitable for a certain entrepreneur to proceed with the second-stage investment. Similarly, when entrepreneurs reach evolutionary stable equilibrium, we have $ER(0) = r_0$, and then we can determine p_3^* at equilibrium.

$$p_3^* = 1, \text{ when } P_{01} < 2(r_0 - R_0)/(R_1 - R_0)$$

$$p_3^* = 2\{1 - (r_0 - R_0)/[(R_1 - R_0)P_{01}]\}, \text{ when } P_{01} \geq 2(r_0 - R_0)/(R_1 - R_0)$$

Similarly, reasoning reveals that the balanced probability p_3^* for companies to continue with digital transformation after displaying unfavorable information is an increasing function of the expected success probability P_{01} under unfavorable information, the success return rate R_1 when continuing investment, and the failure return rate R_0 when continuing investment. It is also a decreasing function of the retained return rate r_0 under unfavorable information.

Assuming $(r_0 - R_0)/(R_1 - R_0) < P_{01} < P_{11} < 2(r_1 - R_0)/(R_1 - R_0)$ holds, the entrepreneur will make a path-dependent equilibrium probability choice to continue investing after making an investment decision in the first stage. That is, when favorable information is revealed, there will be a probability p_2^* of continuing with digital transformation, and when unfavorable information is revealed, there will be a probability p_3^* of continuing with digital transformation.

When entrepreneurs make first-stage investment with probability p_1, the expected return on investment is:

$$ER = P_1(1 - p_1/2)ER(1) + [1 - P_1\left(1 - \frac{p_1}{2}\right)ER(0)$$

$$= P_1(1 - p_1/2)\{R_1P_{11}(1 - P_2/2) + R_0[1 - P_{11}(1 - p_2/2)]\} + [1 - P_1(1 - p_1/2)] \times \{R_1P_{01}(1 - p_3/2) + R_0[1 - P_{01}(1 - p_3/2)$$

Substituting the equilibrium probabilities p_2^* and p_3^*, we obtain:

$$ER = P_1(1 - p_1/2)r_1 + [1 - P_1(1 - p_1/2)]r_0$$

When $p_1 = 1$, $ER = P_1R_1/2 + (1 - P_1/2)r_0 > \hat{r}$, that is, $P_1 > 2(\hat{r} - r_0)/(r_1 - r_0)$, then it is always optimal for entrepreneurs to carry out digital transformation in the first stage. Similarly, when $p_1 = 0$, $ER = P_1r_1 + (1 - P_1)r_0 < \hat{r}$, that is, there is $p_1 < (\hat{r} - r_0)/(r_1 - r_0)$, then it is optimal for entrepreneurs not to carry out digital transformation in the first stage. In other cases, since there is $ER = \hat{r}$ when the evolutionary stable equilibrium is reached, we obtain that the optimal probability of entrepreneurs' digital transformation in the first stage is

$$p_1^* = 2\{1 - (\hat{r} - r_0)/[(r_1 - r_0)p_1]\}$$

The above reasoning shows that the equilibrium probability p_1^* of entrepreneurs' digital transformation in the first stage is an increasing function of the expected success probability p_1 when favorable information occurs after the completion of the investment in the first stage, the retention rate r_1 under favorable information, and the retention rate r_0 under unfavorable information. Is a decreasing function of the reservation rate of return $\hat{r}$ when no digital transformation is carried out.

The above analysis assumes that entrepreneurs are risk neutral; If entrepreneurs are risk-averse, we can assume that entrepreneurs require a risk premium rate of return r_f.

$$p_1^* = 2\{1 - (\hat{r} + r_f - r_0)/[(r_1 - r_0)p_1]\}$$

The findings indicate a decrease in the equilibrium probability of an entrepreneur undertaking a digital transformation in the initial period.

4. Conclusions

This article establishes an evolutionary game model for entrepreneurs to make decisions on digital transformation in the era of digital economy using game theory. When facing the benefits brought by digital transformation, the formation of stable equilibrium strategies for entrepreneurs depends not only on their own characteristics but also on the decisions made by competitors. As digital transformation of enterprises has positive external effects, governments should establish incentive systems to promote digital transformation among SMEs.

Digital transformation is essentially a process of utilizing digital technology innovation. Key leaders

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play a crucial role in making decisions on digital transformation by seizing opportunities and pace, possessing digital thinking ability and professional knowledge, gaining insights into and analyzing internal and external organizational environments, integrating and regulating human resources, material resources, financial resources, and knowledge resources both inside and outside the organization with specific goals in mind. It is particularly important to emphasize data resource development and strengthen the construction of digital infrastructure. At the same time, it needs to be clarified that not every company, process or business model must undergo digital transformation (Andriole 2017), especially for SMEs which need to determine which basic activities or support activities require digitization based on their own resources and capabilities as well as whether they are ready for comprehensive or partial transformations etc. Therefore, it is crucial to clearly define strategic objectives at each stage along with efforts direction while maintaining strategic consistency.

At the government level, our country should fully grasp the opportunities of empowering traditional industries with new generation information technology, follow the laws of industrial development, strengthen planning guidance and policy support, and create favorable conditions to stimulate the enthusiasm for digital transformation in physical enterprises. At the same time, we need to promote deep integration between mobile internet, big data, cloud computing, artificial intelligence and the real economy by taking measures to relax access thresholds for integrated products and services as well as expanding equal market entry for market entities. In addition, in order to prevent the disorderly expansion and barbaric growth of capital, we should support and guide traditional enterprises in achieving digital transformation and development through policies that promote change to increase efficiency. Doing so will further enhance industrial innovation vitality and resource allocation efficiency, thus accelerating high-quality economic development.

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