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Impact of the synergy between technology management and technological capability on new product development: a system dynamics approach

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Abstract: This paper employs system dynamics to explore how the synergy between technology management and technological capability affects new product development. The results show that the synergy between technology management and technological capability has positive impact on new product development. Moreover, the leading synergy processes between technology management and technological capability in different new product development stages are different. This paper deepens the theoretical understanding of how to achieve new product development, and also provides useful guidance for firms to implement new product development.

Keywords: technology management, technological capability, new product development, system dynamics.

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1. Introduction

In the current competitive environment, manufacturing firms need to develop a constant stream of new products in order to maintain sustained growth [1]. From a resource based view, it is argued that the key driving factors of new product development are the resources and capabilities that a firm owns [2]. Resources are the stocks of available factors that are controlled by the firm, while capabilities are firms ' capacities to deploy these resources to perform tasks [3]. Therefore, it can be inferred that there should be a synergy relationship between a firm's resources and capabilities, and investigating how that relationship affecting new product development is critically important for manufacturing firms to improve their competitiveness.

Among a firm's various resources, technological capability, which offers know-how, is the first important resource for new product development [4]. While technology management is the capacity to develop and implement technological capability [5]. Therefore, the synergy relationship between technology management and technological capability is extremely important for academics and practitioners to get a better understanding about how to achieve new product development successfully. Researchers have investigated the relationship between technology management and technological capability in new product development, and it is widely accepted that their effects on new product development are not exerted independently [6,7]. Although the current research has indicated that there exists a synergy relationship between technology management and technological capability, we still have little understanding about how such a relationship affects new product development. Actually, new product development is widely recognized as a process from idea to launch, with each stage composed of a set of required activities needed to accomplish [8]. These required activities in different stages are usually accomplished by different synergy processes between technology management and technological capability. This indicates that there exists different leading synergy processes between technology management and technological capability in different new product development stages. However, few studies focus on this important issue, leaving the leading synergy processes between technology management and technological capability in different new product development stages still unknown.

This paper aims to investigate the undiscovered lead-

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ing synergy processes between technology management and technological capability in different new product development stages. As the new product development can be regarded as a complex system, characterized by nonlinearity and feedback, this paper thus applies system dynamics for analysis. The remainder of this paper is structured as follows. Section 2 is the literature review. Section 3 develops the theoretical analysis of this paper. The methodology is detailed in Section 4, and Section 5 presents the simulation results. The final section contains conclusions, implications, and limitations.

2. Literature review

2.1 Technology management and technological capability

Technology management has developed from R&D management to strategic management of technology [9]. A widely accepted definition regards technology management as the "planning, directing, control, and coordination of the development and implementation of technological capabilities to shape and accomplish the strategic and operational objectives of an organization" [10]. The aims of technology management are not only to improve existing technologies, but also to generate new knowledge and skills in response to the competitive business environment [11]. Therefore, technology management deals with all aspects of integrating technological issues into business decision-making and it is directly relevant to new product development [12]. Following the definition of the National Research Council (NRC), this paper defines technology management as the capability of a firm to reconfigure its technological capability to accomplish firm's objectives.

Technological capability is one of the most important resources that enable a firm to generate product innovation [13]. Therefore, the stronger a firm's technological capability, the greater chances a firm has to generate innovative new products [14,15]. Theoretically, technological capability has been conceptualized as a multidimensional concept, including human capability, equipment capability, information capability and organization capability [6]. Based on this understanding, this paper will investigate the impact of the synergy between technology management and technological capability according to these four dimensions. In detail, we explore the impact of the synergy between technology management and human capability, the synergy between technology management and equipment capability, the synergy between technology management and information capability, and the synergy between technology management and organization capability.

2.2 Relationship between technology management and technological capability

Researchers have investigated the relationship between technology management and technological capability. For instance, Wu et al. found that technology management and technological capability both exerted important influences on successful independent innovation. In addition, technology management and technological capability have interactive effects, and they are coupled in the form of a double helix to realize independent innovation [6]. Ma et al. further revealed that the fit between technology management and technological capability had a positive effect on new product development performance, and the roles of technology management and technological capability were different in different new product development performance groups [16]. Liu et al. argued that new product development can be divided on the basis of the accumulation of technological capability and that the tasks in different technological capability stages are different. They then identified the different technology management practices that are closely associated with product innovation performance in different technological capability stages [17]. Although the current research has widely accepted that a synergy relationship exists between technology management and technological capability, it still does not clarify how that relationship affects new product development. Especially, new product development is a complex activity, which has several stages. In different stages, the effect of the synergy between technology management and technological capability on new product development may be different. However, we still have little understanding about which synergy processes between technology management and technological capability are the most effective in particular new product development stages.

3. Theoretical analysis

3.1 New product development stage

New product development is a difficult activity because it faces a high level of risk and uncertainty. It is widely accepted that the success of new product development should adhere to a process, which can be divided into certain key stages [18]. These key stages can be a blueprint for reducing risk and uncertainty progressively with evaluative steps after each stage. In line with the prior research, this paper divides the new product development into three stages, namely concept development stage, product development stage, and market development stage [19,20]. Then, this paper identifies the leading synergy processes between technology management and technological capability in different new product development stages. However, it should be noted that these three stages are not a rigid process, and not all new product development projects go through every stage. This paper just employs such a perspective to explore the variation of the leading synergy processes between technology management and technological capability.

3.2 Synergy between technology management and technological capability in different new product development stages

Different new product development stages have different tasks to perform [21], and thus the requirements of the synergy between technology management and technological capability are different. In the concept development stage, the main task is to generate ideas and then select the most promising idea to develop into product concepts for further development [22]. At this stage, human capability and information capability can play important roles because they bring firms with new knowledge. As an example, information capability usually serves as the starting point to produce new product ideas. Therefore, by employing human capability and information capability, the synergy between technology management and technological capability can play an important role in providing potential ideas. In the product development stage, the prototypes are developed according to the product concepts, and then further tested and refined [22]. At this stage, human capability is needed because the testing and refining activities should be accomplished by human resources. Therefore, by employing human capability, the synergy between technology management and technological capability can play an important role in carrying out product development activities. The market development stage includes all activities related to product launch, such as product training, after-sales support, and competitor monitoring [22]. At this stage, organization capability is important because it provides basis for the formulation of an effective market development strategy. Therefore, by employing organization capability, the synergy between technology management and technological capability can play an important role in gaining early-market-entry advantages. Based on these arguments, we propose that the synergy between technology management and technological capability is important for new product development, but the leading synergy processes will change across different new product development stages.

4. Methodology

4.1 System dynamics

This paper uses a system dynamics approach to analyze the impact of the synergy between technology management and technological capability on new product development. System dynamics is an approach focusing on the causal feedback between various elements [23], which is a complex system [24]. The system dynamics approach is selected for this paper because it provides an approach based on a mathematical equation formulation to describe how the synergy between technology management and technological capability affects new product development. The model can then be simulated by software, which enables to identify the leading synergy processes across different new product development stages. The system dynamics has been widely used in innovation research [25,26].

4.2 Causal loop diagram

The causal loop diagram describes the causal relationships among the variables within a system. There are two kinds of causal relationships between the variables in a causal loop diagram. One of them is positive feedback loop with + as its representative symbol, and the other is negative feedback loop with − as its representative symbol. The positive feedback loop will make the system status increase, while the negative feedback loop will make the system status decrease. The causal loop diagram acts as a draft of the model design, which facilitates the building of the stock-flow diagram. We can construct the causal loop diagram of the synergy process in different new product development stages based on the different tasks in each stage.

The tasks of the concept development stage are generation and evaluation of new product development ideas. In order to accomplish the tasks, the market research should be done, which can help firms to understand the customer demand and further produce new produce development ideas. After generating new product development ideas, firms should evaluate these ideas through idea screening, idea feasibility checking and so on to select the most promising ideas. At the same time, firms should invest in new product development and promote information sharing to support the generation and evaluation of new product development ideas. Therefore, the causal loop diagram of the synergy process in the concept development stage can be shown as Fig. 1.

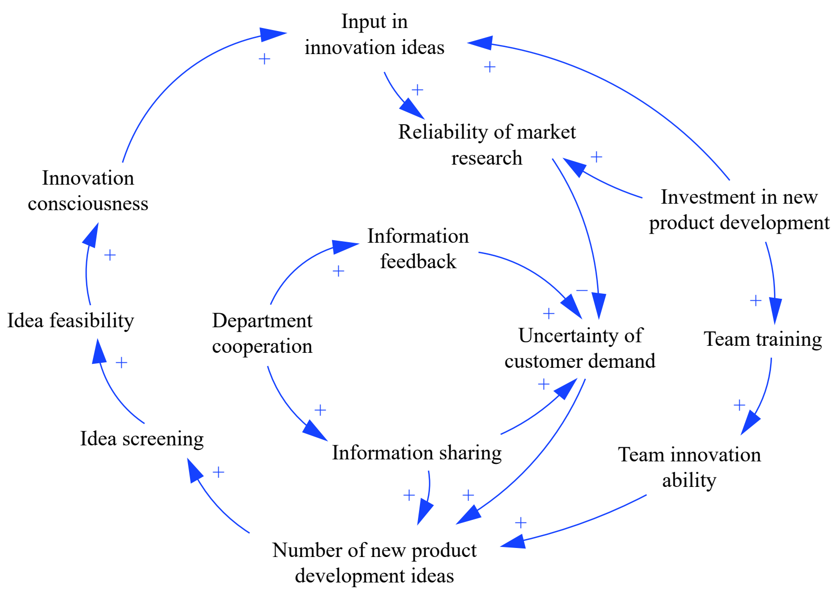


Fig. 1 Causal loop diagram of the synergy process in concept development stage

The task of the product development stage is to develop actual technical products. The actual technical product development is conducted by the firms' equipment, and thus the number of advanced equipment can affect technical process refinement and further affect product quality. At the same time, the actual technical product development also depends on the firms' previous knowledge. Therefore, the number of scientific and technological achievements can be an important source for the promotion of product quality. The logic is that the number of scientific and technological achievements could affect the number of technology reserve, then improve the matching degree between technology and product and the leading degree of product technology, and finally improve the product quality. In addition, in this stage, firms should employ quality management to control the product quality, and invest in new product development to accumulate the scientific and technological achievements. Therefore, the causal loop diagram of the synergy process in the product development stage can be shown as Fig. 2.

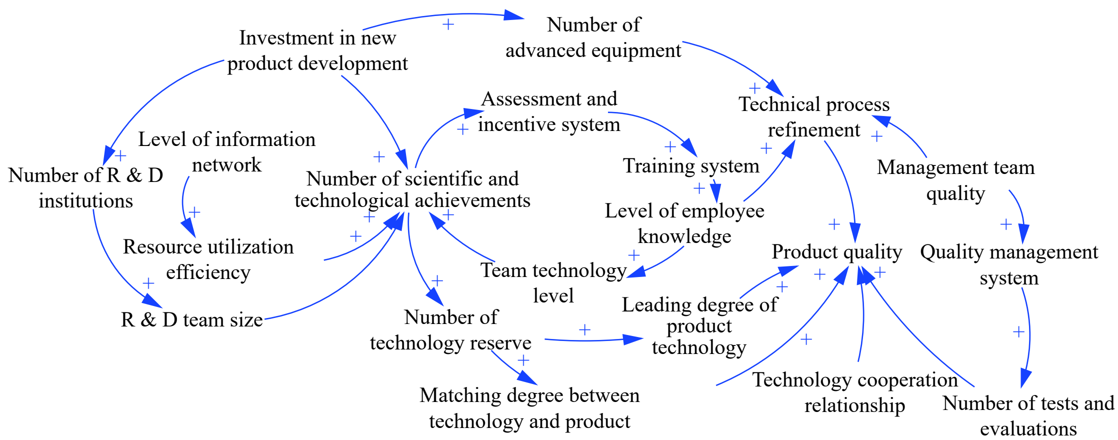


Fig. 2 Causal loop diagram of the synergy process in product development stage

The task of the market development stage is market launch. In this stage, the marketing strategy is important to increase customer satisfaction, which will further contribute to the increasing of market share. At the same time, firms should also construct the information transmission channel to acquire information feedback. This is important to decrease the uncertainty of customer demand, which is critical for the improvement of product quality. Therefore, the causal loop diagram of the synergy process in the market development stage can be shown as Fig. 3.

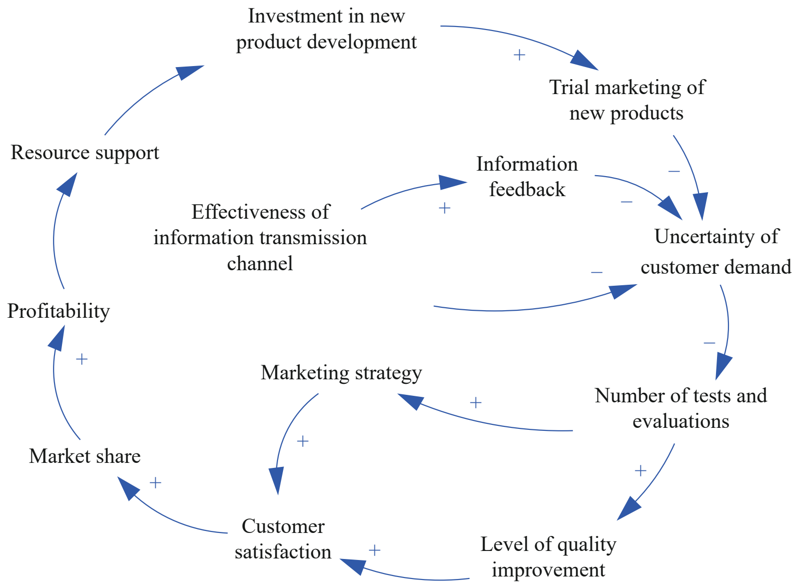


Fig. 3 Causal loop diagram of the synergy process in market development stage

4.3 Stock-flow diagram

In the system dynamics approach, the next step is to develop the stock-flow diagram based on the causal loop diagram. The stock-flow diagram is the model that can be run on the computer. The main difference between the causal loop diagram and the stock-flow diagram is that the causal loop diagram is drawn by arrows, whereas the stock-flow diagram should include equations to allow simulation [27]. Based on the causal loop diagram presented in Fig. 1 to Fig. 3, the stock-flow diagram of the impact of the synergy between technology management and technological capability on new product development in different stages can be developed as Fig. 4, Fig. 5, and Fig. 6.

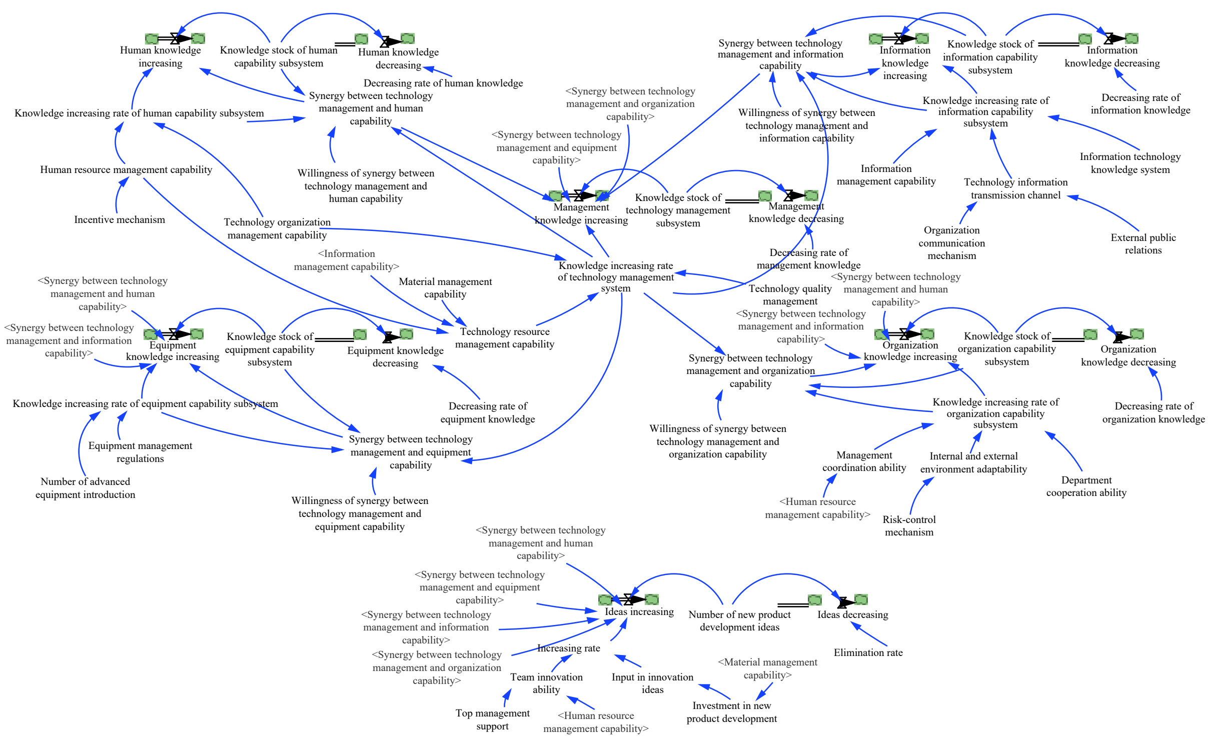


Fig. 4 Stock-flow diagram of the synergy process in concept development stage

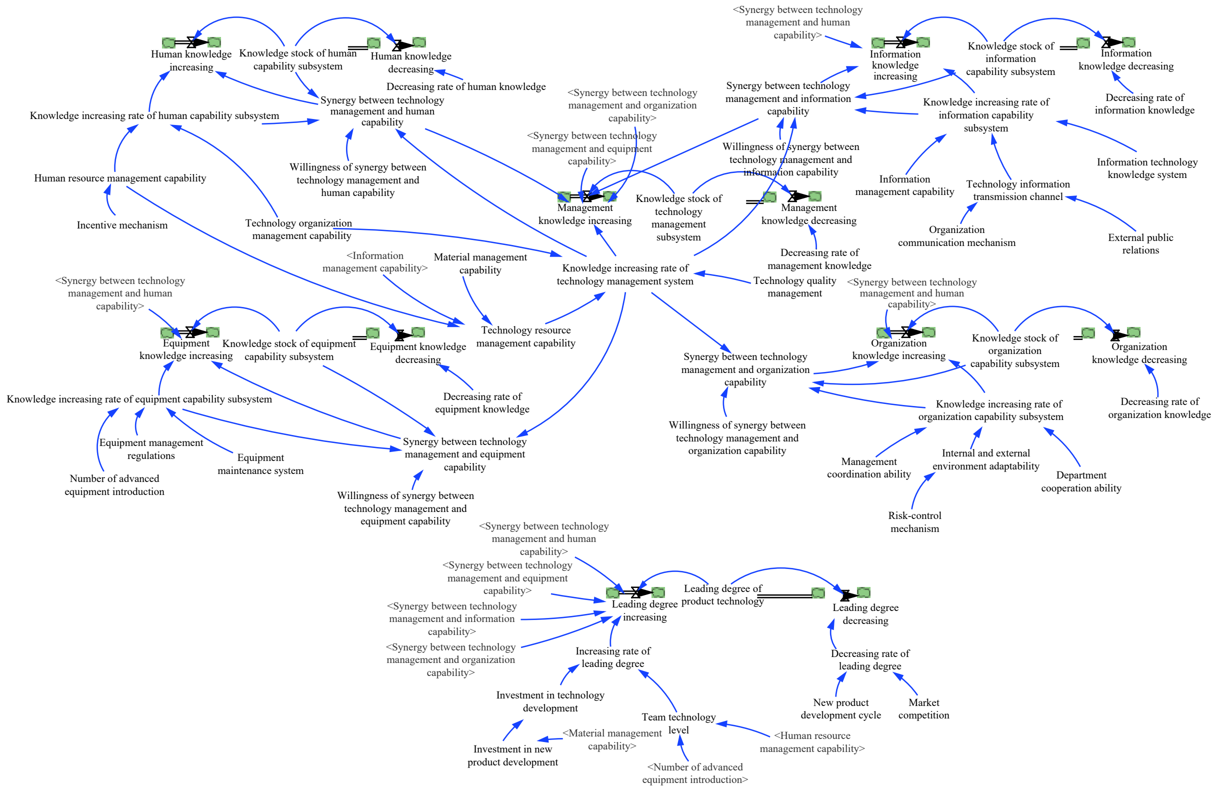


Fig. 5 Stock-flow diagram of the synergy process in product development stage

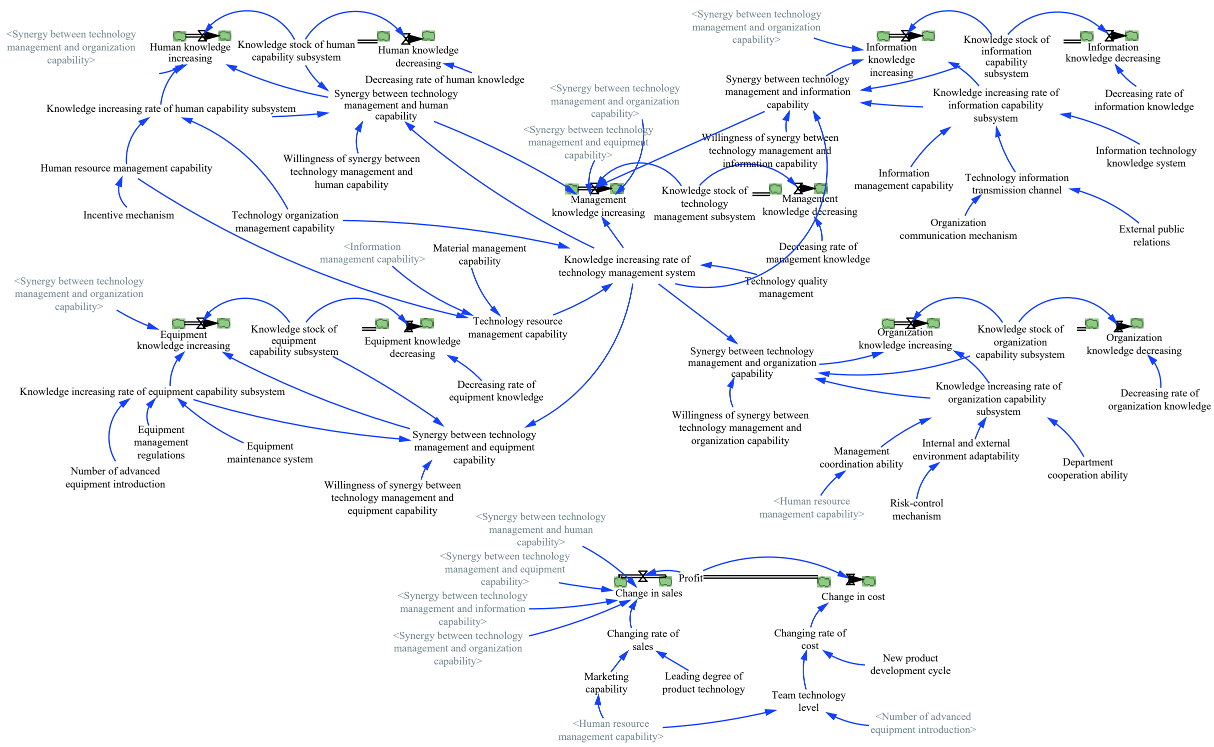


Fig. 6 Stock-flow diagram of the synergy process in market development stage

4.4 Mathematical formulation

There are three types of variables in the stock-flow diagram, namely stock variable, flow variable, and auxiliary variable. The variable types and initial values of the variables in the three stock-flow diagrams are shown in Table 1.

Table 1 Variable types and initial values

Variable name	Variable type	Initial value
Knowledge stock of human capability subsystem	Stock	1
Human knowledge increasing	Flow	—
Human knowledge decreasing	Flow	—
Decreasing rate of human knowledge	Auxiliary variable	0.1
Knowledge increasing rate of human capability subsystem	Auxiliary variable	—
Human resource management capability	Auxiliary variable	—
Incentive mechanism	Auxiliary variable	1
Knowledge stock of information capability subsystem	Stock	1
Information knowledge increasing	Flow	—
Information knowledge decreasing	Flow	—
Decreasing rate of information knowledge	Auxiliary variable	0.1
Knowledge increasing rate of information capability subsystem	Auxiliary variable	—
Information management capability	Auxiliary variable	1
Technology information transmission channel	Auxiliary variable	—
Information technology knowledge system	Auxiliary variable	—
Organization communication mechanism	Auxiliary variable	1
External public relations	Auxiliary variable	1
Knowledge stock of equipment capability subsystem	Stock	1
Equipment knowledge increasing	Flow	—
Equipment knowledge decreasing	Flow	—
Decreasing rate of equipment knowledge	Auxiliary variable	0.1
Knowledge increasing rate of equipment capability subsystem	Auxiliary variable	—
Equipment management regulations	Auxiliary variable	1
Number of advanced equipment introduction	Auxiliary variable	1
Knowledge stock of organization capability subsystem	Stock	1
Organization knowledge increasing	Flow	—
Organization knowledge decreasing	Flow	—
Decreasing rate of organization knowledge	Auxiliary variable	0.1
Knowledge increasing rate of organization capability subsystem	Auxiliary variable	—
Management coordination ability	Auxiliary variable	—
Internal and external environment adaptability	Auxiliary variable	—
Department cooperation ability	Auxiliary variable	1
Risk-control mechanism	Auxiliary variable	1
Knowledge stock of technology management subsystem	Stock	1
Management knowledge increasing	Flow	—
Management knowledge decreasing	Flow	—
Decreasing rate of management knowledge	Auxiliary variable	0.1
Knowledge increasing rate of technology management system	Auxiliary variable	—
Technology resource management capability	Auxiliary variable	—
Technology organization management capability	Auxiliary variable	1
Technology quality management capability	Auxiliary variable	1

Continued

Variable name	Variable type	Initial value
Material management capability	Auxiliary variable	1
Number of new product development ideas	Stock	1
Ideas increasing	Flow	—
Ideas decreasing	Flow	—
Elimination rate	Auxiliary variable	0.85
Increasing rate	Auxiliary variable	—
Team innovation ability	Auxiliary variable	—
Input in innovation ideas	Auxiliary variable	—
Top management support	Auxiliary variable	1
Investment in new product development	Auxiliary variable	—
Leading degree of product technology	Stock	1
Leading degree increasing	Flow	—
Leading degree decreasing	Flow	0.1
Increasing rate of leading degree	Auxiliary variable	—
Investment in technology development	Auxiliary variable	—
Team technology level	Auxiliary variable	—
Decreasing rate of leading degree	Auxiliary variable	—
New product development cycle	Auxiliary variable	1
Market competition	Auxiliary variable	1
Profit	Stock	1
Change in sales	Flow	—
Change in cost	Flow	—
Changing rate of sales	Auxiliary variable	—
Changing rate of cost	Auxiliary variable	—
Marketing capability	Auxiliary variable	—
Leading degree of product technology	Auxiliary variable	1
Synergy between technology management and human capability	Auxiliary variable	—
Synergy between technology management and information capability	Auxiliary variable	—
Synergy between technology management and equipment capability	Auxiliary variable	—
Synergy between technology management and organization capability	Auxiliary variable	—
Willness of synergy between technology management and human capability	Auxiliary variable	0.1
Willness of synergy between technology management and information capability	Auxiliary variable	0.1
Willness of synergy between technology management and equipment capability	Auxiliary variable	0.1
Willness of synergy between technology management and organization capability	Auxiliary variable	0.1

The relationship between the variables should be described as equations. Technology management and technological capability are both the knowledge firms own, and their development can be described by the knowledge stock development. Based on previous research [28], we have the equations in the three stock-flow diagrams.

Knowledge stock of human capability subsystem= $\int_{t_0}^{t}$(Human knowledge increasing(s)−Human knowledge decreasing)(s)ds+Knowledge stock of human capability subsystem(t_0)

Human knowledge increasing=Knowledge stock of human capability subsystem×Knowledge increasing rate of human capability subsystem

Knowledge increasing rate of human capability subsystem=Human resource management capability×Technology organization management capability

Knowledge stock of information capability subsystem= $\int_{t_0}^{t}$(Information knowledge increasing(s)−Information knowledge decreasing(s))ds+Knowledge stock of information capability subsystem(t_0)

Information knowledge increasing=Knowledge stock of information capability subsystem×Knowledge increasing rate of information capability subsystem

Knowledge increasing rate of information capability subsystem=Information management capability×Technology information transmission channel×Information technology knowledge system

Technology information transmission channel=Organization communication mechanism × Weight + External public relations×Weight

Knowledge stock of equipment capability subsystem= $\int_{t_0}^{t}$(Equipment knowledge increasing(s)−Equipment knowledge decreasing(s))ds+Knowledge stock of equipment capability subsystem(t_0)

Equipment knowledge increasing=Knowledge stock of equipment capability subsystem×Knowledge increasing rate of equipment capability subsystem

Knowledge increasing rate of equipment capability subsystem=Equipment management regulations×Number of advanced equipment introduction

Knowledge stock of organization capability subsystem=$\int_{t_0}^{t}$(Organization knowledge increasing(s)−Organization knowledge decreasing(s))ds+Knowledge stock of organization capability subsystem(t_0)

Organization knowledge increasing=Knowledge stock of organization capability subsystem × Knowledge increasing rate of organization capability subsystem

Knowledge increasing rate of organization capability subsystem=Management coordination ability × Internal and external environment adaptability × Department cooperation ability

Knowledge stock of technology management subsystem=$\int_{t_0}^{t}$(Management knowledge increasing(s)−Management knowledge decreasing(s))ds+Knowledge stock of technology management subsystem(t_0)

Management knowledge increasing=Knowledge stock of technology management subsystem×Knowledge increasing rate of technology management system+Synergy between technology management and human capability+Synergy between technology management and information capability+Synergy between technology management and equipment capability+Synergy between technology management and organization capability

Knowledge increasing rate of technology management system=Technology resource management capability×Technology organization management capability×Technology quality management capability

Technology resource management capability=Human resource management capability × Weight + Material management capability × Weight + Information management capability×Weight

Number of new product development ideas=$\int_{t_0}^{t}$(Ideas increasing(s)−Ideas decreasing(s))ds+Number of new product development ideas(t_0)

Ideas increasing=Number of new product development ideas×Increasing rate+Synergy between technology management and human capability+Synergy between technology management and information capability+Synergy between technology management and equipment capability+Synergy between technology management and organization capability

Increasing rate=Team innovation ability×Input in innovation ideas

Team innovation ability=Human resource management capability × Weight + Top management support × Weight

Leading degree of product technology=$\int_{t_0}^{t}$(Leading degree increasing(s) − Leading degree decreasing(s))ds + Leading degree of product technology(t_0)

Leading degree increasing=Leading degree of product technology×Increasing rate of leading degree + Synergy between technology management and human capability + Synergy between technology management and information capability + Synergy between technology management and equipment capability + Synergy between technology management and organization capability

Increasing rate of leading degree=Investment in technology development×Team technology level

Team technology level=Human resource management capability×Weight+Number of advanced equipment introduction×Weight

Leading degree decreasing=Leading degree of product technology×Decreasing rate of leading degree

Decreasing rate of leading degree=New product development cycle×Market competition

Profit=$\int_{t_0}^{t}$(Change in sales(s)−Change in cost(s))ds+Profit(t_0)

Change in sales=Profit×Changing rate of sales+Synergy between technology management and human capability+Synergy between technology management and information capability+Synergy between technology management and equipment capability+Synergy between technology management and organization capability

Change in cost=Profit×Changing rate of cost

Changing rate of sales=Marketing capability×Leading degree of product technology

Changing rate of cost=New product development cycle/Leading degree of product technology

From the knowledge perspective, the synergy between technology management and technological capability can increase the knowledge stock of system. Based on previous research [28], we can derive the synergy between technology management and technological capability.

Synergy between technology management and human capability=Exp(Willingness of synergy between technology management and human capability×ABS(Knowledge increasing rate of technology management system−Knowledge increasing rate of human capability subsystem))×Knowledge stock of human capability subsystem×(Knowledge increasing rate of technology management system+Knowledge increasing rate of human capability subsystem)×0.5

Synergy between technology management and information capability=Exp(Willingness of synergy between technology management and information capability×ABS (Knowledge increasing rate of technology management system−Knowledge increasing rate of information capability subsystem))×Knowledge stock of information capability subsystem×(Knowledge increasing rate of technology management system+Knowledge increasing rate of information capability subsystem)×0.5

Synergy between technology management and equipment capability=Exp(Willingness of synergy between technology management and equipment capability× ABS (Knowledge increasing rate of technology management system−Knowledge increasing rate of equipment capability subsystem))×Knowledge stock of equipment capability subsystem×(Knowledge increasing rate of technology management system+Knowledge increasing rate of equipment capability subsystem)×0.5

Synergy between technology management and organization capability=Exp(Willingness of synergy between technology management and organization capability× ABS (Knowledge increasing rate of technology management system−Knowledge increasing rate of organization capability subsystem))×Knowledge stock of organization capability subsystem×(Knowledge increasing rate of technology management system+Knowledge increasing rate of organization capability subsystem)×0.5

5. Simulation results

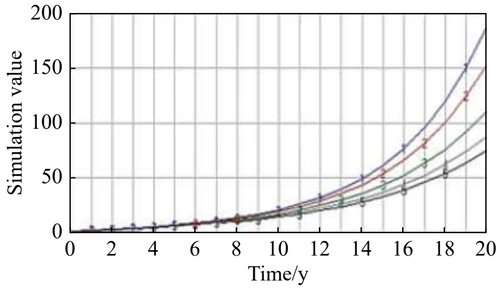
5.1 Model validation

This paper uses several tests to verify the model validation. This paper firstly tests the structural validity of the model. The system dynamics model in this paper is constructed on the basis of theoretical analysis, which ensures the rationality of the model construction. In addition, each equation is checked to confirm the left part is the same with the right part. Secondly, in this paper we conduct extreme-condition test to check whether the system dynamics model behaves realistically. For example, we check if technology management and technological capability are equal to zero, then whether new product development performance remains stable. The results are consistent with reality, indicating that the system dynamics model constructed in this paper is valid.

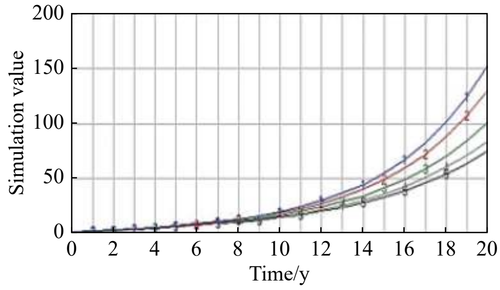
This paper then uses Vensim software to carry out the simulation. The simulation period is 20 years. This paper firstly simulates the impact of the synergy between technology management and technological capability on new product development. Then, this paper further distinguishes the leading synergy processes between technology management and technological capability in different new product development stages by comparing the changes of different stages of new product development performance brought by the synergy between technology management and technological capability.

5.2 Simulation 1: the impact of the synergy between technology management and technological capability on new product development

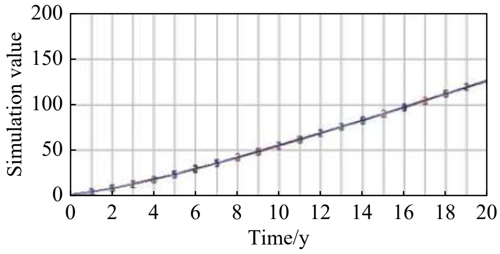
In this simulation, we set the Willingness of synergy between technology management and human capability, the Willingness of synergy between technology management and information capability, the Willingness of synergy between technology management and equipment capability, and the Willingness of synergy between technology management and organization capability as 0, 0.2, 0.4, 0.6, and 0.8 respectively. In order to observe the impact of the synergy between technology management and technological capability on new product development respectively, when verifying one of the synergy effects, setting other synergy willingness as 0. The simulation results are shown in Fig. 7.



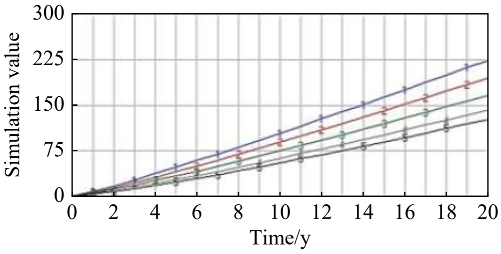
(a) Number of new product development ideas achieved by the synergy between technology management and human capability



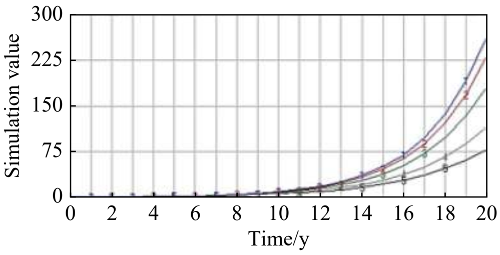
(b) Number of new product development ideas achieved by the synergy between technology management and information capability



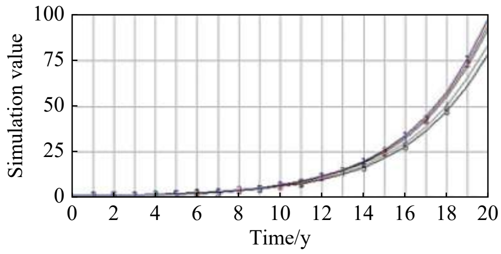
(c) Number of new product development ideas achieved by the synergy between technology management and equipment capability



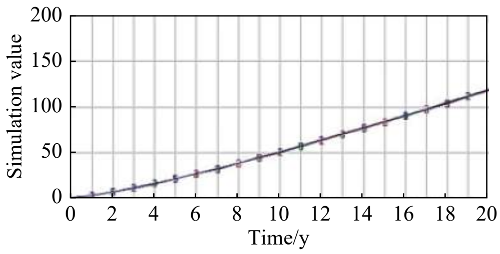
(d) Number of new product development ideas achieved by the synergy between technology management and organization capability



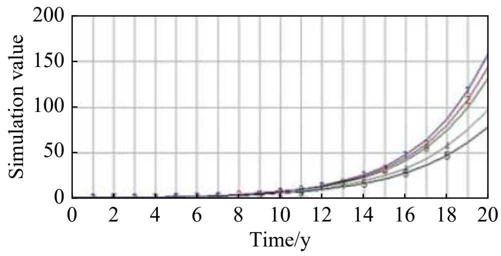
(e) Leading degree of product technology achieved by the synergy between technology management and human capability



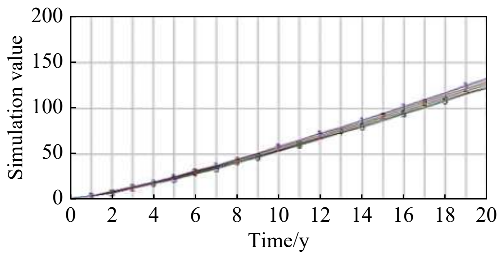
(f) Leading degree of product technology achieved by the synergy between technology management and information capability



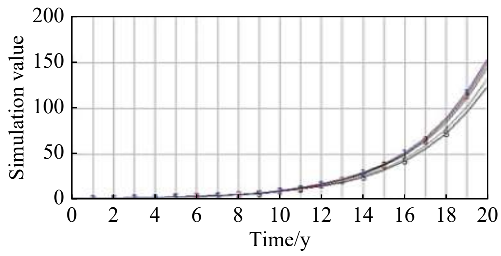
(g) Leading degree of product technology achieved by the synergy between technology management and equipment capability



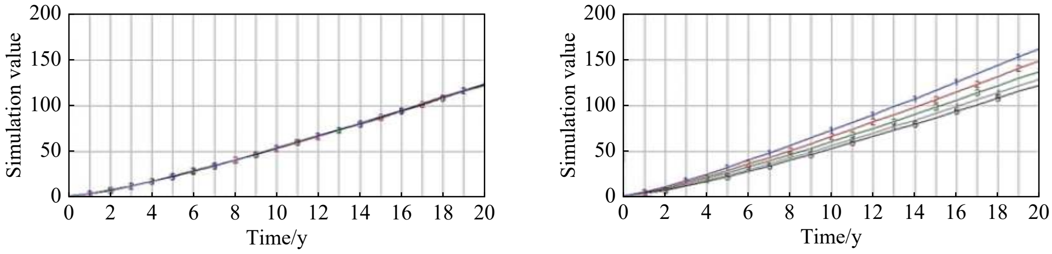
(h) Leading degree of product technology achieved by the synergy between technology management and organization capability



(i) Profit achieved by the synergy between technology management and human capability



(j) Profit achieved by the synergy between technology management and information capability



(k) Profit achieved by the synergy between technology management and equipment capability

(l) Profit achieved by the synergy between technology management and organization capability

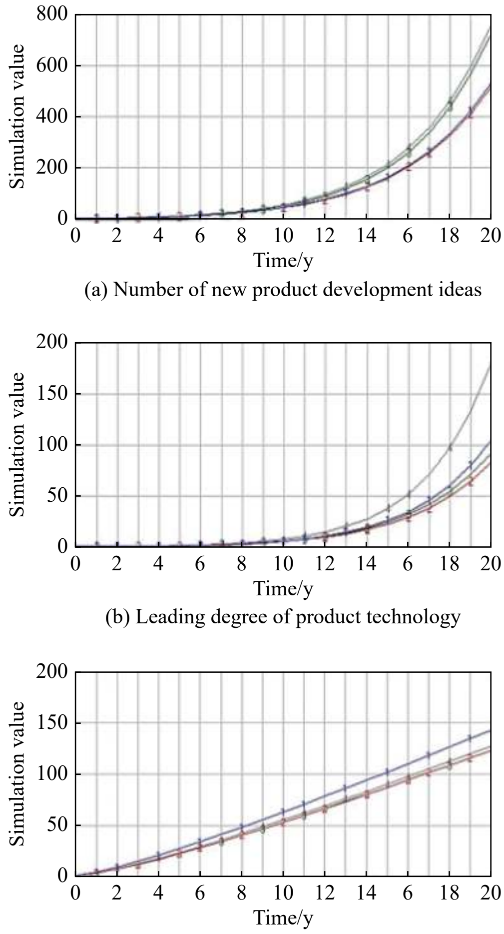
—:Synergy willingness=0; —:Synergy willingness=0.4; —:Synergy willingness=0.2; —:Synergy willingness=0.8.

Fig. 7 Simulation results of impact of synergy between technology management and technological capability on new product development

In Fig. 7, the black line represents the synergy willingness is 0, the gray line represents the synergy willingness is 0.2, the green line represents the synergy willingness is 0.4, the red line represents the synergy willingness is 0.6, and the blue line represents the synergy willingness is 0.8. The number of new product ideas represents concept development performance, the leading degree of product technology represents product development performance and the profit represents market development performance. Overall, the above figures show that with the increasing of the synergy between technology management and technological capability, the new product development performance increases. Therefore, the synergy between technology management and technological capability has positive impact on new product development. Creating new products requires both resources and capabilities. Technological capability, one of the most important resources for new product development, can be very helpful for firms to obtain the knowledge they need [15], While technology management is the capability to make effective use of technological capability [5]. Therefore, technology management and technological capability should have complementary relationship, and this relationship could provide significant benefits for new product development, such as stimulating creativity. In addition, the simulation results also show that different synergies have different effects on new product development performance of different stages. Therefore, we further identify the leading synergy processes between technology management and technological capability in different new product development stages.

5.3 Simulation 2: the leading synergy processes between technology management and technological capability in different new product development stages

In this simulation, we set the willingness of synergy between technology management and human capability, the willingness of synergy between technology management and information capability, the willingness of synergy between technology management and equipment capability, and the willingness of synergy between technology management and organization capability as 0.5, 0.5, 0.5, and 0.5 respectively. Then, by comparing the changes of new product development performance of different stages, we can distinguish the leading synergy processes between technology management and technological capability. That is, comparing to the non-leading synergy processes, the leading synergy processes will improve new product development performance more significantly. The simulation results are shown in Fig. 8.



(a) Number of new product development ideas

(b) Leading degree of product technology

(c) Profit

Fig. 8 Simulation results of the leading synergy processes in different new product development stages

In Fig. 8, the gray line represents the synergy between technology management and human capability, the green line represents the synergy between technology management and information capability, the red line represents the synergy between technology management and equipment capability, and the blue line represents the synergy between technology management and organization capability.

It can be observed that, in the concept development stage, the synergy between technology management and human capability and the synergy between technology management and information capability have more positive impact. Therefore, in the concept development stage, the leading synergy processes are the synergy between technology management and human capability and the synergy between technology management and information capability. In the product development stage, the synergy between technology management and human capability has more positive impact. Therefore, in the product development stage, the leading synergy process is the synergy between technology management and human capability. In the marketing development stage, the synergy between technology management and organization capability has more positive impact. Therefore, in the marketing development stage, the leading synergy process is the synergy between technology management and organization capability.

It has been argued that new product development will be more likely to be success when a firm employs stage-specific patterns integration than attempts to integrate all during all new product development stages [22]. Based on this understanding, this paper proposes that the leading synergy processes between technology management and technological capability may change across different new product development stages. The reason is that the tasks are different in different new product development stages. The concept development stage generally needs to generate and select new product ideas for the next stage. Human capability and information capability play central roles in this stage because they are critical for producing new product ideas. Therefore, the synergy between technology management and human capability and the synergy between technology management and information capability are the leading synergy processes in this stage. The product development stage focuses on developing actual new products based on the concepts developed in the concept development stage, and these activities should be accomplished by human capability. Moreover, human capability can be a bridge in this stage to solve the potential conflicts between manufacturing and the other functions. Therefore, the synergy between technology management and human capability is the leading synergy process in this stage.

The market development stage encompasses tasks related to the market launch. Organization capability is important in this stage because it helps firms to formulate effective market launch tactics. Therefore, the synergy between technology management and organization capability is the leading synergy process in this stage. Altogether, this paper finds that the leading synergy processes between technology management and technological capability will not always be equal in different new product development stages, which demonstrates that new product development is a complex activity.

6. Conclusions

In this paper, we develop a system dynamics model to simulate the impact of the synergy between technology management and technological capability on new product development. The results show that the synergy between technology management and technological capability has positive impact on new product development. Moreover, the leading synergy processes in different new product development stages are different. To be specific, the leading synergy processes in the concept development stage are the synergy between technology management and human capability and the synergy between technology management and information capability. The leading synergy process in the product development stage is the synergy between technology management and human capability. The leading synergy process in the marketing development stage is the synergy between technology management and organization capability.

The results of this paper advance the current literature in several aspects. Firstly, we contribute to the literature on the antecedents of new product development. Although previous research has indicated that there exists interactive relationship between technology management and technological capability, little research investigates the impact of their synergy relationship on new product development. This paper finds that the synergy between technology management and technological capability has positive impact on new product development, which provides new understandings about how to achieve new product development.

Secondly, this paper further offers a more nuanced view about how the synergy between technology management and technological capability affects new product development by identifying the leading synergy processes in different new product development stages. This paper finds that in the concept development stage, the leading synergy processes are the synergy between technology management and human capability and the synergy between technology management and information capability. In the product development stage, the leading synergy process is the synergy between technology management and human capability. In the marketing development stage, the leading synergy process is the synergy between technology management and organization capability. These results indicate that the new product development stage is an important contingent context of the impact of the synergy between technology management and technological capability, which helps to generate a better understanding of the synergy between technology management and technological capability.

This paper also has some practical implications. The results indicate that there exist different leading synergy processes in different new product development stages. Therefore, in the concept development stage, firms should pay attention to the synergy between technology management and human capability and the synergy between technology management and information capability. The practices that can be employed for firms are the following: formulating recruitment plans to recruit more R&D employees, constructing information networks to collect relevant information, and establishing and improving human resource management system and information resource management system. While in the market development stage, the leading synergy process is the synergy between technology management and organization capability. The practices that can be employed for firms are accumulating organization management experience and optimizing organizational structure and R&D culture.

This paper also has some limitations, which leave room for future research. Firstly, the simulation model constructed in this paper could be made suitable modifications to investigate how the synergy between technology management and technological capability affects new product development in different kinds of firms, such as high technology firms and non-high technology firms. Secondly, this paper does not use case study to verify the results. Future research can improve our research by using case study to examine the results.

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