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Technological Innovation Research:
A Structural Equation Modelling Approach

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ABSTRACT

The paper explores the relationship among technological innovation, technological trajectory transition, and firms' innovation performance. Technological innovation is studied from the perspectives of innovation novelty and innovation openness. Technological trajectory transition is categorized into creative cumulative technological trajectory transition and creative disruptive technological trajectory transition. A structural equation model is developed and tested with data collected by surveying 366 Chinese firms. The results indicate that both innovation novelty and innovation openness positively affect creative cumulative technological trajectory transition as well as creative disruptive technological trajectory transition. Innovation openness and creative disruptive technological trajectory transition both positively affect firms' innovation performance. However, neither innovation novelty nor creative cumulative technological trajectory transition positively affects firms' innovation performance. Implications for managers and directions for future studies are discussed.

KEYWORDS

Creative Cumulative, Creative Disruptive, Innovation Performance, Technological Innovation, Technological Trajectory Transition

1. INTRODUCTION

Firms in emerging economies usually face a strategic dilemma, in which they need to decide whether continuing their low-cost and imitation-based competitive strategies or becoming innovation leaders who rely on R&D (Hobday et al., 2004; Xiao et al., 2013). In recent years, some industries in emerging economies have made technological progress through technology import, absorbing, and re-innovation, and gained international competitiveness, which is heavily based on low labor cost. Although the gap between these industries in emerging economies and the corresponding ones in developed countries becomes smaller, a catch-up has never occurred. When these industries in emerging economies follow the same technological trajectory, it seems that they will never catch up with those in developed countries. As the latecomers, they must adopt technological leapfrogging to achieve a catch-up.

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However, although substantial investments have been spent on R&D in emerging economies, little is known about the factors that affect firms' decision regarding the strategic dilemma. To this end, this paper analyzes firms' innovation strategies by investigating the relationship among technological innovation, technological trajectory transition, and firms' innovation performance. Technological innovation is studied from the perspectives of innovation novelty and innovation openness. Two technological trajectory transitions, namely creative cumulative technological trajectory transition and creative disruptive technological trajectory transition, are examined. A structural equation model is developed and tested with data collected by surveying 366 Chinese firms.

The results indicate that both innovation novelty (Lei et al 2020; Li 2018; Yang et al 2018; Wipulanusat et al 2020) and innovation openness positively affects creative cumulative technological trajectory transition as well as creative disruptive technological trajectory transition. Innovation openness and creative disruptive technological trajectory transition positively both affect firms' innovation performance. However, neither innovation novelty nor creative cumulative technological trajectory transition positively affects firms' innovation performance. Based on the results, this paper discusses implications for managers and directions for future studies.

2. THEORETICAL BACKGROUND AND HYPOTHESES DEVELOPMENT

2.1 Innovation Novelty and Innovation Openness

Schumpeter (1934) first presented the concept of innovation and introduced it into economic growth theory. Later, Schumpeter (1942) proposed the innovation theory, in which creative destruction was defined as the continuous change of the internal economic structure by destroying existing things and creating new things. Schumpeter (1942) also identified the two characteristics of creative destruction, namely continuity and radicalness. Utterback and Abernathy (1975) further distinguished incremental innovation and radical innovation based on the level of technologies' newness. Scholars then explored the characteristics of incremental innovation and radical innovation from diverse perspectives. For instance, Dosi (1982) defined radical innovation as extraordinary breakthroughs generated by a new paradigm. In contrast, he defined incremental innovation as normal routine along an existing technological trajectory. Freeman (1992) pointed out that radical innovation is a discontinuous process, such as the introduction of a fuel cell, whereas incremental innovation refers to the continuous improvement of an existing technology system, such as the optimization of an air filter. Christensen and Rosenbloom (1995) studied product performance trajectory based on market dimension and noted that incremental innovation is the development along a certain path, and radical innovation opens a new technological direction.

Early studies thought that Innovation was brought into the market by entrepreneurs solely (Schumpeter, 1934 and 1942). Later, studies on innovation focused on the effect of network on firms' innovation performance. Research models were presented to explore how stakeholders work together to maximize the commercial value of new ideas (Freeman & Soete, 1997; Hippel, 1995). These models highlighted the interaction in an innovation process. Particularly, innovators rely on the interaction with users, suppliers, and other stakeholders in an innovation system. For example, the open innovation model pointed out that when the advantages obtained from firms' in-house R&D reduced, they could acquire knowledge and expertise from external sources (Chesbrough, 2003).

Innovation novelty and innovation openness are the main characteristics of firms' technological innovation strategies (Achi, Salinesi, and Viscusi 2016; Chen and Lei 2020; Chen and Xie 2018; Kumar and Chanda 2018; Lei et al 2019; Li 2012,2013a,b; Li, Asunka et al 2020; Lu and Zheng 2020; Tan et al 2010; Xu, Tan, Zhen and Shen 2008). Innovation novelty involves the development of new knowledge. Firms need to decide the extent of newness in their search, either based on pre-existing knowledge (exploitation) or moving away from their current knowledge base (exploration). Therefore, innovation novelty is the extent of technological newness found in R&D projects or production processes (Bauer & Leker, 2013; Rhee et al., 2010). Innovation openness involves the sources of knowledge creation. It concerns whether innovation relies mainly on internal R&D or searching external resources. Innovation openness is the extent to which firms acquire external resources. Major external resources include R&D cooperation, strategic alliances, and licensing of technologies.

2.2 Technological Trajectory Transition

Technological trajectory is a problem-solving pattern based on a technological paradigm (Dosi, 1982). When external shock is missing, a technological trajectory will evolve along a predictable path in a technological paradigm framework. In this case, existing technologies can be challenged by the emergence of a new technological paradigm. Changes in the external environment might affect the development of an existing technological trajectory. Two point of views were proposed to describe the relationship between a new paradigm and an existing paradigm. One is creative incremental accumulation, while the other is creative destruction. Correspondingly, two evolution processes of technological trajectory transitions were identified, namely creative cumulative technological trajectory transition and creative disruptive technological trajectory transition.

The view of creative incremental accumulation argues that a new technological paradigm does not destroy the existing one. Instead, the former supplements and extends the latter (Andersen, 1998; Bergek et al., 2013; Patel and Pavitt, 1994; Pavitt, 1986). An existing technology will continue working or even hold the dominating position after a new technology emerges. When the existing technology encounters a bottleneck in its development, firms will offset the shortages of the existing technology by looking for new knowledge and external technologies to improve their products' performance. Accordingly, we define creative cumulative technological trajectory transition as the process of problem solving with which firms search new capabilities and technologies beyond their existing knowledge base to supplement and to extend their existing capabilities and technologies. In creative cumulative technological trajectory transition, technological trajectory does not experience fundamental transformation. Instead, existing technological path is optimized through the combination of the new technology and the existing technology. Such path optimization usually leads to the improvement of firms' product performance.

The view of creative disruption argues that a fundamental transformation occurs because a new paradigm replaces the existing one (Christensen &Rosenbloom, 1995; Dosi, 1982). According to Dosi (1982), continuous changes occur when a technological paradigm generates improvements along a technological trajectory, whereas discontinuous changes occur when a new technological paradigm emerges. The emergence of a new technological paradigm will interrupt the technological development track determined by the existing technological paradigm. Technological development will jump into a new track. Therefore, the technology leaps from one continuous s-curve to a new curve (Olin & Shani, 2003). Such a change will generate fierce technological competition and even cause the collapse of the existing competition model (Anderson & Tushman, 1990). The new paradigm represents the discontinuity of the development track. It will redefine the implication of technological progress by pointing out new technological problem categories and guiding different technological development directions. Accordingly, creative disruptive technological trajectory transition is the process in which a new technology replaces an existing technology for achieving a completely different problem-solving method. Technological trajectory will experience a complete transformation. Instead of following the existing path, the new technological development will head for a new direction. Therefore, creative disruptive technological trajectory transition will destroy firms' existing capabilities and drive firms to develop new capabilities required by the new technological direction. In this problem-solving process, new products might be created.

2.3 Technological Innovation and Technological Trajectory Transition

In the initial stage, when a radical innovation develops insufficiently and encounters structural strength originated from the incumbent regime (Markard & Truffer,2008; Smith et al.,2010), a new technology is less likely to replace the existing one that is dominated in the market. In this case, the new technology and the old one coexist (Geels & Schot, 2007). When the pressure from external environment becomes stronger, firms' technological development will encounters a bottleneck. They look for external knowledge and technologies to break the bottleneck. They will combine new and old technologies and improve their products.

In practice, radical innovations will get continuous improvement. When a radical innovation is fully developed, the possibility that firms shift to new technologies increases. Thus, radical innovations contribute to the formation of more prominent technological capabilities. They generate completely new performance attributes to users. Technological changes along established paths are more endogenous to common economic mechanisms. In contrast, radical innovations break existing trajectories and destroy firms' existing abilities and their external network (Dolfsma & Leydesdorff, 2009). They drive firms to develop new abilities along new technological trajectory and to achieve creative disruptive technological trajectory transition. Accordingly, the following hypotheses are proposed.

H1.1 Innovation novelty positively affects creative cumulative technological trajectory transition.
H1.2 Innovation novelty positively affects creative disruptive technological trajectory transition.

Due to path-dependence of technological progress and "Not Invented Here" syndrome, employees usually do not notice the technological development out of the existing technologies. When responding to external pressures, firms first look for internal resources, such as endogenous regeneration and trajectory reposition (Smith et al., 2005). When external pressures rise and internal resources are not enough for resolving the existing technological problems, firms look for external resources to enhance their existing regime's problem-solving ability, including R&D cooperation, strategic alliances, and merging. Openness helps firms, particularly incumbent ones, to get more external resources for fixing their regime problems. External resources help them to extend their abilities and to improve their products' performance.

Firms that are engaged in radical innovations need to make a choice between implementing in-house R&D and acquiring external resources. If they choose to implement in-house R&D, firms can explore new technologies to get competitive advantages. The open innovation model indicates that the advantages originated from in-house R&D will decrease (Chesbrough, 2003). Thus, firms tend to rely on external knowledge and expertise for their innovation. In other words, breakthrough of new technologies drive firms to abandon their old technologies and to adopt new ones. Accordingly, the following hypotheses are proposed.

H2.1 Innovation openness positively affects creative cumulative technological trajectory transition.
H2.2 Innovation openness positively affects creative disruptive technological trajectory transition.

2.4 Technological Innovation and Innovation Performance

Scholars have defined and measured innovation performance from diverse perspectives. For instance, Utterback and Abernathy (1975) noted that innovation performance involves product innovation and process innovation and that the two innovation results are intimately related. Damanpour and Gopalakrishnan (2001) pointed out that product innovation involves products and services that aim to meet users' needs, whereas process innovation involves new elements introduced into production. Menor and Roth (2008) analyzed innovation performance from the perspectives of profits, profit increases, investment returns of innovation projects, and profitability. Hagedoorn and Cloodt (2003) noted that from a narrow sense, innovation performance refers to the commercialization degree of technical inventions and that from a broad sense, innovation performance involves patents, technical improvements, and innovation outcomes acquired from the process of new ideas generation. Patent is the explicit expression of technological innovation and can be used as an indicator for technological abilities accumulated by firms in the process of innovation (Grupp, 1998; Kumaresan & Miyazaki, 1999). In prior studies, patent is adopted to measure the outputs of innovation system. In addition, the evolution of patent structure can reflect technological changes (Andersen, 1998). In existing literature, innovation performance is measured by efficiency and effectiveness.

This paper defines innovation performance as innovation outputs, effects, and speed acquired in the innovation process. Innovation outputs and effects involve effectiveness, including patents, new products, sales growth, investment return, competitive advantage, and customer satisfaction generated by new products. Innovation speed involves efficiency and focuses on the development and launch speed of new products.

Creative destruction refers to the determined cost or quality advantage that radical innovations generate (Schumpeter, 1942). It makes new products more competitive. Strong innovation novelty is likely to cause performance breakthrough. Consequently, strong innovation novelty leads to more knowledge creation, and generates more innovation outputs, such as intellectual property rights and new products (Katila & Ahuja, 2002). Researches on radical innovation proved that introducing new products to the market generates advantages (Therrien et al., 2011). Accordingly, the following hypothesis is proposed.

H3 Innovation novelty positively affects firms' innovation performance.

The open innovation model indicates that the advantages, which firms acquire from in-house R&D decrease, and that firms which are good at utilizing external resources usually achieve good innovation performance (Chesbrough, 2003). Relying on external strength can shorten innovation cycles and improve innovation efficiency. Chen and Chen (2009) noted that achieving externally resources is helpful to offset the insufficiency of internal innovation resources, and that innovation efficiency can be improved by effectively integrating internal and external resources. He and Zeng (2013) pointed out that the effect of independent R&D investment on firms' competitiveness is positively affected by the degree of firms' openness. In other words, openness facilitates the positive effect of independent R&D investment on firms' competitiveness. Accordingly, the following hypothesis is proposed.

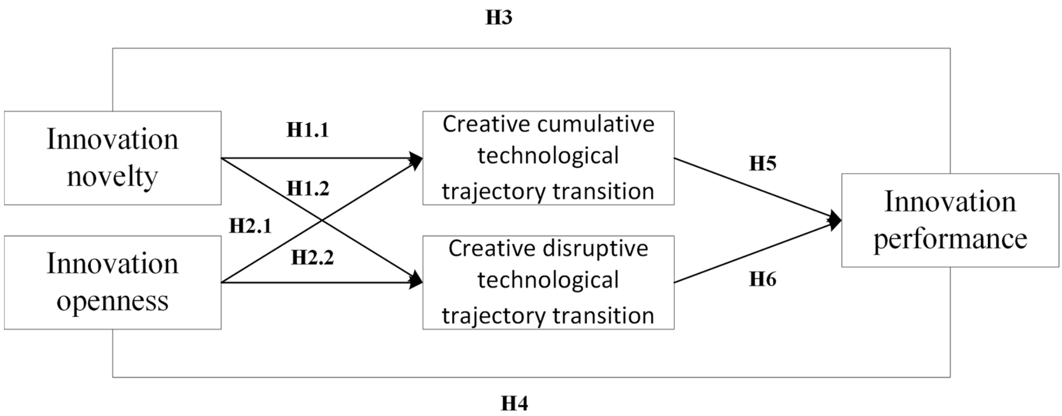
H4 Innovation openness positively affects firms' innovation performance.

2.5 Technological Trajectory Transition and Innovation Performance

Pavitt (1986) proposed the concept of creative accumulation, which describes the process of generating new knowledge based on existing knowledge. Facing with the threats from new technologies, existing technologies will struggle to survive by improving their performances via accelerating innovation speed and expanding innovation scales (Bergek et al., 2013). The reaction of existing technologies might generate some new knowledge, which produce innovation outputs, such as intellectual property rights and new products (Katila & Ahuja, 2002). Cooper and Schendel (1976) found that once new technologies are introduced, existing technologies will achieve continuous improvement until the highest stage of technological development is achieved. Meanwhile, accumulation might generate entry barriers and weaken challengers' advantages (Bergek et al., 2013). Therefore, incumbent firms tend to form a new trajectory by integrating new technologies with the existing technological trajectory for quickly improving the performance of their products. Accordingly, the following hypothesis is proposed.

H5 Creative cumulative technological trajectory transition positively affects firms' innovation performance.

Figure 1. The research model



Creative destruction will generates determined cost or quality advantages (Schumpeter, 1942). Technology substitution is likely to appear because the performance of new technologies will exceed that of the old ones (Adner & Kapoor, 2016). Consequently, the performance of new technologies is likely to exceed that of existing technologies when technological trajectory transition occurs. In this way, new technologies will get excellent reactions in market. The old paradigm constrains the development boundaries of the existing technological trajectory, whereas the new paradigm provides new technological elements, which generate many technological and economic trade patterns. As result, the new technological trajectory must be differentiated from the existing technological progress for producing higher efficiency and lower cost (Dosi, 1988; Rennings et al., 2013). The slope of a new technological trajectory usually exceeds that of an existing technological trajectory when technological trajectory transition occurs (Adner & Kapoor, 2016). This implies faster improvement in performance generated by new technologies. Accordingly, new technologies generate more knowledge and produce more invents and creation. We therefore expect:

H6 Creative disruptive technological trajectory transition positively affects firms' innovation performance.

Figure 1 shows the research model that illustrate the relationship among technological innovation, technological trajectory transition, and firms' innovation performance.

3. RESEARCH METHOD

3.1 Sample and Data Collection

This study developed a questionnaire and conducted a survey to test the hypotheses. Questionnaires were sent to R&D managers or directors of technology center of firms in industrial parks in five provinces in China, including Liaoning, Jilin, Shandong, Zhejiang, and Guangdong. The survey began in May 2008 and stopped in June 2008. Altogether, we received 412 responses, of which 366(or 88.8%) were valid.

The questionnaire contains two parts. Part 1 collects basic information of firms. Part 2 contains questions that measure innovation novelty, innovation openness, creative cumulative technological trajectory transition, creative disruptive technological trajectory transition, and innovation performance with 5-point Likert- scales ranging from 1=strongly disagree to 5=strongly agree.

Table 1. Items for measuring innovation novelty

Items	Measurements
NOV1	In the process of new product development or manufacturing improvement, we will encounter greater risks in introducing new equipment.
NOV2	In the process of new product development or manufacturing improvement, we will encounter greater risks in the replacement of old suppliers by new suppliers.
NOV3	In the process of new product development or manufacturing improvement, we will encounter greater risks in hiring employees with technical knowledge of new domain.
NOV4	In the process of new product development or manufacturing improvement, we will encounter greater risks in investing new manufacturing technologies.

3.2 Measurements

Innovation novelty (NOV) refers to the newness of technologies adopted in R&D. It concerns whether firms' R&D is based on their existing knowledge or apart from exploring new knowledge. Existing literatures have investigated innovation novelty from the perspectives of customers and firms. The customer perspective focuses on the benefits and characteristics provided by new products, such as advantages, better functions, improved performance, and value increment brought to market (Danneels & Kleinschmidt, 2001; Leifer et al., 2000). The firm perspective focuses on the quantity of resources, development cycle, and technological changes required by radical innovation (Hall & Andriani, 2003; Landry et al., 2002). In this paper, the firm perspective is adopted.

Amara et al. (2008) correlated innovation novelty with four forms of knowledge defect, including technological uncertainty, technical inexperience, business inexperience, and technology costs. They measure innovation novelty with five risks that firms encounter in their innovation process. Based on the measurement in Amara et al. (2008), this paper develops four items to measure innovation novelty as shown in Table 1.

Innovation openness (OPE) refers to the degree of utilizing external resources in R&D. Chesbrough (2004) noted that openness could be measured by the amount of projects that firms offered their partners for achieving development. Similarly, Knudsen (2006) measured openness with firms' external sources for innovation. Laursen and Salter (2006) measured openness with breadth and depth of firms' external exploration. Exploration breadth refers to the numbers of firms' external sources or channels. Exploration depth refers to the amount of firms' external sources or channels that can be utilized. Bahemia and Squire (2010) suggested to measure openness with the numbers of firms' new and existing partners. Zhang et al. (2015) measured openness with 10 items from firms' inbound and outbound dimensions. We revise the scale developed by Zhang et al. (2015) and measure openness with four items as shown in Table 2.

Creative cumulative technological trajectory transition (CUM) means that firms supplement and extending their existing technologies and capabilities with new technologies and capabilities to achieve a different problem-solving method and to improve the performance of their products. This trajectory transition is full of accumulation and incremental changes. To our best knowledge, there is no measurement available for examining creative cumulative technological trajectory transition. Thus, we develop five items from the perspectives of technology, capability, and process/products to measure cumulative technological trajectory transition. Table 3 shows the five items.

We define creative disruptive technological trajectory transition (DES) as a fundamental transformation of problem-solving method with which firms completely substitute their existing technologies with new technologies. In this trajectory evolution model, firms gain destructive abilities and a fundamental transformation of trajectory occurs. Firms abandon the abilities they accumulate along their existing technological trajectory and develop new abilities along a new technological direction. There is no measurement for examining creative disruptive technological trajectory

Table 2. Items for measuring innovation openness

Items	Measurements
OPE1	Usually introducing knowledge and technologies outside the firms.
OPE2	Positively searching and utilizing external knowledge and technologies in R&D process, such as research institutes, universities, suppliers, customers, and competitors.
OPE3	Positively searching for cooperation with external institutes in the commercialization activities of new technologies or new products, such as license, open source cooperation, technology transfer, and encouraging entrepreneurship.
OPE4	Selling intellectual property right to acquire commercial value.

Table 3. Items for measuring creative cumulative technological trajectory transition

Items	Measurements
CUM1	When facing with the challenges of new technology, we will not abandon existing technology.
CUM2	When existing technology could not meet users' needs, we will supplement and extend it with new technology.
CUM3	We will search for new ability out of existing knowledge base to extend existing ability.
CUM4	We will integrate existing technology with new technology to acquire a different problem-solving method.
CUM5	We will integrate existing technology with new technology to improve product performance.

transition in the existing literatures. Thus, we develop five items from the perspectives of technology, capability, and process/products to measure creative disruptive technological trajectory transition. The items are shown in Table 4.

Innovation performance (PER) refers to the innovation outputs, effects, and speed that firms acquire in their innovation process. Several approaches have been adopted by scholars to measure firms' innovation performance. For example, Hagedoorn and Cloodt (2003) measured firms' innovation performance with R&D investment, patent applications, patent citations, and new product development. Alegre and Chiva (2013) chose effectiveness of product innovation, process innovation effectiveness and efficiency of innovation to measure firms' innovation performance. Mallén et al. (2015) measured firms' organizational performance with customer loyalty, sales growth, profitability, and the rate of return on investment. Santos-Vijande et al. (2012) examined firms' innovation performance by comparing the growth of sales, market shares, and profits between firms and their competitors. Qian et al. (2010) investigated firms' innovation performance by checking their new products/services

Table 4. Items for measuring creative disruptive technological trajectory transition

Items	Measurements
DES1	When new technology emerges, we will substitute existing technology with new technology.
DES2	When existing technology does not meet users' needs, we will shift to new technology.
DES3	We will destroy existing abilities and develop new abilities in new technological direction.
DES4	We will substitute existing technology with new technology to achieve a complete transformation of problem-solving method.
DES5	We will substitute existing technology with new technology to provide new products.

Table 5. Items for measuring innovation performance

Items	Measurements
PER1	We usually launch new products or services earlier than competitors do.
PER2	There are more high technologies contained in our products than that of competitors.
PER3	The market responses of our new products are better than that of competitors.
PER4	The development speed of our new products is faster than that of competitors.
PER5	The Input-output rate of our new products is higher than that of competitors.

and applications of new technologies. Xie and Xu (2014) developed six items to check firms' new products and patents. Liu (2014) proposed six items for investigating firms' product innovation and technical innovation. Yuan et al. (2015) developed 12 items to examine firms' process performance and result performance. According to the previous studies, we develop five items to measure firms' innovation performance as show in Table 5.

The annual sales of the firms in the survey ranged from less than 60 million RMB to more than 10 billion RMB. Forty-six of the firms have been established for 1-3 years (12.6% of the whole sample). Ninety six have been established for 3-5 years (26.2%). One hundred and twenty three have been established for 5-10 years (33.6%). One hundred and one have been established more than 10 years (27.6%). One hundred and five firms are in the industry of information transformation, computer service and software (28.7%). Ninety-five firms are in the industry of vehicle and parts manufacturing (26%). Sixty-nine firms are in chemical industry (18.9%). Thirty-six firms are in the industry of electrical machinery (9.8%). Sixty-one firms are in transportation, warehousing and post industry (16.7%).

4. EMPIRICAL ANALYSIS

4.1 Measurement Validation

We apply factor analysis to validate our framework. First, we adopt SPSS to analyze the relevance of the variables. As shown in Table 6, the results of correlation analysis indicate that all variables correlate to each other. Consequently, we can conclude that our framework is rational.

Second, we adopt SPSS to calculate Cronbach's alpha for each variable to assess the reliability of variables. The results of reliability test are shown in Table 7. Cronbach's alpha for Openness (OPE) is 0.664, which is less than 0.7 and implies an unsatisfactory reliability. Cronbach's alpha for Openness (OPE) is 0.736 when the fourth item in its measurements is removed. This implied a satisfactory reliability. Consequently, we eliminate the fourth item in the subsequent empirical analysis. Most items are adopted from the existing literatures. Some are revised according to the suggestions from managers and experts in the survey. Therefore, content validity of the measurements is established. Moreover, the results of factor analysis indicated construct validity for each variable.

4.2 Model Testing and Estimation

We apply LISREL to estimate each path coefficient in the conceptual model and calculate their T-values. The results are shown in Figure 2. Testing results indicate that all path coefficients are significant at the 0.01 level. The fit indices CFI, NFI, NNFI, IFI, GFI, PNFI and RFI exceed or are close to 0.90. Therefore, the overall fit of the model is satisfactory.

Table 6. Results of correlation analysis

		NOV	OPE	CUM	DES	PER
NOV	Pearson	1.000				
	Significance					
	N	366				
OPE	Pearson	0.121	1.000			
	Significance	0.016				
	N	366	366			
CUM	Pearson	0.121	0.407	1.000		
	Significance	0.015	0.000			
	N	366	366	366		
DES	Pearson	0.091	0.443	0.597	1.000	
	Significance	0.069	0.000	0.000		
	N	366	366	366	366	
PER	Pearson	0.055	0.457	0.448	0.587	1.000
	Significance	0.275	0.000	0.000	0.000	
	N	366	366	366	366	366

5. DISCUSSION

Among the eight hypotheses tested by the model, six are supported and two are rejected. The details are listed in Table 8.

The effect of innovation novelty on creative cumulative (0.118/2.402) and disruptive (0.117/2.278) technological trajectory transitions are positive and significant. Thus, Hypotheses 1.1 and 1.2 are supported. Radical innovations imply to break the existing technological trajectory and to develop new technological directions. In the initial stage, radical innovations may develop insufficiently, and therefore, perform inferior to dominant technologies. Challenged by emerging technologies, existing technologies will improve gradually to consolidate their dominance. However, it is difficult for existing technologies to meet requirements through incremental improvements in the market that continuously changes. Therefore, incumbent firms will consider integrating new technologies with the existing technologies for improving the performance of their products. The performance of new technologies improves quickly in practice. New technologies are likely to surpass the existing technologies soon. As a result, firms will shift to a new technology trajectory.

The effect of innovation openness on creative cumulative (0.172/1.826) and disruptive (0.168/1.726) technological trajectory transitions are positive and significant. Therefore, Hypotheses 2.1 and 2.2 are supported. Larger innovation openness means that firms investment more on searching external resources. The search might generate more new knowledge and technological abilities for firms. As a result, firms will supplement and extend their existing technologies. They are more likely to shift to a new technological direction because they will benefit from introducing, assimilating and innovating of external advanced technologies.

The effect of innovation novelty on firms' innovation performance (0.031/0.517) is not significant. Thus, Hypothesis 3 is rejected. Radical innovations can create a series of attributes and generate determined cost or quality advantage. High novelty implies that firms spend more investment on exploring new knowledge or developing new technologies. As a result, more new knowledge and products are produced. However, innovation novelty does not always promote innovation performance.

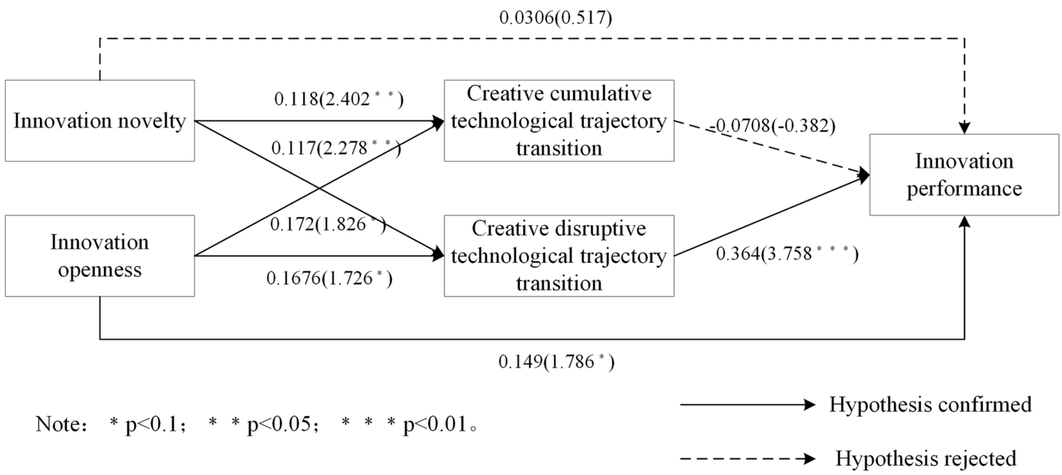
Table 7. Results of reliability test

Latent variables	Items	Cronbach's alpha after eliminating item	Cronbach's alpha
NOV	NOV1	0.680	0.723
	NOV2	0.616	
	NOV3	0.655	
	NOV4	0.692	
OPE	OPE1	0.515	0.664
	OPE2	0.576	
	OPE3	0.523	
	OPE4	0.736	
CUM	CUM1	0.868	0.852
	CUM2	0.819	
	CUM3	0.814	
	CUM4	0.810	
	CUM5	0.793	
DES	DES1	0.815	0.840
	DES2	0.818	
	DES3	0.825	
	DES4	0.784	
	DES5	0.796	
PER	PER1	0.866	0.902
	PER2	0.893	
	PER3	0.878	
	PER4	0.877	
	PER5	0.885	
Aggregate table	-	-	0.931

The reason is that many firms are not engaged in radical innovations due to their weak technical competence. They prefer low-cost approaches, such as technology introduction and imitation, for acquiring competitive advantage. In addition, high innovation novelty generates complexities in R&D and requires intense communications. Development of new products will be delayed because more resources are spent on fixing issues caused by complexities and extra communications. Therefore, even though firms invest more on generating innovation novelty, the development cycle of new products will not be shortened.

The effect of innovation openness on firms' innovation performance (0.149/1.786) is positive and significant. Thus, Hypothesis 4 is supported. In the open innovation model, external knowledge can be integrated, whereas internal knowledge can be extracted. In an innovation process, firms' outside factors will expand their knowledge base. Meanwhile, firms' internal knowledge can be extracted and released to the market. When integrating with external sources and exporting internal resources, firms can benefit from creative ideas. They tend to produce new products or services, and improve their innovation performance. If firms invest more on R&D cooperation, technology introduction,

Figure 2. Results of testing the structural equation model



and strategic alliances, their competitiveness will be improved. The industry-university-research cooperation mode will keep the innovation process open and increase firms' technological innovative capabilities.

The effect of creative cumulative technological trajectory transition on firms' innovation performance (0.071/-0.038) is not significant. Thus, Hypothesis 5 is rejected. Accumulation generates entry barriers and weakens attackers' advantage in market (Bergek et al., 2013). Creativity and accumulation are two indispensable aspects of creative cumulative technological trajectory transition. Knowledge and technology accumulations reflect firms' historical experiences. Lack of knowledge and technology will weaken the contribution that creative cumulative technological trajectory transition generates to firms' performance. Creative accumulation requires firms to explore new knowledge or capabilities out of their knowledge base to supplement and extend their existing capabilities. When

Table 8. Results of hypotheses test

Relationship	Hypotheses	Result
Innovation novelty and technological trajectory transition	**H1.1:** Innovation novelty positively affects creative cumulative technological trajectory transition.	Supported
	H1.2: Innovation novelty positively affects creative disruptive technological trajectory transition.	Supported
Innovation openness and technological trajectory transition	**H2.1:** Innovation openness positively affects creative cumulative technological trajectory transition	Supported
	H2.2: Innovation openness positively affects creative disruptive technological trajectory transition.	Supported
Innovation novelty and innovation performance	**H3:** Innovation novelty positively affects firms' innovation performance.	Rejected
Innovation openness and innovation performance	**H4:** Innovation openness positively affects their innovation performance.	Supported
Technological trajectory transition and innovation performance	**H5:** Creative cumulative technological trajectory transition positively affects firms' innovation performance.	Rejected
	H6: Creative disruptive technological trajectory transition positively affects firms' innovation performance.	Supported

accumulation is complete, firms' innovation performance will be improved because they possess new knowledge, generate innovation outputs, and launch competitive products.

The effect of creative disruptive technological trajectory transition on firms' innovation performance (0.364/3.758) is significant. Thus, Hypothesis 6 is supported. Creative destruction generates great advantages in costs and quality. Therefore, technical improvement in an existing technological trajectory will slow down gradually. Meanwhile, latecomers will pour in, and therefore, the competitive advantage of new technologies decreases incrementally. Because the new technological trajectory is advantageous in efficiency and costs, firms shift their technological direction and developing abilities for acquiring competitive advantage in the new technological trajectory. Based on antecedent technology accumulation, firms can build entry barriers and become the leader in market. They launch new products and their innovation performance will be improved.

6. CONCLUSION

In this study, we develop a structural equation model to explore the relationship among technological innovation, technological trajectory transition, and innovation performance. In specific, two aspects of firms' innovation strategies, namely innovation novelty and innovation openness, are examined. We conduct a survey to test the model. Technological trajectory transition is categorized into creative cumulative technological trajectory transition and creative disruptive technological trajectory transition.

The results of the empirical test indicate that innovation novelty positively affects creative cumulative technological trajectory transition and creative disruptive technological trajectory transition. However, innovation novelty does not positively affect firms' innovation performance. Innovation openness positively affects creative cumulative technological trajectory transition, creative disruptive technological trajectory transition, and firms' innovation performance. Creative cumulative technological trajectory transition does not positively affect firms' innovation performance. However, creative disruptive technological trajectory transition positively affects firms' innovation performance.

The following implications can be get from the results of analysis for managers.

First, firms should adopt creative disruptive technological trajectory transition to improve their innovation performance. Instead of making incremental improvement along the existing technological trajectory, firms should replace their existing technologies with emerging technologies, develop capabilities fitted new technological directions, and develop new products. Creative disruptive technological trajectory transition is more difficult than creative cumulative technological trajectory transition. Searching new technologies and integrating them with existing technologies will not damage firms' existing capabilities or harm their existing technique systems and manufacturing process. Firms should adopt creative disruptive technological trajectory transition to supplement and to extend their capabilities. Abandoning existing technologies and shifting to a new technological trajectory will generate challenges. Firms might lose some capabilities that they accumulate by following the existing technological trajectory. Their organizational structure and manufacturing processes might be changed. However, radical innovation and subsequent managerial reform will generate competitive advantages for firms.

Creative disruptive technological trajectory transition is an effective approach to acquire determined competitive advantage and to realize technological catch-up. Firms that do not lead the market usually adopt imitation-based competitive strategies to achieve gradual improvements through introduction, absorption, and re-innovation. Although technology introduction is a low-cost approach to make technology progress, it is difficult for these firms to realize technological catch-up if they continue to follow established technological trajectories. Technology reforms initiated by market leaders will drive these firms to fall into a passive situation. Expertise and experiences that these firms accumulate by following the existing technological trajectory will be ineffective. The emerging of new paradigms provide opportunities for latecomers to catch up. Because in new paradigms, all firms, including the market leaders, share the same starting point. Latecomers can catch up with market leaders by leapfrogging technological trajectories and exploiting new paths.

Firms that are not market leaders should explore along new technological directions. Meanwhile, government should support innovation and entrepreneurship practices by making proper policies. Industrial transformation and enterprises' innovative development should be guided properly. Moreover, government should take measures to cultivate entrepreneurs.

Second, firms should engage in radical innovation by increasing investment on R&D. In this way, they can acquire knowledge and technologies with higher novelties and heterogeneities. At the end, they will find new technological paradigms. Firms need to convert new knowledge and technologies into their own capabilities for obtaining innovation-driven development and endogenous growth. Creative cumulative technological trajectory transition supplements firms' existing capabilities via their acquired new knowledge and technologies. However, it does not positively affect firms' innovation performance. The key of innovation-driven transformation is creative disruptive technological trajectory transition that is based on radical innovation. Other than increasing investment, firms should explore approaches that can transform the new knowledge generated in radical innovation into their own capabilities and can help them convert new technologies into new products. The value of new inventions and technologies can be realized through launching new products that meet market needs. Firms should implement technology replacement and improve their abilities required by new technological directions.

Third, firms should conduct more open innovations and improve their innovation performance through acquiring external resources. Meanwhile, firms should focus on increasing their technological competence and absorptive capacity. Firms with strong technological competence will benefit from overflow effect. In addition, firms should acquire the abilities of performing innovation independently and acquiring external resources selectively. They should develop models that help them to coordinate openness and independence in their innovation process.

Finally, absorptive capacity is the prerequisite for firms to recognize and acquire external knowledge and technologies. By assimilating the external knowledge and technologies, firms can improve their technological competence. Absorptive capacity is a key factor in achieving technological competence through organizational cooperation. Strong absorptive capacity enables firms to recognize, introduce, and assimilate new external knowledge and technologies. It also enable them to combine the new external knowledge and technologies with their existing knowledge. As a result, their existing knowledge and capabilities will be supplemented. Latecomers should continuously improve their abilities in recognizing, acquiring, and transforming external knowledge and technologies through adopting new equipment and hiring technical talents and experts.

The questionnaires were sent to R&D managers or directors of technology center of firms in industrial parks, this study also reveals the importance of new technologies or emerging technologies that must be paid attention including enterprise systems (Wang et al 2007; Xu 2011; Xu et al 2008, 2012, 2013), industrial information integration (Chen 2016, 2020; Gorkhali and Xu 2016, 2019; Hou, Kataev et al 2015; Li and Burgueno 2019; Lu 2016; Xu 2013, 2015,2016, 2020a; Peruzzini and Stjepandić 2018), management analytics (Haenlein et al 2019; Zhao et al 2014), big data analytics (Abbasian et al 2018; Aceto et al 2020; Chen, Chen et al 2016; Chen, Oliverio et al 2019; Chong & Shi 2015; Duan & Xiong 2015; Furtado et al 2017; Hämäläinen & Inkinen 2019; Khan and Javaid 2020; Kim 2017; Li & Xu 2020; Verma et al 2020; Wang et al 2020; Xu & Duan 2019), blockchain (Li 2020; Xu and Viriyasitavat 2019), deep learning (Alguliyev et al 2019; Chen, Cai et al 2020; Lu 2019), and IoT (Li, Xu and Zhao 2018; Li, Li and Zhao 2014; Xu, He and Li 2014; Xu 2020b).

This paper provides guidance for firms to resolve the dilemmas inherent in their innovation practices when they try to catch up market leaders. Some questions need to be explore by future studies. For example, the roles that firms' technological capability and their absorptive capacity play in firms' innovation novelty and innovation openness need to be explored. Moreover, how the two capabilities are related and how they intermediate technological innovation and firms' innovation performance need to be examined as well. What factors should be studied when analyzing radical innovation maturity and firms' capability basis in the process of implementing implement technological trajectory transition? When can technological trajectory transition make firms to performance better?

Because new indicators are adopted in the research model, more firms should be studies in future research to verify the results. Moreover, more work is needed to refine and test the new indicators, such as creative cumulative technological trajectory transition and creative disruptive technological trajectory transition. The research model is tested with data collected by surveying Chinese firms' technological innovation and catch-up processes. Future research should collect data from firms in other emerging economies to verify the results.

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