The Impacts of Technology Management on Product Innovation: The Role of Technological Capability

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ABSTRACT

Despite the growing importance of management practices, few studies have empirically examined the influence of technology management on product innovation, especially in the presence of technological capability. This article explores how technology management relates to product innovation through the contingency role of technological capability. The results of correspondence analysis to test the proposed hypotheses showed that the technology management practices that are closely associated with product innovation performance are not identical in different technological capability stages. In the low technological capability stage, information management, equipment management and fund management have greater correlations with product innovation performance; in the medium technological capability stage, human resource management, organization management, quality management and standardized management have greater correlations with product innovation performance; in the high technological capability stage, cultural management, achievement management, and risk management have greater correlations with product innovation performance. The research results theoretically deepen the understanding of how technology management exerts its impact and provide theoretical guidance for the improvement of product innovation performance for firms in different technological capability stages.

INDEX TERMS

Product innovation, technological capability, technology management.

I. INTRODUCTION

Product innovation is important for firms because it can help firms continuously bring forth new products, which may, in turn, provide firms with novel means to earn high profits [1]. Although firms have invested substantial resources and capabilities into product innovation, the success rate has not surpassed 25% [2]. Therefore, research on how to realize product innovation is necessary.

Numerous variables have been identified as antecedents of product innovation performance. These antecedents can be classified into three types: individual factors, organizational factors and environmental factors [3]. Some of these impact factors are presented in Table 1. This article will delve into organizational factors because the previous literature has argued that they exert the greatest influence on product innovation [13]. Within this group, the literature has investigated the impact of general firm characteristics such as size and age. Nonetheless, all the organizational factors, the most critical are management practices. The empirical literature has focused on certain management practices, such as accounting practices [14], knowledge management practices [15], and human resource management practices [16]. However, the current research has not focused on the impact of technology management, especially its practices, on product innovation. Technology management comprises various practices that help firms implement product innovation at the strategic and operational levels [17]. In reality, technologies are always changing, which creates challenges and opportunities for product innovation that need to be captured and converted through effective technology management [18]. Therefore, it is necessary to understand how technology management
TABLE 1. Summary of the studies of the driving factors of product innovation.

| Study                          | Impact factors of product innovation | Main conclusions                                      |
|-------------------------------|-------------------------------------|-------------------------------------------------------|
|                               | Individual factors | Organizational factors | Environmental factors |                                                      |
| Bettenourt et al. (2017) [4]  | √                      |                      |                       | Individual abilities enhance innovation performance. |
| Enkel et al. (2017) [5]       | √                      |                      |                       | Individual level absorptive capacity contributes to the realization of innovation. |
| Guo et al. (2017) [6]         | √                      |                      |                       | Employees’ creativity is fundamental for product innovation. |
| Liu and Atuahene-Gima (2018) [7] |                      | √                      |                       | An emphasis on creative marketing predicts better product innovation performance. |
| Najafi-Tavani et al. (2018) [8] |                      | √                      |                       | Collaborative innovation networks improve new product performance. |
| Silva et al. (2019) [9]       |                      | √                      |                       | Importer feedback contributes to product innovation at the exporter firm. |
| Hueske et al. (2015) [10]     |                      |                      | √                      | The impact of the external environment in particular is critical for innovation. |
| Eisend et al. (2016) [11]     |                      |                      | √                      | National culture affects product innovation. |
| Wu et al. (2019) [12]         |                      |                      | √                      | Institutional environment affects innovation performance. |

and its practices affect product innovation. This article fills this gap by exploring the effect of technology management and its practices on product innovation.

Furthermore, technology management can be regarded as the ability to implement technological capability [18]. According to the resource-based view, technological capability is a set of resources that offers know-how to change existing products or create new products [19]. As indicated by previous research, each technology management practice is associated with a certain level of technological capability [20]. Based on this understanding, it is reasonable to argue that technology management practices may vary in different technological capability stages due to their inherently different characteristics [21]. Although it is increasingly accepted that technology management is closely related to product innovation, the current research has not yet revealed the differences in technology management practices in different technological capability stages. A key question here is what key technology management practices are associated with product innovation performance in different technological capability stages. Through answering this research question, we can better understand how technology management affects product innovation.

In sum, the purpose of this article is to investigate the impacts of technology management on product innovation by considering the contingency role of technological capability. To this end, this article is structured as follows. The next section introduces the related theories and proposes the hypotheses. Section 3 presents the method. Section 4 offers the analysis and results. Section 5 further discusses these results. The final section offers the conclusion, which includes theoretical contributions, managerial implications, limitations and future research directions.

II. THEORETICAL FRAMEWORK AND HYPOTHESES

Research on technology management began in the early 1970s. From the very beginning, technology management originated from R&D management. With the development of the discipline, technology management evolved into innovation management, technology planning and, finally, the strategic management of technology [22]. In the technology management literature, a widely accepted definition considers technology management as the “planning, directing, control and coordination of the development and implementation of technological capabilities” [23]. This definition clearly emphasizes understanding technology management as a process that achieves firms’ objectives through the transformation of technological capability. More recently, Cetindamar et al. (2016) have indicated that technology management activities are typically linked to business processes at the strategic and operational levels [24]. Based on this understanding, technology management is the configuration of management systems that govern the strategic and operational functioning of the firm to help it achieve its goals. Technology management is a professional task that includes six generic processes: identification, selection, acquisition, exploitation, protection, and learning [25]. These processes involve integrative technology management practices: fund management, equipment management, human resource management, information management, achievement management, culture management, organization management, quality management, standardization management, and risk management.

Technological capability has been regarded as one of the most important strategic resources that enables firms to establish competitive advantages [26]. A firm’s technological capability is a form of tacit knowledge with VRIN
characteristics (valuable, rare, inimitable, and nonsubstitutable). As a result, a firm with superior technological capability can achieve higher differentiation because it is difficult for its competitors to accomplish similar tasks without similar technological capability [27]. In addition, technological capability is strongly related to absorptive capacity, which is the ability to assimilate and apply knowledge. This ability can be very helpful, since the higher the level of a firm’s technological capability is, the more easily it can understand knowledge, and thus, the chances are greater that such knowledge will be used in the innovation [28]. Following previous research, this article defines technological capability as a kind of vital strategic resource that a firm owns.

Because technological capability is conceptualized as a kind of vital strategic resource, the accumulation of technological capability becomes a basic problem in product innovation research. It has been argued that the accumulation of technological capability proceeds from simpler to more complex [29]. Some researchers have differentiated technological capability as either “routine” or “innovative.” “Routine” technological capability is the capability to perform innovation activities with the given requirements, and “innovative” technological capability consists of possessing the technology-changing skills needed to create [30]. Another stream of research has argued that firms in the high technological capability stage attempt to expand R&D investment based on their accumulated capability, while firms in the low technological capability stage show upward rigidity in R&D investment [31]. Therefore, it is widely accepted that there may be different product innovation tasks in different technological capability stages and that the technology management practices required to accomplish these tasks also differ across different technological capability stages. Based on the above arguments, the conceptual framework of this article is shown as Figure 1.

A. TECHNOLOGY MANAGEMENT PRACTICES IN THE LOW TECHNOLOGICAL CAPABILITY STAGE

It has been argued that there are three operation modes—original equipment manufacturer (OEM), original design manufacturer (ODM), and original brand manufacturer (OBM)—and that these three operation modes reflect different stages of technological capability [32]. Generally, OEM represents the lowest technological capability stage because OEM firms do not have their own brand, instead making products that bear another firm’s brand. In this stage, a firm concentrates on understanding their competitors’ products [32], which requires information management, equipment management and fund management. Firms in the low technological capability stage are required to seek knowledge because it is often the only way to approach product innovation [33]. The use of information management is therefore important. Information management serves to identify, coordinate and exploit information that enables process automation, decision-making, information retrieval, etc. Firms can employ information management to establish partnerships, integrate contributions and coordinate cooperation [34]. For example, there are many useful information system tools with which firms can recognize the potential space for partnerships and thus systematically integrate partners’ knowledge into their own product innovation. Firms can also employ information management to contribute to the implementation of effective knowledge exchange [35]. Moreover, the knowledge acquired in this stage is often embedded in equipment, and it is thus necessary for firms to employ equipment management to assimilate [36]. Equipment management recognizes, plans and regulates equipment status and acquires timely information about equipment. Effective equipment management, such as systematic record-keeping, helps firms understand how the equipment operates and discover hidden knowledge [37]. Such knowledge can be applied to different working teams through equipment maintenance practices, which addresses the knowledge limitations in product innovation [38]. Finally, financial resources may be particularly vulnerable, and accessing technology financial resources is one of the most important factors for firms in this stage to acquire information and equipment [39]. Fund management collects, leverages and transfers technology financial resources, such as R&D investment. To enhance the availability of financial resources, firms should try to leverage fund management to estimate the demand for R&D funds and collect such funds from multiple sources. Based on the above theoretical analysis, this article proposes the following hypothesis:

H1: In the low technological capability stage, information management, equipment management and fund management are more closely related to product innovation performance.

B. TECHNOLOGY MANAGEMENT PRACTICES IN THE MEDIUM TECHNOLOGICAL CAPABILITY STAGE

As they increasingly implement imported product designs, OEM firms also accumulate substantial experience in production and become more familiar with product innovation. Over time, OEM firms will improve their technological capability, thereby upgrading to ODM firms. The ODM firm resembles an OEM, but ODM producers also design products for
their clients. In the ODM stage, the main task is switching to designing products [32], which requires human resource management, organization management, quality management, and standardization management. Product design needs employees to try to generate innovative ideas, and firms thus should employ human resource management and organization management to support such activities. Human resource management recruits, selects, trains and develops R&D employees. Firms can use human resource management techniques, such as training-focused and performance-based rewards, to provide opportunities and incentives for employees to develop their human capital, consequently helping them produce creative ideas [40]. Organization management creates, builds, and maintains the organization to transform product innovation strategy into product innovation output. Organizational management, such as cooperation and coordination across units, is expected to increase knowledge spillovers within a firm [41]. In particular, a cross-functional team is often suggested as a critical organizational structure in designing products, and many firms utilize cross-functional teams to elicit product innovation [42]. Together, human resource management and organization management have been seen as essential for ODM firms to achieve product innovation [43]. At the same time, firms should also use quality management and standardization management to establish linkages between the new knowledge and previous knowledge. Quality management is a systematic way of guaranteeing that organized activities happen in the way they are planned. Quality management practices, such as information analysis, involve searching for and disseminating the information related to research work, which assists in transferring know-how within the organization [44]. Standardization management establishes norms or requirements applied to technical systems. Standardization management practices provide evaluated knowledge, such as formal standards and technical standards, which are free for employees to access [45]. By applying quality management and standardization management, firms can store the knowledge generated in product innovation activities and further help employees acquire the knowledge they need [46]. This last is of critical importance to employees who are working in the same technological area. Based on the above theoretical analysis, this article proposes the following hypothesis:

H2: In the medium technological capability stage, human resource management, organization management, quality management, and standardization management are more closely related to product innovation performance.

C. TECHNOLOGY MANAGEMENT PRACTICES IN THE HIGH TECHNOLOGICAL CAPABILITY STAGE

A firm’s relative success in designing products will inherently improve its technological capability over time through internal efforts in product innovation. In consequence, a firm will develop its own brand and the ability to launch products by itself, which means it has transformed to the OBM stage [32]. An OBM firm produces and sells products with its own brand, which requires greater innovation [47]. In this stage, culture management, achievement management and risk management are important for product innovation. Organizational culture comprises the values, beliefs and hidden assumptions embedded within organizational members [48]. Culture management encourages an innovation-oriented organizational culture related to creativity, worker participation, and responsibility sharing [49]. This kind of organizational culture can encourage employees to put forward new ideas continuously [50]. Achievement management recognizes, creates, and applies previous technology achievements, which involves the management of knowledge flows and the creation of knowledge assets within the organization. Achievement management aims to ensure that knowledge is used effectively and efficiently to achieve long-term benefit [51]. Through achievement management techniques, such as knowledge obtaining, knowledge refining, knowledge storing and knowledge sharing, firms can preserve the new knowledge formed through the product innovation process [52], which can be an important prerequisite for exploring new product innovation areas. Ultimately, the development of radical innovation involves diverse risks, including technological risk, market risk, and financial risk [53]. Risk management is therefore necessary to identify, analyze, monitor and control risk in the product innovation process, which is essential to formulating plans that limit risk as early as possible [54]. Firms that employ risk management, including qualitative or quantitative risk analysis techniques, can evaluate past decisions, predict future conditions, and rearrange strategic plans accordingly [55]. Therefore, risk management also becomes an important component in the high technological capability stage. Based on the above theoretical analysis, this article proposes the following hypothesis:

H3: In the high technological capability stage, culture management, achievement management and risk management are more closely related to product innovation performance.

III. METHOD

A. SAMPLE AND DATA COLLECTION

To test the proposed hypotheses, this article collected data from firms through a questionnaire survey. The respondents to this survey were generally senior managers who had a synthetic understanding of their firm’s technology management, technological capability and product innovation performance. Common method variance (CMV) is usually a concern when carrying out questionnaire surveys. To address this concern, several steps were employed to control. This article assured that the respondents would remain anonymous. Furthermore, the respondents to the different variables were different. Specifically, this article collected answers regarding technology management and technological capability from the managers of the technology management departments or CEOs and collected answers regarding product innovation performance from the managers of the R&D departments. This article sent questionnaires to a total of 300 Chinese manufacturing firms, and 249 firms ultimately provided feedback.
Among them, 212 firms provided complete data. Therefore, the effective response rate of this article is 70.667%. In order to address the concern of non-response bias, this article ran the independent t-test for unequal variances between the first 10 percent and last 10 percent respondents. The t-tests yielded no statistically significant differences, which suggests that the non-response bias is not a significant concern. Among the valid questionnaires, 23.389% were aerospace firms, 15.213% were biopharmaceutical firms, 17.932% were automobile firms, 20.785% were petrochemical firms, 12.518% were steel firms, and 10.163% were railway equipment firms. We randomly separated the sample into two parts for hypothesis testing and robustness tests.

B. VARIABLE MEASUREMENT

All the constructs in this article were measured through multiple-item scales, which were compiled through intensive review of the related research. The questionnaire development process was as follows. First, the original scales regarding each construct were found. Second, since all the original scales were in English, the original scales were translated into Chinese. Third, the Chinese scales were retranslated into English by a third party. Finally, we carefully compared the original English scales and retranslated English scales and found no substantial difference between them.

The scale used by Liu et al. [56] was chosen to measure technology management, which comprises fund management, equipment management, human resource management, information management, achievement management, culture management, organization management, quality management, standardization management, and risk management. The scale for technological capability originated from the research of Yu et al. [57] and comprises human capability, equipment capability, information capability and organization capability. Product innovation performance was measured through the scale by Hsu and Fang (2009) [58]. All scale items were answered on a 5-point Likert scale in which 1 represented strongly disagree, 3 represented a neutral response, and 5 represented strongly agree.

IV. ANALYSIS AND RESULTS

A. DATA ANALYSIS

Cronbach’s α coefficient was used to evaluate the reliability of the data; the results are shown in Table 2. The Cronbach’s α coefficient of all scales exceeded the threshold of 0.7, which indicates acceptable reliability of the data.

The items were generated from high-quality, peer-reviewed research. The questionnaire was sent to several professors and executives for evaluation before it was sent to respondents. Based on their comments, some items were reworded to enhance clarity. This feedback guaranteed the content validity of the scale.

This article used exploratory factor analysis to test construct validity. The results showed that technology management, technological capability, and product innovation performance could extract ten factors, four factors, and one factor, respectively. Regarding the main indicators, all the KMO indexes had a value higher than 0.7 (0.934, 0.837 and 0.739, respectively); all the Bartlett’s tests were significant at a level of less than 0.05 (0.000); all the cumulative variance contribution rates were higher than 70% (76.582%, 77.231% and 73.225%, respectively). Furthermore, all the factor loadings were 0.5 or greater for the underlying dimension and less than 0.4 for other dimensions. The results indicated that the construct validity was verified.

Average variance extracted (AVE) square roots were calculated to test the discriminant validity, which are shown in Table 3. The results showed that all the square roots of the AVE of each construct were no more than their cross-correlations, and thus the discriminant validity was confirmed.

Table 3 shows the descriptive statistics and correlations of all constructs. In sum, the correlations among all constructs were not greater than 0.6, so there is no concern about multicollinearity.

B. HYPOTHESIS TESTING

This article employs SPSS 24.0 to run correspondence analysis to test the proposed hypotheses. Correspondence analysis is a widely used method in management research that draws from the row and column in the contingency table to illustrate the most important relationships among the variables. This approach is performed by using the variables to draw scatterplots. In the scatterplots, the variables with similar scores are clustered, which reveals that there exist high degrees of association among them with the analyzed variable. Although the scatterplot can be described through multiple dimensions, it is common to use only the first two dimensions, as these reflect the greatest deviation from the data.

The correspondence analysis results for the low technological capability stage are shown in Table 4 and Figure 2. As the results showed, Dimension 1 explains 87.30% of the variance with a singular value of 0.015, while Dimension 2 explains 12.70% of the variance with a singular value of 0.015. The two dimensions together account for 100% of the variance, which demonstrates that it is reasonable to express
The correspondence analysis results for the medium technological capability stage are shown in Table 5 and Figure 3. As the results showed, Dimension 1 explains 71.10% of the variance with a singular value of 0.023, while Dimension 2 explains 28.90% of the variance with a singular value of 0.014. The two dimensions together account for 100% of the variance, which demonstrates that it is reasonable to express the original data in the form of a two-dimensional plot. As shown in Figure 3, human resource management, organization management, quality management, and standardization management are relatively close to high product innovation performance. There are no substantial differences between the robustness results and the obtained results. Thus, H1 is verified.
TABLE 5. The correspondence analysis results of medium technological capability stage.

| Dimension | Singular value | Singular value confidence | Inertia and percentage of inertia |
|-----------|----------------|---------------------------|----------------------------------|
|           |               |                           |                                  |
| 1         | 0.023         |                           | 0.001                           |
| 2         | 0.014         |                           | 0.000                           |
| Total     |               |                           | 0.001                           |

FIGURE 3. The correspondence analysis results of medium technological capability stage.

...innovation performance, indicating that in the medium technological capability stage, human resource management, organization management, quality management, and standardization management are more closely related to high product innovation performance. There are no substantial differences between the robustness results and the obtained results. Thus, H2 is verified.

The correspondence analysis results for the high technological capability stage are shown in Table 6 and Figure 4. As the results showed, Dimension 1 explains 82.10% of the variance with a singular value of 0.025, while Dimension 2 explains 17.90% of the variance with a singular value of 0.012. The two dimensions together account for 100% of the variance, which demonstrates that it is reasonable to express the original data in the form of a two-dimensional plot. As shown in Figure 4, achievement management, culture management, and risk management are relatively close to high product innovation performance, indicating that in the high technological capability stage, achievement management, culture management, and risk management are more closely related to high product innovation performance. There are no substantial differences between the robustness results and the obtained results. Thus, H3 is verified.

V. DISCUSSION

The resource-based view points out that resources and capability are important for achieving competitive advantages [59]. Technological capability is an important resource in product innovation, while technology management is the capability to make effective use of technological capability. Therefore, there is a close internal relationship between technology management and technological capability. Based on this understanding, Wu et al. (2012) have argued that there are interactive effects between technology management and technological capability, which are coupled in a double helix formation [36]. This article further reveals that the relationship between technology management and technological capability is more complex. To be specific, the technology management practices in different technological capability stages are different. This knowledge is highly relevant for understanding technology management, which aims to develop and exploit technological capability. Thus, this article provides a new...
TABLE 6. The correspondence analysis results of high technological capability stage.

| Dimension | Singular value and singular value confidence | Inertia and percentage of inertia |
|-----------|---------------------------------------------|----------------------------------|
|           | Singular value | Standard deviation | Correlation | Inertia | Percentage | Cumulative percentage |
| 1         | 0.025           | 0.022               | 0.019       | 0.001   | 0.821      | 0.821                |
| 2         | 0.012           | 0.023               |             | 0.000   | 0.179      | 1.000                |
| Total     |                 |                     |             | 0.001   | 1.000      | 1.000                |

FIGURE 4. The correspondence analysis results of high technological capability stage.

explanation for the double helix relationship between technology management and technological capability.

Furthermore, this article identifies which technology management practices are closely related to product innovation in different technological capability stages. Previous research has pointed out that new product development has several key stages according to the implementation process, and different stages have different characteristics [60]. This article further indicates that product innovation can also be divided on the basis of the accumulation of technological capability and that the tasks in different technological capability stages are also different. The results showed that there exist different but important technology management practices in different technological capability stages. In the low technological capability stage, information management, equipment management and fund management are more important for product innovation; in the medium technological capability stage, human resource management, organization management, quality management and standardized management are more important; and in the high technological capability stage, cultural management, achievement management, and risk management are more important. The research results demonstrate that technology management practices will not always be equal during product innovation, which supports the importance of the contingency view in product innovation.

VI. CONCLUSION

A. THEORETICAL CONTRIBUTIONS

This article makes several theoretical contributions to the current research. First, this article enriches product innovation theory by revealing how technology management affects product innovation. Although much research has investigated the impact of technology management on product innovation, it has only focused on select practices. This article explores the impact of technology management on product innovation from a more holistic perspective by considering ten technology management practices together. Our findings show that the technology management practices that are closely related to product innovation performance differ in different technological capability stages. In particular, information management, equipment management and fund management
are more closely related to product innovation performance in the low technological capability stage; human resource management, organization management, quality management, and standardization management are more closely related to product innovation performance in the medium technological capability stage; and culture management, achievement management, and risk management are more closely related to product innovation performance in the high technological capability stage. These findings suggest that the relationship between technology management and product innovation performance is not straightforward.

Second, this article adds a new contingency context by revealing that innovation requires different technology management practices in different technological capability stages. Previous research has indicated that the technology life cycle is an important contingency context for technology management [61]. In fact, the technology life cycle is stimulated by technological capability since the transition of different technologies depends on technology innovation [62]. Therefore, this article starts from the factor that triggers the technology life cycle and explores the different technology management practices in different technological capability stages. The results show that the technology management practices associated with product innovation performance in different technological capability stages also differ. Incorporating technological capability into the research framework for the contingent factors of technology management not only deepens the theoretical understanding of the relationship between technology management and technological capability but also provides new research directions concerning the relationship between technology management and product innovation.

Third, this article also serves as a useful supplement to the resource-based view. The resource-based view believes that product innovation is the process through which firms use their own resources and capability to develop new products, but it does not give a clear explanation of how to use such assets. By employing correspondence analysis, this article clarifies that technology management should be configured in different technological capability stages with aims to maximize product innovation performance. This article thus offers a configured perspective that could resolve similar research questions.

**B. MANAGERIAL IMPLICATIONS**

This article also provides valuable implications for managers when employing technology management to improve product innovation performance. In reality, firms cannot always use all management practices simultaneously; thus, managers must decide which management practices are proper. This article provides managers with relevant knowledge to reach these tough decisions by identifying the different technology management practices in different technological capability stages.

Specifically, firms can use information management, equipment management and fund management to improve product innovation performance in the low technological capability stage. The detailed practices that firms can employ are identifying key knowledge sources; accessing appropriate information; allowing operators to work with more than one machine; transferring knowledge among operators generated from equipment; estimating the demand of R&D funds; and collecting R&D funds from multiple sources. Firms can use human resource management, organization management, quality management, and standardization management to improve product innovation performance in the medium technological capability stage. The detailed practices that firms can employ are providing a considerable amount of training; emphasizing the individual’s contributions; clarifying process specifications; reviewing product design thoroughness; providing common languages and methodologies for innovation; and using standardized methods of implementation. Firms can use culture management, achievement management and risk management to improve product innovation performance in the high technological capability stage. The detailed practices that firms can employ are maintaining high quality internal communication; encouraging willingness to experiment with new ideas; indexing and classifying information for appropriate availability; updating information databases; conducting frequent tests; and preparing alternative solutions.

**C. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS**

This article inevitably has some limitations that further research can address. First, this article does not consider the potential complementary effects among technology management practices. Further research should investigate the specific relationships among technology management practices. Second, the research results are confined by the data. The data used in this article are cross-sectional. Further research can be conducted over a longitudinal period. Finally, varying the questionnaire respondents presents another opportunity for future research. The sample used in this article is limited to the manufacturing industry. Nevertheless, different industries may prefer different technological capabilities, and thus, they may have different technology management practices. Using cross-industry data for research is strongly encouraged to improve the generalizability of the results.

While the idea of exploring the contingency context in product innovation is not novel, research on how to improve product innovation performance in different technological capability stages is still in its infancy. The empirical evidence in this article offers a meaningful starting point for research on the relationship among technology management, technological capability and product innovation.

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