# “Erudite” or “Specialized”: An Empirical Study of Firms’ Patent Portfolio Strategies in The Context of Heterogeneous Technical Standards——Multiple Linear Regression Equations Based on Stata Software

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**Abstract**—This article attempts to explore such a question that what type of patent portfolio strategy should firms adapt to improve their innovation performance? Regarding the impacts of patent portfolio strategies for innovation, the extant literature holds conflicting views. This study analyzes the relationship between patent portfolio strategies and innovation performance and examines the moderating effect of heterogeneous technical standards. First, the research model introduces two variables: patent portfolio strategy and innovation performance, to explore the relationship between them. In the second step, two the heterogeneity of technical standards are introduced into the original model as a regulating variable to analyze the different innovation performance of different invention portfolio strategies in different situations. Based on the heterogeneity of technical standards, this paper divides into four scenarios to explore the relationship between invention patent portfolio strategy and innovation performance. By studying the patents of 159 Chinese firms in 11 industries from 2010 to 2019 and analyzing the cross-sectional data of technical standards and firm innovation performance, using Stata software and multiple linear regression model, this research finds that (1) a patent portfolio that focuses on a narrow range of technical areas is more beneficial for firm innovation in comparison to a diversified one; (2) the dynamics of technical standards significantly and negatively moderates the relationship between the patent portfolio strategies and innovation performance; (3) For industries with a high degree of dynamics and low degree of complexity in technical standards, a diversified patent portfolio strategy is more conducive to firm innovation. The research findings explain the conflicting results in previous studies regarding patent portfolio strategies and innovation performance and provide theoretical guidance for Chinese firms in developing a patent portfolio strategy.

**Keywords**: technical standard; Patent portfolio; Patent portfolio strategy

## 1. Introduction

In recent years, China has surpassed the United States and Japan in the number of patent applications, becoming the leading patent applicant in the world. One of the important reasons is that many firms are applying for more patents in various technical areas and establishing a diversified patent portfolio that covers a wide range of areas to achieve innovation and gain

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competitive advantages, which cannot be achieved by a specialized portfolio strategy[1][2]. However, the rapid increase in the number of patents has led to patent quality problems, and there are concerns that firms' innovation quality is not in pace with their patent application rate[3]. A key decision for firms to make regarding innovation strategies is whether to choose an "erudite" strategy featuring diversified patents in a wide range of technical areas or a specialized strategy focusing on a narrow range of technical areas.

This article aims to answer this question: "Which patent portfolio strategy would be optimal for firm innovation under circumstances with different technical standards?" The existing studies pointed to contradicting opinions regarding the relationship between patent portfolio strategies and innovation performance. Some researchers have found that the erudite patent portfolio strategy can mitigate the impact of uncertain future technological development, prevent firms from being stuck in obsolete technical routes, and thus help the firm to continuously innovate[1][4][5]. However, some other researchers, such as Zheng, Bian, Zhu, and Zhang [6]and Granstrand et al. [7], have suggested the opposite, maintaining that an excessive degree of technological diversification hinders firms from developing strong capabilities in a specific area and hence that a specialized patent portfolio strategy is more beneficial for firms' innovation performance.

This study believes that the inconclusive results are due to a lack of analysis on the external environment such as the characteristics of the industry each firm belongs to. In particular, the importance of technical standards for each industry on a firm's optimal innovation portfolio strategy has not been investigated[8]. A technical standard is essentially a set or a series of compulsory requirements or technical specifications with guiding functions[9]. For a firm that is establishing a diversified patent portfolio across various technical areas, technical standards can help it to realize the connectivity between technologies and standardization[10].

The extant literature indicates that technical standards significantly influence industry development, reduce the degree of the diversity of technical norms, generate short-term coordination and long-term learning effects[11], and facilitate technological development, thereby stimulating innovation in the entire industry[12][13] [14] and even leading to changes in the structure of related industries[15]. To successfully commercialize their products, firms must conform to industria standards, maintain their long-term competitiveness, adopt different strategies to turn their technologies into industrial standards, and influence other standards related to their technologies[16][17][18], thereby resolving technical issues, obtaining external knowledge, and promoting their interest[9][19]. However, the existing research treats technical standards as a single entity and does not analyze their heterogeneity among different industries. Questions about the impact of various technical standards on these two patent portfolio strategies and their moderating effects on innovation are unanswered.

The heterogeneity of technical standards has a profound influence on the R&D and innovation of firms. From the perspective of the degree of complexity, technical standards, as an important document guiding firms' technological R&D, can bring external knowledge to the firms, including product quality requirements, related technical requirements, and testing methods[20][21]. From the perspective of dynamic changes, changes in technical standards usually indicate the emergence of new technical norms and rules, which entail changes in different areas related to the existing technical standards, including the knowledge system and mechanical equipment, thus substantially influencing firms' R&D activities[22].

Based on the KBV, this study examines the moderating role of technical standards on the relationship between the two patent portfolio strategies and innovation performance. We raise the following questions: “What are the impacts of erudite and specialized patent portfolio strategies on innovation performance?” “How do heterogeneous technical standards impact the relationship between patent portfolio strategies and innovation performance?” From a perspective of technical standards' heterogeneity, this study examines the impact of patent portfolio strategies on innovation, further enriches the related research, and provides valuable insights for Chinese firms on patent portfolio strategy adoption.

## 2. Research Theory and Hypotheses

### 2.1 Theoretical Basis

The KBV maintains that knowledge is the most important strategic resource for firms[23] and differences in the performance of firms originate from their differences in knowledge storage and utilization ability[24][25]. To better improve performance, firms must expand their knowledge storage and optimize resource allocation, and by doing so, they can effectively utilize the knowledge and transform it into innovative achievements.

Based on its nature, knowledge can be divided into two categories—explicit and tacit[26]. Explicit knowledge refers to the knowledge that is coded and explained and thus can be obtained by anyone inside or outside a firm. Explicit knowledge includes patents, design drawings, and research papers[27]. Tacit knowledge refers to the knowledge that has been accumulated in a firm’s long-term operation and production. This type of knowledge cannot be coded, such as experience, and usually exists in the form of “learning by working” [28]. Based on its origins, knowledge can be classified as external and internal. In an era of complex technologies and a rapidly changing competitive environment, firms must combine external and internal knowledge to address R&D risks[29].

A patent portfolio refers to a group of patents that are significantly different from each other while being closely related[4]. By strategically establishing a patent portfolio that is extensive and complex, firms make the total value of their patent portfolios significantly higher than the combined value of all individual patients. Hence, they can obtain competitive advantages that cannot be obtained through each patent individually[30]. A patent portfolio reflects a firm’s strategic technological planning, which is a firm’s internal and tacit knowledge. Technical standards are technical rules that are voluntarily negotiated and conformed to by firms and other stakeholders[31]. As a type of normative document, technical standards are external and explicit knowledge, representing the minimum technical requirements for firms in an industry. Both types of knowledge have a significant impact on firms’ innovation and R&D. Therefore, this study examines technical standards, patent portfolio diversity, and innovation performance in a single framework.

### 2.2 Research Hypotheses

#### 2.2.1 Patent Portfolio Strategies and Innovation Performance

The concept of the patent portfolio was first put forth by a German researcher, Brockhoff[32], and it means that a firm identifies its core technology by analyzing patents and subsequently

establishing a strategic technology portfolio that centers on its core technologies[33][34]. As a strategic combination of patents, a patent portfolio primarily aims to help firms obtain competitive and innovative advantages that are more optimal than those of their competitors, resulting in a scale effect of technologies that cannot be achieved by individual patents. This has become a new innovation strategy approach for firms[35]. An erudite strategy requires firms to conduct technical R&D and patent applications in various technical areas to acquire a diverse knowledge base, whereas a specialized strategy requires firms to secure their position in a few technical areas by focusing their resources and energy on these areas.

An erudite strategy can bring many benefits to firms. On the one hand, R&D and innovation activities require a substantial influx of funds and human resources and thus entail tremendous risks that are further aggravated by the uncertainties of technological development. A diversified knowledge base can mitigate the negative impacts, and firms can prevent themselves from falling to technological lock-in by establishing a patent portfolio across various technical areas[36]. On the other hand, some existing studies have suggested that it is vital for firms to tap into unfamiliar technical areas in advance to timely identify opportunities in emerging technological development, and heterogeneous knowledge of various areas is likely to lead to cross-disciplinary innovation[37]. It would be difficult for firms to discover new innovation opportunities without diversified strategic planning for technologies[38]. Moreover, strategic planning for patents can prevent firms from falling victim to the "patent thicket," ensuring that researchers can freely carry out technological R&D without worrying about infringement. By establishing a diversified patent portfolio, firms can use it as an "aggressive strategy" to enhance their bargaining power [1].

The erudite strategy has its limitations. Some existing studies have pointed out that although knowledge of different technical types can interact with each other and create more learning opportunities and innovation possibilities, the mere accumulation of knowledge cannot increase the value of technologies[39], and firms need to integrate the diversified knowledge. Thus, the integration of cross-disciplinary knowledge of technologies adds to the difficulty of innovation. Moreover, a firm has to invest more resources to maintain a diversified knowledge base, which increases innovation costs and risks, thereby making it difficult to focus on a particular technical area and gain advantages over competitors since the innovation efforts of the firm are divided. However, since core competitiveness is the basis on which firms utilize technological diversity[7][40], firms fall into the trap of "excessive diversification."

As the overall situation of Chinese firms is that majority of them have relatively poor innovation strength, it is difficult for them to integrate the knowledge elements of various technical areas and generate synergy in innovation. Firms have a limited amount of resources and are unable to effectively coordinate inputs, such as human resources and R&D funds, which a diversified patent portfolio requires. Moreover, as China's patent protection mechanism has yet to be improved, the benefits of aggressive strategy to establish strategical patent combinations are not significant. A specialized strategy is more suitable for Chinese firms under such circumstances. Therefore, this study puts forth the following hypothesis:

H1: An erudite patent portfolio hinders the innovation performance of firms; a specialized patent portfolio stimulates the innovation performance of firms.

### 2.2.2 The Moderating Effect of Dynamic Heterogeneity of Technical Standards

The development of science and technology has led to the development of technical norms, but it would be disadvantageous if there are several possible technical norms for one type of technology. In such a situation, technical standards are needed to unify the norms and guide the development trajectory of technologies. After one or a group of technical norms are successfully released and become the leading design, they develop into technical standards[41]. Hence, technical standards are a type or a series of compulsory requirements or technical specifications with guiding functions to ensure that products and processes meet the requirements, quality, and compatibility[42]. The main bodies that formulate technical standards are international organizations as well as national and industrial associations. Technical standards have profound impacts on the development of every firm and even the entire industry[43].

It is well documented that standard setting is beneficial to the macroeconomy and the entire industry[44]. The benefits also extend to firms that participate in the formal standardization process because not only can they shape standard development but also enhance access to a wide range of knowledge sources in standards committee[9][19][17]. However, in the Chinese context, the government has a defining role in formulating technology standards, and most firms, especially small and medium-sized enterprises, have little influence on how standards are formulated[45][46]. Hence, instead of shaping the standards to their benefit, firms must adapt to the uncertain environment of a new technology standard that profoundly impacts how their own technologies are applied.

A patent portfolio strategy requires a firm to tap into various technical areas. For integrated development of systematic features of technologies and different techniques, specific technical standards are needed to ensure that firms can successfully combine various technologies in products and processes [47]. With the development of technologies, technical standards are continuously revised or updated, and newer and more optimal technical norms are introduced. Such changes stimulate firm innovation[13], but at the same time, it means that old technical norms and their related systems, such as mechanical equipment, processes, and knowledge system, will either be updated or obsolete. Therefore, concentrating all resources of a firm on one area might lead to a risk of substantial sunk cost. One of the purposes of establishing an erudite patent portfolio is to address the uncertainties of technological development so that firms can carry out technical planning in advance, obtain diversified knowledge elements, and diversify the risks of R&D. When technical standards change frequently, a diversified knowledge base can be more effective and prevents firms from becoming path-dependent. Thus, implementing a diversified technical strategy can aid in adapting to dynamic changes in an environment[48]. Therefore, we put forth the following hypothesis:

H2: In an environment with high dynamism of technical standards, an erudite strategy can better improve firm innovation performance than a specialized strategy.

### 2.2.3 The Moderating Effect of Complexity Heterogeneity of Technical Standards

Technical standards represent the coding of technical elements of an industry, and they exist in various forms such as publications and electronic databases containing extensive technical information, including the technical specifications required for firms' product R&D, testing, and commercialization[22]. Although the external knowledge introduced by technical standards is beneficial for firms' technological R&D and innovation, such benefits are not exclusive to one

firm—other stakeholders can access the technical standards. Therefore, a firm needs to absorb and digest external knowledge brought by technical standards more quickly than its competitors and successfully transform them into commercialized innovation outcomes[40].

When adopting an erudite patent portfolio strategy, a firm needs to coordinate R&D in different technical areas, which dilutes its innovative resources. Due to uncertainties in R&D investment, having a diversified knowledge base is not beneficial for either a firm's in-depth development in a specialized technical area and gaining a competitive edge[8]. Due to the complexity of knowledge sources, a firm needs to allocate many human resources and a considerable amount of time and R&D to tackle the challenges. Therefore, adopting an erudite patent portfolio strategy is not beneficial for firm innovation but leads to high costs of internal coordination and innovation risks. A specialized strategy is better at promoting a firm's in-depth development in a specific technical area. Thus, this article puts forth the following hypothesis:

H3: With the increase in the complexity of technical standards, a specialized strategy can better improve firm innovation performance than an erudite strategy.

#### 2.2.4 The Interactive Moderating Effect of Dynamics and Complexity of Technical Standards

To have a better understanding of the relationship between patent portfolio strategies and innovation performance, this study examines the interactive moderating effects of the dynamics and complexity of technical standards. There are four possible scenarios, which are as follows: the standards have a low degree of both dynamics and complexity; the standards have a high degree of dynamics and a low degree of complexity; the standards have a low degree of dynamics and a high degree of complexity; the standards have a high degree of both dynamics and complexity.

When the standards have a low degree of dynamics and a high degree of complexity, the changes in technical norms faced by firms are not radical, but the technical information in technical standards is relatively complex, thus adopting a specialized patent portfolio strategy will be more productive. When the standards have a high degree of dynamics and a low degree of complexity, firms face frequent changes in the technical environment, but technical information in the technical standards are relatively easy to understand, thus adopting an erudite patent portfolio strategy will be more productive. Thus, this article puts forth the following hypotheses:

H4a: The dynamics and complexity of standards interactively moderate the relationship between the diversity of patent portfolios and innovation performance.

H4b: When the standards have a low degree of dynamics and a high degree of complexity, a specialized patent portfolio strategy is beneficial for firm innovation; when the standards have a high degree of dynamics and a low degree of complexity, an erudite patent portfolio strategy is beneficial for firm innovation.

The theoretical framework developed by this study is illustrated in Figure 1.

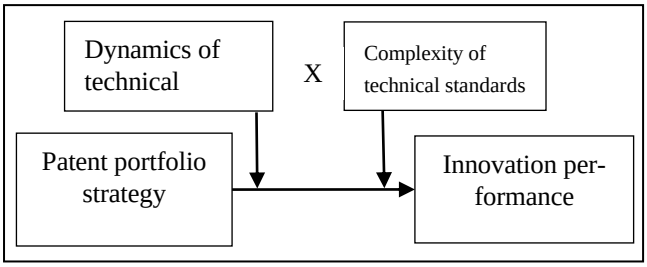


Figure 1. Theoretical Framework

## 3. Research Design

### 3.1 Data

The data sample contains firms from China's Growth Enterprise Market (GEM) Board and Science and Technology Innovation Board (STAR Market) from 2010 to 2019. To explore the innovation performance of firms under different technical standards, the data comprise 11 industries, including semi-conductor, synthetic material, software engineering, etc. After factoring out samples with missing information, a sample of 159 high-tech firms was obtained. Moreover, we manually collected the information of the technical standards in the 11 industries from 2010 to 2019 from the standard database of www.cnki.net. The data include national and industrial technical standards.

### 3.2 Definition of Variables

#### 3.2.1 Independent Variables

The patent portfolio strategies of firms: Portfolio diversity is the core feature of patent portfolio strategies, reflecting the internal structural features of a patent portfolio[6]. It shows the degree of technological diversity of firms and aims to enhance existing technological capabilities or develop new technological capabilities. When a firm's patent portfolio has a high degree of diversity, it leans toward the erudite strategy; when a firm's patent portfolio has a low degree of diversity, it learns toward the specialized strategy. Following the existing studies[49], this study employs the revised Herfindahl index (HHI) to measure the diversity of patent portfolios to prevent the inconsistency arising from the fact that firm differs from each other in patent holdings.

$HHI_{\mathrm{i}} = \sum_{\mathrm{k}=1}^{\mathrm{k}} [\frac{N_{ik}}{N_i}]^2$ . The diversity of patent portfolios is as follows: $PPD_{\mathrm{i}} = 1 - [\frac{N_i * HHI_i - 1}{N_i - 1}]$, where i represents the index of firms; k represents the type of technology; Nik indicates the number of patents of k-type technology owned by i firms; and Ni stands for the total number of patents owned by i firms. The value of PPD is within the range of 0 to 1. The smaller the value, the lower the degree of patent portfolio diversity.

### 3.2.2 Dependent Variables

Innovation performance: The existing studies often use the number of inventions and patents to measure a firm's innovation performance. To prevent measurement errors caused by the different number of patents of different firms, this study uses the proportion of a firm's invention patents to its total inventions to measure innovation performance [50].

### 3.2.3 Moderating Variables

Dynamics of technical standards: The dynamics of technical standards indicate the degree of changes in technical standards of industry. To prevent variances caused by the different number of standards in the 11 industries, this study uses the standard deviation of the number of standards in each industry from 2011 to 2019 to represent this variable. The larger the standard deviation, the more frequent the changes in technical standards occur and the higher the dynamism.

The Complexity of technical standards: The complexity of technical standards represents the degree of the complexity of technical standards of industry. This study uses the average number of pages of documents released from 2010 to 2019 in the 11 industries to represent this variable. When the number is high, it indicates that the technical standards contain more information and thus the degree of technological complexity is higher.

### 3.2.4 Control Variables

To control other factors on firm innovation performance, this study introduces other controlled variables, firm size, which is the firm's annual average value of assets (for clarity, the unit of the annual average value of assets is 10 million); firm age, which is the gap between the year a company went public and 2019; and the firm's R&D investment, which is the ratio of annual R&D investment to operating income.

## 4. Empirical Findings and Analysis

### 4.1 Descriptive Statistics and Correlation Analysis

Table 1 reports the descriptive statistics and the correlation analysis of the main variables. As shown in Table 1, the correlation coefficient of the diversity of patent portfolios and innovation performance is −0.0884, suggesting that the diversity of patent portfolios and innovation performance are negatively correlated. The dynamics of technical standards have a significant and positive impact on innovation performance, and the correlation coefficient of dynamics and innovation performance is 0.42 ($p < 0.01$). A variance inflation factor (VIF) test was performed, and the maximum value is 1.18, indicating that there is no multicollinearity.

Table 1. Descriptive Statistics of the Variables (Mean, Variance, and Correlation Coefficient)

| Variable | Mean | Variance | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|---|
| **Innovation performance** | 0.62 | 0.08 | 1 | | | | | | |
| **Diversity of patent portfo-** | 0.63 | 0.04 | -0.0884 | 1 | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **lios** | | | | | | | | | |
| **Dynamics of standards** | 6.96 | 12.35 | 0.4181*** | 0.1795** | 1 | | | | |
| **Complexity of standards** | 24.29 | 97.77 | 0.0232 | -0.1924** | -0.1597** | 1 | | | |
| **Age** | 19.17 | 21.60 | -0.0261 | 0.1170 | 0.0163 | -0.0086 | 1 | | |
| **Size** | 23.84 | 440.00 | -0.1437* | -0.1569** | -0.1372* | 0.0538 | 0.1962** | 1 | |
| **R&D investment** | 8.83 | 45.68 | 0.3675*** | -0.0793 | 0.1583** | 0.2993*** | -0.0968 | -0.0608 | 1 |

Note: N = 176; * indicates $p < 0.1$; **indicates $p < 0.05$; *** indicates $p < 0.01$

## 4.2 Hypotheses Testing

In this study, stata16 was used to perform multiple regression to verify the main and moderating effects. The results are presented in Table 2. Model 1 only added the control and dependent variables. Based on Model 1, Model 2 added three variables—the diversity of patent portfolios, dynamics of standards, and complexity of standards. Model 3 combined the second-order interaction items of the three variables to verify the moderating effects of technical standards. Model 4 added the third-order interaction items of the three variables.

As shown in Table 2, in Model 1, the coefficient of R&D investment is positive and significant, indicating that the more a firm invests in R&D, the more it enhances firm innovation. In Model 2, the coefficient of the diversity of patent portfolios is −0.231 ($p < 0.05$), suggesting that diversity of patent portfolios and innovation performance are negatively correlated, and a specialized strategy is more beneficial for firm innovation, supporting H1. In Model 3, the multiplicative interaction item of the diversity of patent portfolios and dynamics of standards is 0.0743 ($p < 0.05$), indicating that the dynamics alleviate the negative correlation between the diversity of patent portfolios and innovation performance. With an increase in the dynamics of technical standards, an erudite strategy can better improve firm innovation performance than a specialized strategy, supporting H2. In Model 3, the multiplicative interaction item of the diversity of patent portfolios and complexity of standards is −0.00482 ($p < 0.10$), which does not support H3. In Model 4, the third-order interactive coefficient is −0.00737 ($p < 0.05$), supporting H4a and implying that the dynamics and complexity of technical standards interactively moderate the relationship between the diversity of patent portfolios and innovation performance. The moderating effects of the dynamics of technical standards are depicted in Figure 2.

Table 2. Results of the Hierarchical Regression Analysis

| | Innovation Quality | | | |
|---|---|---|---|---|
| Names of Variables | Model 1 | Model 2 | Model 3 | Model 4 |
| Diversity of patent portfolios | | -0.231** | -0.487 | -1.489*** |
| | | (0.104) | (0.329) | (0.516) |
| Dynamics of standards | | 0.0301*** | -0.0681** | -0.181*** |
| | | (0.00570) | (0.0307) | (0.0545) |
| Complexity of standards | | -0.000877 | -0.0108 | -0.0407*** |
| | | (0.00208) | (0.00765) | (0.0142) |

| | | | | |
|---|---|---|---|---|
| **Multiplicative Interaction Items** | | | | |
| Diversity x Dynamics | | | 0.0743** | 0.239*** |
| | | | (0.0356) | (0.0750) |
| Diversity x Complexity | | | -0.00482 | 0.0419* |
| | | | (0.0115) | (0.0219) |
| Dynamics x Complexity | | | 0.00221*** | 0.00705*** |
| | | | (0.000510) | (0.00201) |
| Diversity x Dynamics x Complexity | | | | -0.00737** |
| | | | | (0.00296) |
| **Controlled Variables** | | | | |
| Age | -0.00171* | 0.00213 | 0.00180 | 0.00139 |
| | (0.00100) | (0.00423) | (0.00403) | (0.00396) |
| Size | 0.00206 | -0.00138 | -0.00119 | -0.00101 |
| | (0.00454) | (0.000945) | (0.000899) | (0.000887) |
| R&D investment | 0.0150*** | 0.0124*** | 0.0103*** | 0.0106*** |
| | (0.00307) | (0.00303) | (0.00293) | (0.00288) |
| Constants | 0.485*** | 0.455*** | 0.938*** | 1.598*** |
| | (0.0948) | (0.120) | (0.226) | (0.346) |
| Observed value | 159 | 159 | 159 | 159 |
| R square | 0.151 | 0.297 | 0.379 | 0.404 |
| Adjusted R square | 0.135 | 0.269 | 0.341 | 0.363 |
| F value | 9.189 | 10.68 | 10.09 | 10.02 |

Note: N = 176; * indicates p < 0.1; **indicates p < 0.05; *** indicates p < 0.01

To verify H4b, that is, when the standards have a low degree of dynamics and a high degree of complexity, a specialized patent portfolio strategy is more beneficial for firm innovation, and when the standards have a high degree of dynamics and a low degree of complexity, an erudite patent portfolio strategy is more beneficial for firm innovation. Following the same approach of the existing studies[51], we categorize technical standards into four scenarios based on median—"high dynamics," "low dynamics," "high complexity," and "low complexity"—and combines two of these scenarios. Therefore, the following four scenarios are generated: (1) a "double low," implying that the standards have a low degree of both dynamics and complexity; (2) the standards have a high degree of dynamics and a low degree of complexity; (3) the standards have a low degree of dynamics and a high degree of complexity; (4) a "double high," implying that the standards have a high degree of both dynamics and complexity.

Based on the regression results in Table 3, when the standards have a low degree of both dynamics and complexity, the diversity of patent portfolios and innovation performance are significantly and negatively correlated, and the coefficient is −0.600 ($p < 0.01$). When the standards have a high degree of dynamics and a low degree of complexity, the diversity of patent portfolios and innovation performance are significantly and positively correlated, and the coefficient is 0.522 ($p < 0.05$). However, the regression coefficients of the remaining two scenarios are not significant. Therefore, H4b is partly supported, that is, when technical standards have a high degree of dynamics and a low degree of complexity, a specialized strategy is more beneficial for firm innovation. To illustrate the moderating effects directly, this study depicts the moderating effect of the interaction items in Figure 3.

Table 3. Results of the Regression Analysis

| | Innovation Performance | | | |
|---|---|---|---|---|
| Names of variables | Double Low | Low dynamics, high complexity | High dynamics, low complexity | Double high |
| Diversity of patent portfolio | -0.600*** | -0.397 | 0.522** | -0.238 |
| | (0.230) | (0.292) | (0.211) | (0.151) |
| Age | 0.00265 | 0.00265 | 0.00265 | 0.00265 |
| | (0.00423) | (0.00423) | (0.00423) | (0.00423) |
| Size | -0.00127 | -0.00127 | -0.00127 | -0.00127 |
| | (0.000954) | (0.000954) | (0.000954) | (0.000954) |
| R&D investment | 0.00956*** | 0.00956*** | 0.00956*** | 0.00956*** |
| | (0.00324) | (0.00324) | (0.00324) | (0.00324) |
| Constants | 0.818*** | 0.524*** | 0.152 | 0.732*** |
| | (0.163) | (0.196) | (0.170) | (0.129) |

| | | | | |
|---|---|---|---|---|
| Observed value | 159 | 159 | 159 | 159 |
| R square | 0.327 | 0.327 | 0.327 | 0.327 |
| Adjusted R square | 0.282 | 0.282 | 0.282 | 0.282 |
| F value | 7.206 | 7.206 | 7.206 | 7.206 |

Note: N = 176; * indicates p < 0.1; **indicates p < 0.05; *** indicates p < 0.01

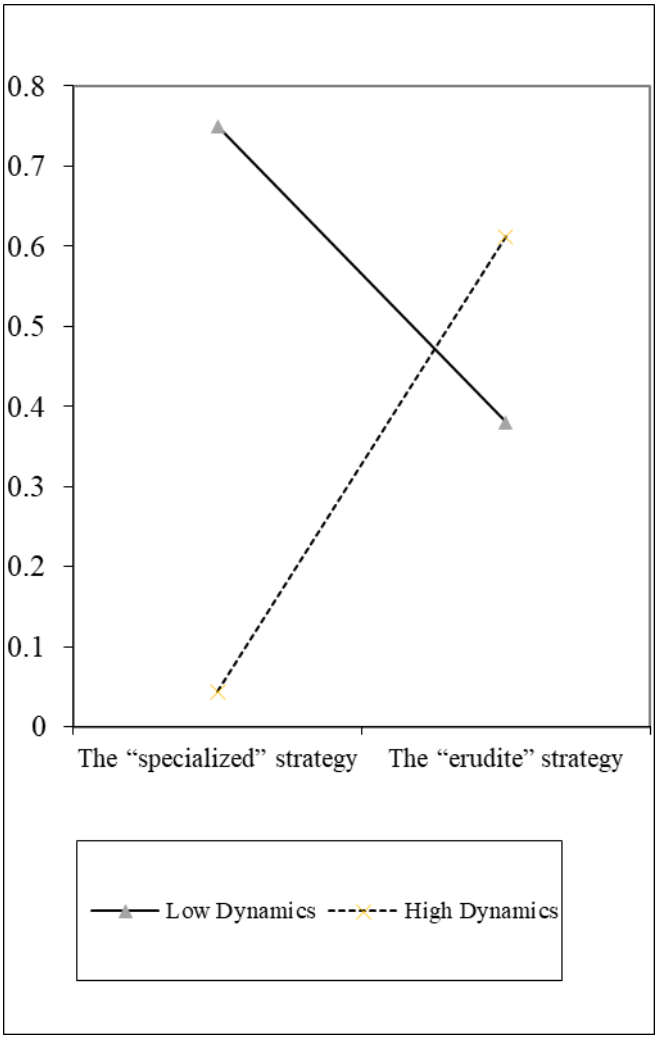


Figure 2 The Moderating Effects of the Dynamics of Technical Standards

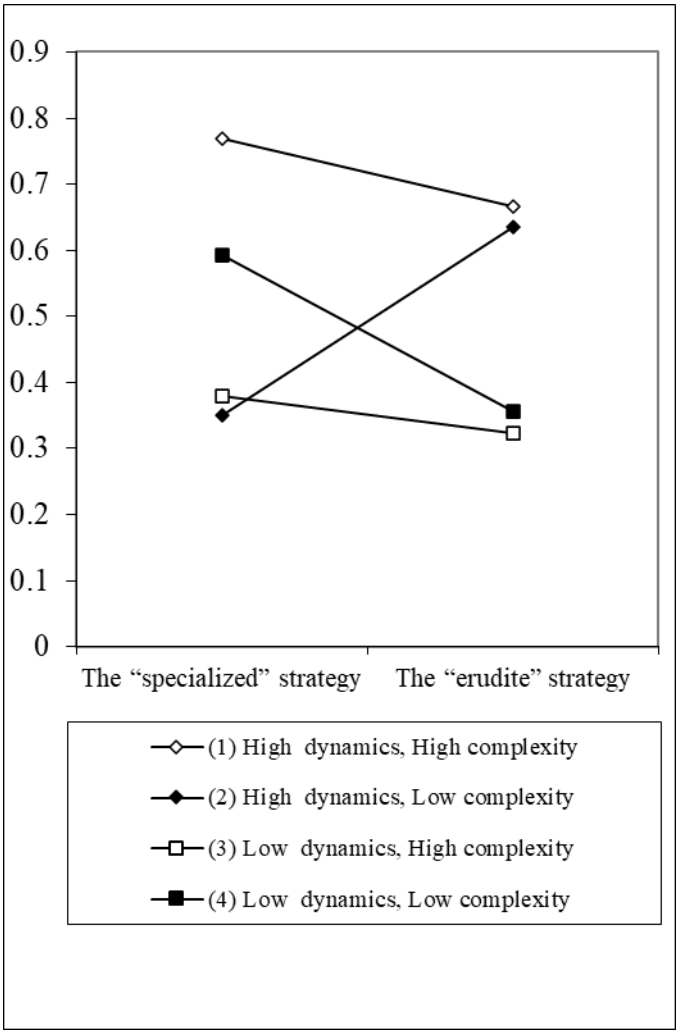


Figure 3. The Interactive Effects

## 5. Conclusions

From the perspective of heterogeneous technical standards, this study employs a data set of 159 firms in 11 industries from 2010 to 2019, including patents, technical standards documents, and firm properties. It adopts the multiple linear models to arrive at the following conclusions. First, a firm’s diversity of patent portfolios and its innovation performance are negatively correlated. This suggests that establishing an erudite patent portfolio strategy is not beneficial for improving firm innovation performance. Although firms acquire diverse knowledge in various technical areas through the diversity of patent portfolios, overall, the limitations outweigh the benefits. Therefore, a firm should adopt a specialized strategy that focuses on R&D investment in a narrow range of technical areas. Second, the dynamic changes in tech-

nical standards significantly weaken the negative correlation between an erudite patent portfolio and innovation performance. In other words, when a firm is in an industry that has frequent changes in technical standards, the negative impacts of the diversity of patent portfolios on innovation performance are reduced. Therefore, a firm can adopt a diversification strategy to address the risks of future uncertainties. Third, based on two properties of technical standards, this study classifies four scenarios, and it finds that when a firm is in an environment in which the degree of dynamics and complexity of standards are both low, the diversity of patent portfolios and innovation performance are significantly and negatively correlated; hence, a specialized strategy will be more beneficial for improving the firm's innovation performance. However, when the technical standards have a high degree of dynamics and a low degree of complexity, the diversity of patent portfolios and innovation performance are significantly and positively correlated; hence, an erudite strategy will be more beneficial for improving the firm's innovation performance.

The existing studies have contradicting opinions about the impact of patent portfolio strategies on innovation. Some researchers believe that an erudite patent portfolio strategy is beneficial for firm innovation, whereas others have found that a specialized patent portfolio strategy is beneficial for firm innovation. The reason for these contradicting findings is due to a lack of detailed analysis of the external environment. This study suggests that under various circumstances of heterogeneous technical standards, the relationship between patent portfolio strategies and innovation performance will dramatically change, and this phenomenon corresponds to the different views in the existing literature about the relationship between the two. This study also explains the paradoxical arguments in the existing literature about the relationship between patent portfolio strategies and innovation performance and complements the related studies. However, this study's empirical analysis reveals the moderating effects of technical standards on the relationship between patent portfolio strategies and the innovation performance of firms. This study regards technical standards as a source of external and explicit knowledge, which strengthens our understanding of technical standards' role in firm innovation and R&D activities. In the existing literature, most of the studies on technical standards focus on the formulation mechanism of technical standards or the effects of technical standards on innovation performance. This study combines specific strategic scenarios of firms to analyze the roles of technical standards, thus facilitating future studies on technical standards.

Regarding managerial practices, this study offers practical implications. Chinese firms should be cautious when establishing a diversified patent portfolios strategy. Compared to those of developed countries, the innovation capabilities of Chinese firms are nonetheless relatively weak. As innovation risks are high, integrating the knowledge elements of different areas can be challenging. Therefore, an erudite patent portfolio strategy has more risks than benefits. Firms should establish their core competitiveness in specific technical areas. For firms in mature industries, such as the electrical industry, a specialized strategy is more beneficial for firm innovation. However, for firms that are in industries that have frequent changes in technical standards and where the degree of complexity of the technical standards is not high, an erudite patent portfolio has more advantages than disadvantages. For firms in emerging industries, such as semiconductor materials and electronic components, a diversified knowledge base is beneficial for firm innovation. Therefore, between erudite and specialized innovation strategies, firms should consider the properties of the technical standards in their industries to fully understand the pros and cons of the diversity of patent portfolios.

This study has some limitations. First, this study does not reveal the influence mechanism of patent portfolio strategies on innovation performance. Second, the empirical data do not prove the impact of the complexity of technical standards on innovation performance, which may be due to the lack of ability to consider the knowledge absorption and transformation of firms. Therefore, future research may add this to the research framework of this study. Moreover, among the four scenarios of technical standards, the effects of the remaining two scenarios on the relationship between patent portfolio strategies and innovation were not supported by empirical research. Therefore, future studies can expand the sample size to obtain more comprehensive findings.

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