# Relationship Strength Affects Firms' Technological Innovation Performance: Study of the Conditional Process

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**Abstract.** In this paper, we empirically analyze the influence mechanism of innovation performance of relationship strength firms through the panel data of patents and standards of 15 firms in China's OLED industry from 2014 to 2020, using hierarchical regression and bias-corrected percentile Bootstrap method for testing. The findings show that: relationship strength positively affects firm innovation performance; relationship strength positively affects firm innovation performance through the mediating effect of network location; the effect of network location on innovation performance is moderated by technological diversification; the mediating effect of network location is also moderated by technological diversification, and the higher the degree of technological diversification, the stronger the mediating effect of network location. The findings enrich the research on innovation performance and R&D networks, and provide theoretical guidance for Chinese firms to build effective R&D networks and technology diversification strategies.

**Keywords:** Relationship Strength; Technological Diversity; Network Location; Technology Innovation Performance.

## 1. Introduction

The OLED industry, as one of the emerging industries, has great application prospects in many fields such as notebook computers and smartphones, and is receiving attention and importance from countries around the world. The network is also gradually evolving, and in the network, evolution will also encounter how to maintain a good partnership and choose a network advantageous position to enhance innovation performance, etc. How to deal with the relationship between the three is of great importance to enhance the status and influence of enterprises in the OLED innovation network.

Granovetter proposed embedding theory, which classifies the types of embedded relationships into relational embedding and structural embedding [1], describing the changes that occur in social networks in terms of relational strength and network location, respectively, and there are many studies on how the two-affect innovation performance respectively. Bian proposed the "strong relationship strength hypothesis", which argues that strong relationships are more effective and powerful than weak relationships in Chinese social networks [2], while the weak relationship school started with Granovetter's "weak relationship strength hypothesis" theory, which measured the strength of relationships in terms of frequency of interaction, depth of feeling, intimacy, and reciprocity [3], and Burt's focus on the importance of network location, which led to the development of Burt focused on the importance of network location and developed the creative "structural hole" theory, in which firms occupying the structural hole act as a "bridge" for resource exchange and have an absolute information and control advantage [4]. On this basis, many scholars have conducted in-depth studies on the strength of relationships and network location on the innovation performance of firms. In addition, technological diversity, as a measure of the degree of diversity in knowledge and technology base [5], can help organizations achieve economies of scale and synergy effects [6], and Robins et al. found through their study that technological diversity in firms affects the innovation performance of firms by increasing knowledge absorption capacity [7].

Looking at the existing literature, we can find that there are still some shortcomings in the existing studies: the influence of strong and weak relationships on innovation performance is still controversial; whether the interaction between relationship strength and network location has an impact on technological innovation performance lacks sufficient theoretical support; in analyzing the relationship between social networks or technological diversity on innovation performance, the

existing studies only consider the influence of one party on innovation performance, ignoring the joint effect of both The existing studies only consider the influence of one party on innovation performance, but ignore the joint effect of both on innovation performance.

Based on the above limitations, this paper collects secondary data through Derwent database, takes relationship strength and network location as independent variables and mediating variables in embedding theory, and investigates the coupling relationship between relationship strength, network location and innovation performance, and links them with social network embedding theory by introducing technological diversity as a moderating variable to study the joint effect of both on innovation performance. The findings of this paper extend the existing research. The findings of this paper extend the existing research results of strong and weak relationships on technological innovation, enrich the social network theory, and have implications and guidance for the maintenance of inter-firm cooperative relationships, the choice of network location, and the degree of technological diversification.

## 2. Theoretical Basis and Research Hypothesit

### 2.1 The Effect of Relationship Strength on Innovation Performance

Granovetter defined relationship strength as a linear combination of interaction frequency, emotional intensity, mutual trust and reciprocal service [3]. Scientific knowledge creation is a complex and accumulated process. To digest and absorb scientific knowledge, enterprises must have a certain cognitive basis and a certain level of knowledge background. Therefore, enterprises with strong relationships have the following three advantages: First, in terms of acquiring new useful knowledge, Lowik et al. confirmed the inverted U-shaped relationship between relationship strength and knowledge acquisition and creation, and pointed out that new knowledge generated by strong relationships can last for a long time [8]. Second, in terms of information transmission and communication, strong relationships promote the transmission of "fine-grained" information, detailed knowledge and professional skills because the common cognitive framework between partners is formed in long-term interaction [9]. Thirdly, in terms of improving innovation output, McFayden showed that at a high level of relationship strength, a curve effect appeared with the reduction of knowledge creation required for innovation. This effect shows that innovation results when trust and freshness are precisely balanced [10]. According to the above logic, this paper puts forward the hypothesis:

Hypothesis 1: Relationship strength has a significant positive impact on innovation performance

### 2.2 The Mediating Role of Network Location

In cooperative innovation networks, network location is an important variable in network embedding theory. Enterprise network location is the result of establishing the relationship between enterprises and other actors. Each enterprise has a different position in the network, and an enterprise with a good network location will have more advantages in information acquisition and processing.

According to the weak relation theory of Granovetter, through the bridging function of weak relation, actors can access remote and heterogeneous network locations and avoid establishing redundant connections [3]. Jill believed that weakly connected actors were characterized by low communication frequency, short relationship maintenance time and low similarity, so that knowledge heterogeneity of each other was strong. Uzzi believed that the close connection in the network has the risk of convergence of ideas and opinions generated by repeated interaction, and the lack of information inflow from weak connection may lead to the lack of information diversity, which is not conducive to enterprises' search for a better network location [11]. To sum up, a weak relationship will expand an enterprise's knowledge network, better access to heterogeneous knowledge, and promote the enterprise to obtain an advantageous network location. Based on the above analysis, this paper proposes hypotheses:

Hypothesis 2: Relationship strength has a significant negative impact on network location.

Levin and Cross believe that the positive impact of strong relationships on knowledge search depends on the mediating role of trust, if the weak connection between enterprises trust each other, so it is more advantageous to obtain valuable knowledge [12], the dominant network participant with other enterprise's trust mechanism, the enterprise together, which was not connected a wide variety of information can be obtained, and tools can be used to establish close relationships between previously unrelated parties [13] because each participant can share their current knowledge and insights into development. Such information is valuable for providing a perspective on how knowledge in a specific field relates to knowledge in other fields [14]. Exposure to insights from unfamiliar fields can stimulate enterprises to reflect on their knowledge network and broaden the range of choices, which is more conducive to innovative output [15]. Based on the above analysis, hypotheses are proposed:

Hypothesis 3: Relationship strength positively affects innovation performance through network location.

### 2.3 The Moderating Effect of Technological Diversification

Leten defined technological diversification as the formation of a broader technological network by enterprises expanding new technological fields [16]. Therefore, in essence, technological diversification is a process of knowledge innovation and product innovation [17], that is, the behavior or state of an enterprise extending its original technological capability to the field of new technology, which results in the expansion of technological scope [18]. Technological capability diversification includes the new invention and recombination of technological elements [19], but it pays more attention to the change of the combination relation of elements, namely structural innovation, so it has the advantages of low research risk and low R&D investment [20]. In addition, technological diversification is the basis for enterprises to implement diversified development strategies, and is also an important factor determining the growth potential and development space of enterprises. It helps enterprises to more accurately identify cutting-edge technological opportunities or major technological changes, reduces enterprises' dependence on a single technology field, and effectively avoids technology lock-in [21]. Based on the above analysis, hypotheses are proposed:

Hypothesis 4: Technological diversification has a positive moderating effect on the relationship between network location and innovation performance.

Based on the above assumptions and theoretical deduction, this paper constructed a moderated mediation model, as shown in Fig. 1.

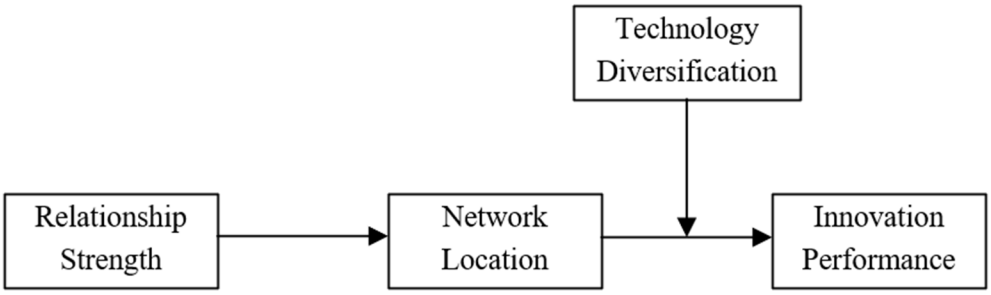


**Fig 1.** Study model

## 3. Study Design

### 3.1 Data Collection

The measurement data of this study are mainly derived from the co-application patents filed by the OLED industry between 2014 and 2020 in Derwent database. First of all, based on the 3-year joint patent application, we will build a collaborative R&D network for the OLED industry each year, respectively, from 2018 to 2020 and 2017 to 2019... In the five knowledge networks from 2014 to

2016, degree centrality and other indicators of each node in the network were calculated based on the annual collaborative research and development network.

### 3.2 Variable Measurement

Innovation performance. Because of the OLED industry belongs to the one of strategic emerging industries, generally through the patent application to enterprise's intellectual property rights protection, at the same time, considering the specific use of science and technology in enterprise's production and manufacturing needs certain limitation, namely considering the hysteresis effect of innovation output, so this article use the enterprise t + 1 year to apply for patents to measure the innovation performance of the enterprise.

Relationship strength. This paper refers to the measurement method of partnership strength by Claudia et al. [22]. Based on the joint patent network of enterprises, the ratio of the total number of cooperation each year to the number of partners in the current year is used to measure the strength of the relationship. The higher the relationship strength of an enterprise, the higher the interaction frequency between the enterprise and its partners, and vice versa.

Network location. In this paper, network centrality is used to measure the network position of an enterprise. Network centrality mainly reflects the degree to which an enterprise is at the core of the network. At present, the indexes used to measure network centrality mainly include degree centrality, intermediary centrality and proximity centrality. Degree centrality refers to the number of network members directly connected to nodes. The more the number of network members, the closer the company is to the network center, the higher the degree centrality. Therefore, degree centrality is used to measure the position of nodes in the network, that is, the network position of enterprises.

Technological diversification. At present, there are many methods to construct the index of technological diversification, such as measuring the number of technology categories, entropy index and Herfindhal index. The Herfindhal index not only considers the field of patent technology coverage, but also takes the number of applications in different fields as the weight index, so as to better reflect the technological diversification of enterprises. This paper selects the group of international Patent Classification Number (IPC) as the technical domain classification unit. The Herfindhal index is calculated by the following formula

$$\text{Herfindahl index} = 1 - \sum_{i=1}^{n} p_i^2$$

Where, n is the number of patented technology categories of the enterprise, $p_i$ represents the proportion of the number of patents belonging to each category in the total number of patent applications of the enterprise. Here, the patents applied by enterprises in the same year are considered as the objects. The Value of the Herfindahl index ranges from 0 to 1, and a higher value indicates a higher degree of technological diversification.

Control variables: (1) Age. Due to the different ages of enterprises, there are great differences in knowledge, technology and resources of enterprises. Generally speaking, the longer an enterprise has been established, the more knowledge it has accumulated in various technical fields, the more technology and resources it has obtained, and the easier it is to transform innovation input into innovation output. Therefore, age of enterprise is taken as one of the control variables in this paper. (2) Structural holes. Structural holes refer to non-redundant connections between enterprises and other nodes. Enterprises with more structural holes can obtain more heterogeneous knowledge, technology and resources. Firstly, Pajek software is used to calculate the limit system of the enterprise. Since it is the reverse measurement of structural hole and its value is between 0 and 1, the difference between 1 and the limit system is calculated, and the natural logarithm of the difference is used as the index to measure the richness of structural hole of the enterprise. (3) Country. Considering that the policies and economic development level of different countries are very different, which may affect the innovation performance of enterprises, this study introduces two virtual control variables, namely whether the enterprise is located in Korea or China

### 3.3 Hierarchical Regression Analysis

In order to test the research hypothesis proposed above, this study first uses hierarchical regression to preliminarily test the moderated mediation model and uses robust standard error. In order to avoid the problem of multicollinearity between variables when constructing the interaction terms between moderating variables and explanatory variables, data are centrally processed in this study. As shown in Table 2, M2 shows that relationship strength has a significant positive impact on innovation performance (β=0.2334, P<0.001), indicating that the higher the relationship strength is, the higher the innovation performance of an enterprise is. Hypothesis 1 is verified. M6 shows that relationship strength has a significant negative impact on network location (β=-0.079, P<0.05), indicating that the higher the relationship strength is, the more remote the enterprise's network location is. Hypothesis 2 has been verified. M3 put relationship strength and network location into the equation, relationship strength still has a significant positive impact on innovation performance (β= 0.3041, P<0.001), and network location also has a significant positive impact on innovation performance (β= 0.8952, P<0.001). This indicates the influence of the strength of partial network location intermediary relationship on innovation performance. Hypothesis 3 is verified.

**Table 1.** Hierarchical regression analysis

| Variables | Innovation Performance | | | | Network Location |
|---|---|---|---|---|---|
| | M1 | M2 | M3 | M4 | M5 |
| Relationship Strength | 0.2334*** | 0.3041*** | 0.2165*** | | -0.079* |
| | (0.0626) | (0.0565) | (0.0587) | | (0.0351) |
| Network Location | | 0.8952*** | 0.4707** | | |
| | | (0.1881) | (0.1968) | | |
| Technology Diversification | | | 1.9306*** | | |
| | | | (0.4418) | | |
| Network Location*Technology Diversification | | | 1.1615* | | |
| | | | (0.4420) | | |
| Age | -0.2123** | -0.2619*** | -0.3011*** | 0.051 | 0.0554 |
| | (0.0674) | (0.0596) | (0.0535) | (0.039) | (0.0378) |
| Korea | 0.8984*** | 0.4950** | 0.8217*** | 0.419*** | 0.4506*** |
| | (0.1746) | (0.1741) | (0.1755) | (0.100) | (0.0980) |
| China | 0.6209* | 0.3499 | 0.4194 | 0.111 | 0.3026 |
| | (0.2732) | (0.2446) | (0.2157) | (0.131) | (0.1534) |
| Structural Hole | 12.4873*** | 0.3442 | 4.0995 | 13.805*** | 13.5647*** |
| | (1.4779) | (2.8581) | (2.6831) | (0.847) | (0.8297) |
| $R^2$ | 0.6532 | 0.7408 | 0.8193 | 0.799 | 0.8133 |
| Adj $R^2$ | 0.6234 | 0.7254 | 0.7921 | 0.785 | 0.7945 |
| F | 21.3477*** | 27.3571*** | 29.0265*** | 55.011*** | 49.3811*** |

M4 put the interaction terms of relationship strength, network location, technological diversity, network location and technological diversity into the equation at the same time, and the interaction term has a significant positive impact on innovation performance (β=1.1615, P<0.05), indicating that

technological diversity plays a positive moderating role between network location and innovation performance. Hypothesis 4 is verified. At this time, network location still has a significant positive impact on innovation performance (β=0.4707, P<0.01), indicating that the mediation effect still exists.

## 4. Research Conclusion

This study focuses on the conditional process of relationship strength influencing innovation performance, and explores the mediating effect of network location and the moderating effect of technological diversification. The results show that relationship strength positively affects firm innovation performance; Relationship strength has a positive impact on firm innovation performance through the mediating effect of network location, that is, relationship strength makes firms close to the network center, which leads to more knowledge and resources and improves firm innovation performance. The effect of network location on innovation performance is moderated by technological diversification. Compared with low-technology diversification, high-tech diversification improves the core competitiveness of enterprises, thus enhancing the transmission effect of network location on innovation performance. The mediating effect of network location is also moderated by technological diversification. When the degree of technological diversification is high, the mediating effect of network location is stronger, and vice versa. These conclusions provide theoretical guidance for exploring the impact of relationship strength on firm innovation performance.

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