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# Exploring the Open Innovation Information Spillover Effect: Conceptual Framework Construction and Exploratory Analysis

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**ABSTRACT** Since its launch, open innovation has been one of the hottest research topics in the field of innovation management. However, most of the current literature focuses on open innovation participants, severing the link between actors engaging in open innovation activities and social third-party firms, i.e., lacks discussions of the social attributes of open innovation. Therefore, via the perspective of the evolution of open innovation participants, this paper reviews current research from the aspects of unilateral subjects, bilateral subjects, and third-party subjects. Integrating the perspective with a sociological view, this paper theoretically constructs a framework for the open innovation information spillover effect. Moreover, taking Huawei Technologies Co., Ltd., as an example, this paper verifies the practical existence of the information spillover effect among firms' open innovation activities. This paper aims to extend the research boundary of open innovation, thereby providing a theoretical reference for further studies.

**INDEX TERMS** Open innovation, information spillover, third-party firms, exploratory analysis, patents.

## I. INTRODUCTION

Amid the rapid changes in technology and markets and the increasing globalization of competition, a growing number of researchers and practitioners have begun to advocate for innovation activities more openly [1]. Such an innovation paradigm is defined as open innovation by the academic community. Since Professor Chesbrough first proposed it in 2003, open innovation has become one of the hottest topics in the field of innovation management [2]. Open innovation has been widely discussed in academic research, business practices, and policy formulations because this innovation paradigm complements the current era's innovation characteristics, i.e., the increased integration of technology and industry and a greater depth of collaboration and subject participation [3]. Moreover, this innovation paradigm can better cope with the rapidly changing technology and market

environments, helping firms achieve improved performance and competitiveness [4].

Thus far, open innovation has produced fruitful research results. As it evolved, most early studies comprised case studies of large-scale American technology enterprises, such as Xerox, Lucent, Intel, IBM, etc. [3], [5]. Scholars broadened the industrial fields of open innovation research, extending it to low-end industrial firms, the public sector, and non-profit organizations [6]–[8]. The analysis units were widened from the firm level to the project, industry, and regional levels [9], [10]. Research methods shifted from case studies to large-sample empirical studies, and research scenarios were gradually expanded beyond the United States [11]. Further, scholars' research questions gradually moved from “*what is open innovation*” to “*why and how do firms conduct open innovation*”, i.e., from the initial focus on definitions, modes, merits, demerits, etc., to a more in-depth study of collaboration, openness, performance, knowledge integration, intellectual property rights (IPRs), and various other aspects of open innovation [12]–[18].

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However, the research objects within discussions of these issues were primarily innovation implementers and their collaborators—little attention was given to social third-party firms [19]–[21]. Taking the broad topic of open innovation performance research as an example, scholars primarily investigated the performance changes of firms implementing innovation, comprising economic and innovation performance [22], [23]. Additionally, regarding open innovation collaboration, most researchers explored how firms carrying out open innovation choose external partners [24] or how they form stable collaboration relations with external partners to enhance their innovation capabilities or performances [25]. Further open innovation research, which investigates different topics, will not be summarized in this study [26]–[31]. In the context of open innovation, knowledge flows between firms frequently, allowing a large amount of innovation-related information to penetrate blurred organizational boundaries and at times be obtained by social third-party firms, thus affecting their open innovation decision-making. Accordingly, an information spillover effect of open innovation forms. However, the existing studies sever the connection between open innovation activities and social third-party firms, focusing instead on the implementers and their collaborators in open innovation, seldom discussing the impact of open innovation on third-party firms; i.e., they lack discussions regarding the social attributes of open innovation.

Therefore, this paper aims to fill this research gap. Specifically, this study first conducts a comprehensive review of open innovation from the perspective of the change of innovation participants, integrating views from sociology, to link open innovation implementers, collaborators, and third-party firms; i.e., it theoretically constructs a conceptual framework of the open innovation information spillover effect. Next, this paper investigates the open innovation information spillover effect within Huawei Technologies Co., Ltd. (Huawei). Since it is a single case study, this paper selects two typical open innovation modes—patent alliance and patent trading—as research objects to enhance the credibility of this single case study's results.

The scholarly contribution of this paper is twofold. First, from the perspective of sociology, firms theoretically exist in a complex social system, and they influence each other. Any practice of firms will be influenced by the practices of other firms, which then naturally affects each firm. As firms implement open innovation, an extensive external collaboration will release a large amount of innovation information, which is of great value for social third-party firms since it can be used to solve the information asymmetry and uncertainty of their innovation activities. Consequently, open innovation practices among external firms tend to be highly concerned with social third-party firms, which functions as a vital information reference in their innovation decision-making. Hence, this paper breaks away from the existing research framework of open innovation, which mainly focuses on innovation implementers and collaborators, to discuss the social

attributes of open innovation, i.e., demonstrating how open innovation information spillover effect provides a novel perspective and expands new fields for open innovation research, thereby enriching and perfecting the existing theoretical system of open innovation. After detailing the theory of the open innovation information spillover effect, this paper conducts an exploratory analysis of a typical firm to further establish the practical existence of this spillover effect. The results of this exploratory analysis confirm the information spillover effect of open innovation, offering a realistic basis for innovation participants to pay attention to the spillover effect when engaging in future open innovation practices. For example, for firms that are innovation implementers and collaborators, a clear understanding of the information spillover effect may help them to better plan and manage open innovation activities. For third-party firms, an awareness of the information spillover effect of open innovation can facilitate more effective use of innovative information between external firms. For policymakers, recognizing that the information spillover effect of open innovation has great reference value may encourage their use of policy tools to promote the social spillover function of open innovation.

The remainder of the paper is arranged as follows: Section II systematically reviews the existing literature from the perspective of the change in open innovation participants. Integrating the sociological view, this paper then constructs a conceptual framework regarding the information spillover effect of the open innovation information spillover effect. Section III comprises an exploratory case study concerning Huawei's open innovation practices, investigating whether there is an information spillover effect among actual open innovation activities. Finally, Section IV concludes this study, proposing limitations as well as future directions.

## II. LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

In a complex and shifting environment, traditional closed innovation no longer meets all the innovation needs of firms [32]. Consequently, more firms tend to openly engage in innovation practices, i.e., to carry out open innovation [33]. Since it was first put forward, open innovation research has produced fruitful results—the research subjects of which are primarily implementers and collaborators—with little attention given to social third-party firms [19]–[21]. In the context of open innovation, firms' boundaries become increasingly blurred and transparent to make knowledge flow frequently, raising the possibility that innovative information will penetrate outward. This information can then flow to social third-party firms for subsequent use in their innovation practices, thus having an open innovation information spillover effect. From this perspective, a firm's open innovation practice is not only limited to itself and its collaborators but also connected with social third-party firms. This link has received little attention in the previous literature, severing the connection between firms directly involved in open innovation and social third-party firms; i.e., scholars have not

discussed the social attributes of open innovation. To clearly illustrate this spillover effect, this section first reviews the literature concerning open innovation and then divides it into three stages according to shifts in research subjects (innovation participants), namely, unilateral implementers, bilateral partners, and third parties. Next, this paper identifies the limitations of the existing literature and integrates the views of sociology to suggest that open innovation activities impact third-party firms, thereby constructing a conceptual framework of the open innovation information spillover effect.

#### **A. THE FIRST STAGE: FOCUS ON UNILATERAL IMPLEMENTERS OF OPEN INNOVATION**

Open innovation is defined as a concept at the relationship level because it must first answer who it is open to; i.e., it entails cooperation and interaction with other firms, which contrasts with traditional closed innovation [34]. In the traditional closed innovation mode, firms mainly rely on their internal resources to complete all aspects of innovation [3]. In the open innovation mode, however, firms must extensively collaborate with other organizations to form various and complex interactive relationships, effecting innovation through the cooperation and participation of multiple subjects, via a coupling process [35]. Yet, from the perspective of the development of open innovation research, a large number of studies, especially early ones, focused primarily on open innovation implementers, through research topics including the motivations, modes, and obstacles in implementing open innovation, as well as the impacts on firms' different performances.

First, regarding firms' motivations to implement open innovation, scholars have mainly elaborated on two aspects. One aspect stems from transaction cost theory, the belief that firms' external innovation activities can solve highly proprietary property assets, reduce the uncertainty of supervision and collaborators, internalize innovation spillover, balance the contribution of collaborators, and reduce the risk of opportunism by outsiders [36]. The other aspect follows resource-based theory, holding that firms implement open innovation to develop and utilize resource complementarity, scope economy, obtain rapid market access, and reduce risks and costs [37]. Moreover, some scholars, from the perspective of the external environment, emphasize the role of factors such as rapid technological iteration, globalization, market changes, and uncertainties, a wide distribution of innovative talent, rising innovation costs, and increased product complexity [5]. Meanwhile, other research identifies certain factors that hinder open innovation. For example, Salter *et al.* [38] believe that an internal organization's attitude towards seeking external partners is the main obstacle to open innovation.

Second, regarding open innovation modes, the definition of open innovation demonstrates that it is a process in which a firm uses the inward and/or outward knowledge flow to improve the success rate of innovation. Therefore,

most works separate open innovation modes into two types: inward and outward open innovation [39]. Enkel *et al.* [32], Gassmann and Enkel [17], and West and Bogers [40] thus emphasize that firms should use both knowledge flows to divide the open innovation mode into inbound, outbound, and coupled open innovation. Most of the current literature emphasizes the inbound mode, i.e., firms obtain innovation-related ideas, technology, knowledge, and resources from the outside [13]. Outbound open innovation refers to firms making full use of external markets to actively develop and utilize their internal technologies, such as patent licensing and trading activities [1]. Coupled open innovation activities stress that firms simultaneously use internal and external resources and the market to innovate [41].

Finally, scholars have expanded the limitations of early case studies, using extensive sample data to analyze the relationship between open innovation and firms' different kinds of performance. However, due to the complexity and heterogeneity of open innovation, no consistent conclusions have yet been reached [42]. Most literature finds that open innovation can improve innovation performance (or other indicators, such as the economy) [43], [44]—i.e., that the more open a firm is to the outside, the more its performance will improve. Yet, not all scholars agree with this view; some suggest that the implementation of open innovation will reduce firms' performance [45]. Others, combining both views, depict an inverted U-shaped relationship between open innovation and performance, holding that the implementation of open strategies will indeed promote performance improvement. However, if a firm excessively relies on external resources, it will increase the search, coordinate, and monitor costs, thereby reducing organizational performance [46]. Moreover, some researchers simply contend that there is no relationship between them [47].

#### **B. THE SECOND STAGE: FOCUS ON BILATERAL PARTNERS OF OPEN INNOVATION**

In detailed studies of open innovation, some scholars not only consider innovation implementers but also begin to incorporate their collaborators into the analytical framework, focusing on the bilateral partners of open innovation, i.e., who to open to and how to coordinate and manage partners to avoid the so-called "open innovation paradox". The existing literature indicates that firms' external collaborators mainly include customers, suppliers, universities, and research institutions [48]. Therefore, how these collaborators are coordinated and managed has attracted the attention of scholars. Naqshbandi *et al.* [49] pointed out that the relationship of managers with external firms, universities, research institutes, or government personnel can help firms seek, acquire, transform, and utilize new knowledge, thereby facilitating both inbound and outbound open innovation. Meanwhile, the existing literature also suggests that the heterogeneity of external collaborators will have different influences on firms. Accordingly, Inauen and Schenker-Wicki [50] argue that firms that choose customers, suppliers, universities, and

competitors within their industry as external partners will actively promote innovation performance. By contrast, collaborating with firms outside their industry or with consulting firms will have a negative or insignificant impact on innovation performance.

Significantly, scholars within the relevant literature have gradually realized that there may be a natural conflict between implementers and collaborators. On the one hand, knowledge should be shared between partners; on the other, it should be protected, reflecting the paradox of open innovation [51]. Specifically, sharing knowledge, technology, and experience between open innovation partners is of great benefit, allowing both parties to complement each other [52]. However, without effective management, firms may face the risk of insufficient protection due to excessive knowledge-sharing, weakening their competitive advantages and in turn facilitating the leakage of relevant assets and the risk of free-riding [53]. Scholars have attempted to solve this paradox. For example, Enkel *et al.* [32] identified five aspects that should be considered when analyzing such conflicts: collaboration objectives and characteristics, knowledge characteristics, intellectual property protection capability, relationships between partners, and the external collaboration environment.

### C. THE THIRD STAGE: GRADUAL FOCUS ON THIRD PARTIES OF OPEN INNOVATION

In recent years, there have been new developments in open innovation research. In addition to focusing on unilateral implementers and bilateral partners, the research perspective has gradually expanded to third parties of open innovation. Such research is represented by scholars such as Roper *et al.* [19]. They used panel survey data of the Irish innovation group from 1994 to 2008 to identify the innovation connection width between firms and various external subjects—customers, suppliers, competitors, joint ventures, consulting firms, universities, industrial laboratories, and government laboratories—as open innovation input. The average value of the innovation connection width of other firms in the industry measures the spillover effect. The results prove that the implementation of open innovation has a positive spillover effect on other firms within the industry and confirm that this can significantly promote firms' economic performance. Later, Roper *et al.* [54] further analyzed the impact of this spillover effect on firms' innovation performance in a subsequent study based on British innovation survey data. Here, they considered the spillover effects of a local interactive knowledge search (represented by the number of local innovation collaborator types) and a local non-interactive knowledge search (measured by the importance of conferences, scientific or technical publications, industry associations, technical standards, etc. to firms' innovation). The results show that local interactive knowledge sources positively affect firms' innovation performance, while local non-interactive knowledge sources have a negative spillover effect.

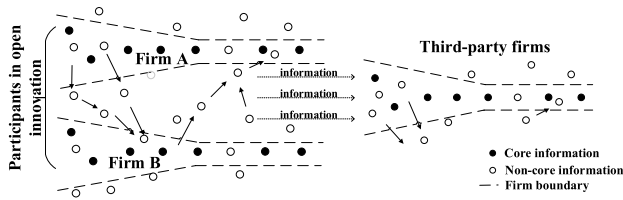
Other scholars have performed somewhat similar studies. For example, Drivas *et al.* [55] explored the impact of exclusive licenses on non-licensees based on American universities' licensing data from 1977 to 2009. The results indicate that universities licensing patents to firms would attract other innovators (non-licensees) to cite these licensed technologies, thereby producing information externalities. In other words, the patent licensing of universities can produce both license fees social benefits. Thompson *et al.* [56] analyzed licensing events amid the invention patents of the University of California from 1997 to 2007 and investigated the impact of academic patents on the citation of academic publications within the same field. The research results demonstrated that inventors' patent licensing events could increase the citation counts of papers published by the same inventors.

### D. CONCEPTUAL FRAMEWORK OF THE OPEN INNOVATION INFORMATION SPILLOVER EFFECT

The above literature review shows that the focus of open innovation research has expanded from innovation implementers in the early stage to include both implementers and their collaborators in the second stage, and then recently further expanded to the third stage, which began to focus on third parties of open innovation.

From a sociological perspective, firms do not exist in isolation but interact with others extensively to form social networks [26]. It follows that any firm's practices will be affected by other external peers, which then naturally affect other firms [27]. Therefore, the subjects involved in open innovation practices are limited to those who directly participate in open innovation, i.e., innovation implementers, collaborators, and other social firms, comprising the third-party firms mentioned here. Moreover, in contrast to traditional closed innovation, open innovation holds that firms cannot carry out innovation activities in isolation amid the fierce environment of innovation competition and must pay attention to and utilize valuable external ideas and resources as much as possible. Extensive external collaborations—alliances, mergers and acquisitions, etc.—make firms' boundaries increasingly blurred and transparent, facilitating flows of knowledge or information [28], [29]. As a result, given that firms participate in external collaboration extensively, the visualization and social attention of their innovation activities are improved, enhancing the possibility that a large amount of innovative and useful information will also flow to social third-party firms [30]. Furthermore, from the perspective of social third-party firms, the characteristics of high uncertainty and risk of innovation will inherently drive them to pay close attention to the corresponding innovation practices of other firms to obtain timely innovation information, maintaining the consistency between their innovation practices and market orientation [31]. Collectively, compared with closed innovation, this spilled-over information is of great value in solving information asymmetry and innovation uncertainty among firms, although the core technology and knowledge are still protected.





**FIGURE 1.** The conceptual framework of the open innovation information spillover effect.

However, although the evolution of the existing literature shows that the boundary of open innovation research is continuously expanding and gradually approaching real open innovation activities, there is still room for further expansion, especially within the third stage. The studies in the third stage stand out from the existing research framework through their early discussion of third parties of open innovation, but they still have some limitations. First, these studies did not strictly distinguish between open innovation participants and third parties. Roper *et al.* [19], [54], for example, proposed the so-called concept of “open innovation spillover” but held that firms’ open innovation would spill over knowledge to other firms within the same industry. Clearly, their research still focused on open innovation implementers. Second, these works focus only on a single mode of open innovation, i.e., inbound innovation. As the literature review demonstrates, there are several open innovation modes with different impacts upon third-party firms. Whether the results of inbound open innovation are consistent with those of outbound innovation is still unknown. Finally, the data sources of these studies are relatively limited. For example, Roper *et al.* [19], [54] used survey data from developed countries. Whether the research results apply to developing countries is unknown. Additionally, Drivas *et al.* [55] and Thompson *et al.* [56] discussed only university patent licensing; they did not investigate firms’ licensing activities. Moreover, open innovation practices include not only patent licensing but also many other forms, such as patent trading.

Therefore, this paper proposes that open innovation practices should not only involve the subjects directly involved but also encompass third-party firms. Due to extensive external collaboration and increasingly blurred organizational boundaries, open innovation practices will inevitably overflow innovation-related useful information to third-party firms, thereby forming an information spillover effect (see Figure 1).

### III. EXPLORATORY ANALYSIS BASED ON HUAWEI TECHNOLOGIES CO., LTD.

The previous section theorizes an information spillover effect among firms’ open innovation activities, constructing a conceptual framework through a systematic literature review based on the shifting participants in open innovation that integrates sociological views. This section conducts an exploratory analysis of Huawei to verify the spillover effect in practice. Specifically, this section first presents the data

to be used in the study, including patent alliances and patent trade. Next, the related methods are introduced individually. The final subsection lists the results of the analysis.

#### A. DATA SOURCES

This section intends to verify the open innovation information spillover effect in practice through the single case study of Huawei. Since Huawei’s open innovation practices have both inbound and outbound modes, this paper considers both as reflecting reality, effectively compensating for the deficiency in existing studies that focus primarily on one or the other. This paper represents inbound and outbound open innovation with patent alliances and patent trading, which are two of Huawei’s typical open innovation practices [57]–[59].

The reason for selecting Huawei as the case study object is twofold. First, it typifies firms’ innovation activities in developing countries. Huawei is an innovative firm with the largest number of patents in China, listed among the world’s top 100 most valuable brands [59]. Meanwhile, open innovation is a critical part of Huawei’s innovation strategy. Huawei’s leapfrog upgrade and development are achieved through open innovation [60]. Therefore, Huawei is a typical representative for this study. Second, Huawei’s data collection is convenient. Huawei has long been engaged in innovation practices, producing numerous data that function as a good observation window, easily accessed through various public channels, such as its official website, reports, journals, etc.

Generally, the data used in this study are from various sources, such as official websites, news, annual reports, monographs, and journals. Although secondary data are used, they mutually support one another due to their multiple origins, increase their credibility and reliability [61]. With regard to patent alliances, this study chooses the WiMAX Patent Alliance (WiMAX) as the research object. Before joining WiMAX, it was difficult for Huawei to break through the patent barriers built by the Open Patent Alliance (OPA). Therefore, compared with the other firms in WiMAX, Huawei’s high business costs made its products less competitive. After joining WiMAX, Huawei could carry out patent cross-licensing with these firms, which quickly shattered its previous patent barriers, providing space and guarantees for its industrial development and income. An intuitive result is that Huawei’s innovation performance has changed significantly since joining WiMAX in 2009 (see Table 1). Significantly, it is impossible to directly measure the changes in Huawei’s open innovation practice before and after joining WiMAX. The number of granted invention patents and the amount of R&D investment, which were obtained from the National Intellectual Property Administration, PRC (CNIPA, <http://www.cnipa.gov.cn>) and Huawei’s annual reports, are used to describe Huawei’s overall innovation practice, thereby reflecting its open innovation practice from the outside, given that open innovation plays a vital role in its innovation strategy. Patent trading data are also collected from CNIPA. Since patent grants take some time to complete, the end period for data collection is set to 2018.

**TABLE 1.** Huawei’s granted patents and R&D Investment from 2000 to 2018.

Year	Nr. of granted patents	R&D investment
2000	8	20
2001	11	30
2002	17	31
2003	125	32
2004	521	40
2005	493	47
2006	484	59
2007	1028	71
2008	2703	100
2009	3744	133
2010	2826	166
2011	2804	237
2012	2828	301
2013	2503	316
2014	2409	408
2015	2404	596
2016	2883	764
2017	3338	897
2018	3464	1015

The beginning year is set to 2000 for patent alliance data and 2004 for patent trading data due to data availability considerations and the starting year of relevant events.

Moreover, it should be noted that patent trading data are from the information and communications technology (ICT) industry. The reasons are as follows. First, the ICT industry’s technology develops rapidly. Compared with other industries, ICT has apparent advantages in the number, frequency, and updating speed of patent applications as one of the main battlefields for contemporary technological innovation [62]. Second, in terms of patent trading, the total number of firms patent trading in this industry is 179,479, accounting for approximately 30% of all industries (614,251). The data are therefore well-representative. As a result, this paper obtains patent trading data from the ICT industry according to the corresponding International Patent Citation (IPC) code offered by the OECD [63], which is shown in Table 2. Accordingly, this study searched for and identified all firms relevant to firm patent trading data in the ICT industry from CNIPA, and a total of 179,479 records were obtained.

**B. RESEARCH METHODS**

The exploratory analysis of Huawei aims to practically confirm the open innovation information spillover effect through two methods. First, in terms of patent alliance analysis, this paper regards Huawei’s patent grants and R&D investments before and after joining WiMAX as different behaviors, divided into two groups; i.e., before and after

**TABLE 2.** ICT industry and IPC codes.

ICT industry	IPC code
<b>Telecommunications</b>	G01S; G08C; G09C; H01P; H01Q; H01S; H1S5; H03B; H03C; H03D; H03H; H03M; H04B; H04J; H04K; H04L; H04M; H04Q
<b>Consumer electronics</b>	G11B; H03F; H03G; H03J; H04H; H04N; H04R; H04S
<b>Computer, office machinery</b>	B07C; B41J; B41K; G02F; G03G; G05F; G06; G07; G09G; G10L; G11C; H03K; H03L
<b>Others</b>	G01B; G01C; G01D; G01F; G01G; G01H; G01J; G01K; G01L; G01M; G01N; G01P; G01R; G01V; G01W; G02B6; G05B; G08G; G09B; H01B11; H01J; H01L

joining WiMAX. A significant difference would demonstrate that Huawei’s patent grants and R&D investments are affected after joining WiMAX, reflecting from the outside how Huawei’s open innovation practices are affected by other firms. In this subsection, the Wilcoxon rank-sum test was used. Second, this paper directly evaluates whether Huawei’s patent trading is influenced by other firms in the ICT industry through the Granger causality test, which is a common test method for information spillover [64].

The following section elaborates on the Wilcoxon rank-sum test and Granger causality test to fully introduce the case study method.

1) CASE STUDY METHOD

Case studies are one of the empirical methods commonly used in management research [65]. An exploratory single case study is used to discover new problems and build conceptual models [66]. Combined with the research purpose, this paper adopts this method and selects Huawei as the case study object to explore whether its open innovation practices are influenced by other firms, i.e., whether there is an information spillover effect among firms’ open innovation practices.

2) WILCOXON RANK-SUM TEST METHOD

The signed-rank test method proposed by Wilcoxon [67] was developed based on the traditional signed-rank test for paired data. The method is often used to test whether there is a significant difference between two samples’ paired variables. The primary analysis steps are described as follows:

- Find the absolute value  $|X_i - Y_i|$  of the difference between  $X_i$  and  $Y_i$  of the paired sample data.
- Sort the obtained absolute values in ascending order and assign a rank, denoted as  $R_i$ . Of these, if  $|X_i - Y_i|$  is 0, then  $R_i$  is 0. Moreover, if there is an equal  $R_i$ , then  $R_i$  is the average of the two.
- When  $X_i - Y_i > 0$ , define  $W^+$  as its corresponding positive rank-sum. When  $X_i - Y_i < 0$ , define  $W^-$  as its corresponding negative rank-sum.
- Assuming  $H_0 : X_i - Y_i = 0, H_1 : X_i - Y_i \neq 0$ , if the difference between  $W^+$  and  $W^-$  is small, then there is no significant difference in the sample data of the two pairs. If the difference between  $W^+$  and  $W^-$  is large,

then there is a significant difference in the two pairs of sample data. Therefore, statistic  $W = \min(W^+, W^-)$ .

- The statistic  $W$  obeys the Wilcoxon signed-rank distribution. In the case of a large sample, a statistic that approximately obeys the normal distribution can be constructed, as shown in Formula (1):

$$Z = \frac{W - \frac{n(n+1)}{4}}{\sqrt{\frac{n(n+1)(2n+1)}{24}}} \quad (1)$$

The  $Z$  statistic and its corresponding probability p-value can be calculated with related software. If the p-value corresponding to the statistic  $Z$  value in the result is more significant than the given significance level, the null hypothesis is accepted; i.e., there is no significant difference between the two pairs of sample data. If the p-value corresponding to the statistical  $Z$  value in the result is less than the given significance level, the null hypothesis is rejected, and the sample data of the two pairs are considered to be significantly different.

### 3) GRANGER CAUSALITY TEST METHOD

As the Granger causality test is closely related to time series information, it is called the information spillover test in many studies [64]. Granger [68] proposed the concept of ‘‘causality’’ when studying the time series’ mutual prediction ability, which does not refer to real causality. It is only defined from the perspective of the sequence of information occurrence and the prediction effect. Specifically, suppose the sum of squares of the prediction residuals of  $X$  with the existence of historical information on  $Y$  is significantly smaller than that without  $X$  information. In this case, the existence of  $X$  significantly improves the prediction accuracy of  $Y$ ; i.e.,  $X$  can be said to be the Granger cause of  $Y$ . The regression formula is shown in Formula (2):

$$Y_t = \gamma + \sum_{i=1}^n \alpha_i Y_{t-i} + \sum_{j=1}^n \beta_j X_{t-j} + \varepsilon_t \quad (2)$$

where,  $Y_t$  and  $X_t$  represent two sets of time series data,  $X_{t-j}$  is the lag value of  $X_t$ ,  $Y_{t-i}$  is the lag value of  $Y_t$ ,  $\gamma$  is a constant,  $\alpha_i$  and  $\beta_j$  are regression coefficients, and  $\varepsilon_t$  is a random error. The null hypothesis  $H_0$  of the model is ‘‘ $X$  is not the cause of the change in  $Y$ ’’. If at least one of the coefficients  $\beta_j, j = 1, 2, 3, \dots$  is significantly not 0, reject the null hypothesis and accept the alternative hypothesis that ‘‘ $X$  is the cause of the change in  $Y$ ’’; i.e., the past information of  $X$  will affect  $Y$ .

Moreover, before the Granger causality test, the traditional regression analysis requires that all time series involved in the study be stable for the time series data. Therefore, to ensure that the regression is meaningful and prevent the phenomenon of ‘‘false regression’’, the steps of this study in the Granger causality test are as follows.

First, the stationarity of the time series data is tested. This study refers to the augmented Dickey-Fuller (ADF) method [69] for the stationarity test, and the expression is

shown in formula (3):

$$\Delta Y_t = \alpha + \beta Y_{t-1} + \varepsilon_t \quad (3)$$

where,  $\Delta$  is the first-order difference symbol,  $\alpha$  and  $\beta$  are parameters, and  $\varepsilon_t$  is a random error term subject to independent and identical distributions (iid).

Second, according to the results of the ADF stationarity test, determine whether to use cointegration analysis. When the variables in the test results are stable, false regression will not occur. Furthermore, when variables are unstable, it is necessary to use cointegration analysis to process non-stationary time series data to analyze the long-term dynamic equilibrium relationship between the variables. This study uses the EG-ADF method to test this. Using this method requires two steps. The first step is to use the time series  $Y_t$  to perform least squares (OLS) regression on the time series  $X_t$ , as shown in Formula (4):

$$Y_t = \alpha + \beta X_t + \varepsilon_t \quad (4)$$

The estimated values of the regression coefficients obtained by the above equation are  $\hat{\alpha}$  and  $\hat{\beta}$  respectively, and the residual estimated value can be obtained by formula (5):

$$\hat{\varepsilon} = Y_t - \hat{\alpha} - \hat{\beta} X_t \quad (5)$$

In the second step, the unit root test is performed on the residual  $\hat{\varepsilon}$  obtained by formula (5) using the ADF method.

Finally, the Granger causality test is carried out to comprehensively and accurately judge the causality between time series variables. Significantly, the data used in this study are all in the form of a natural logarithm. The purpose of taking the logarithm of the data is to maintain the cointegration relationship between variables and alleviate the heteroscedasticity problem of the sample data.

### C. RESULTS AND DISCUSSIONS

This subsection presents the results concerning the information spillover effect of Huawei’s inbound and outbound open innovation practices, which are represented by patent alliance and patent trading, respectively.

#### 1) PATENT ALLIANCE ANALYSIS OF HUAWEI

This paper collects data regarding the number of Huawei granted invention patents and the number of R&D investments from 2000 to 2018 (see Table 1). After Huawei joined WiMAX, these two numbers showed an evident upward trend. The Wilcoxon rank-sum test was adopted to verify whether they changed significantly before and after the patent alliance was joined. Specifically, the data from 2000 to 2009, before Huawei joined WiMAX, were taken as the control group, and the data from 2010 to 2018 were taken as the experimental group.

Table 3 presents the results of the Wilcoxon rank-sum test. Before and after Huawei joined WiMAX, the  $Z$  values of its granted invention patents and R&D investments were  $-2.694$  and  $-3.674$ , respectively. The p-values were

TABLE 3. Wilcoxon rank-sum test results.

	Comparison before/after Huawei joined WiMAX patent alliance
Patent grant	-2.694 (0.007)
R&D investment	-3.674 (0.001)

Note: The data in the table refers to the Z, and the corresponding p-value is shown in parentheses.

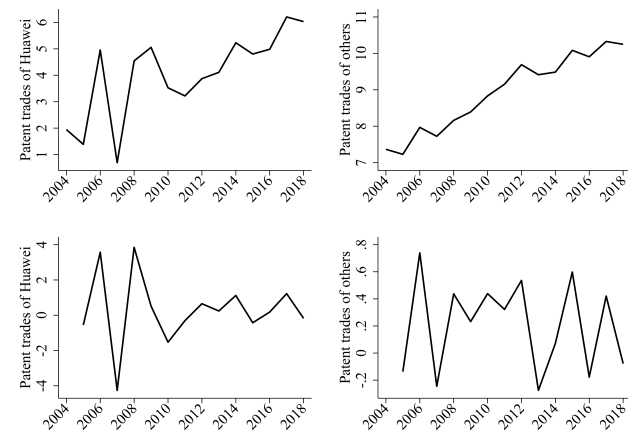


FIGURE 2. Distribution of patent trades between Huawei and other firms from 2004 to 2018. Note: the upper two figures present the time-series graph of patent trades of Huawei and other ICT firms. The lower two figures show the first-order difference trend of patent trades between Huawei and other ICT firms from 2005 to 2018. The values in the pictures are all logarithmic.

0.007 and 0.001, which both reject the null hypothesis at the significance level of 1%. As a result, there is a significant difference between the mean values of the control group and the experimental group, which can be considered to be from different distributions. Ignoring other factors, joining WiMAX changed Huawei's number of granted invention patents and its amount of R&D investment. Therefore, Huawei's innovation practices underwent significant changes after joining the WiMAX patent alliance. Since open innovation is an essential part of Huawei's innovation strategy, this result reflects that Huawei's open innovation practice is influenced by others.

## 2) PATENT TRADING ANALYSIS OF HUAWEI

According to the literature, information spillover is generally judged via the Granger causality test, which is conducted in this section. The empirical process includes the following three aspects: first, the ADF test method is used to judge the stationarity of the time series; second, the EG-ADF cointegration test is carried out on the non-stationary time series data, and the cointegration equation is established; third, the Granger causality test is conducted.

This paper draws the time-series graph of patent trades of Huawei and other ICT firms (as shown in the upper two graphs in Figure 2) before the unit root test. The number of patent trades by Huawei showed a fluctuating trend from 2004 to 2009 and a U-shaped growth trend after 2010. On the whole, the number of patent trades of other ICT firms

TABLE 4. ADF unit root test results.

variables	ADF	(c, t, p)	1% threshold	5% threshold	10% threshold	p-value	result
lnhw	-1.763	(1, 0, 1)	-3.750	-3.000	-2.630	0.399	unstable
lnother	-1.411	(1, 1, 1)	-4.380	-3.600	-3.240	0.858	unstable
Dlnhw	-5.748	(1, 0, 1)	-3.750	-3.000	-2.630	0.000	stable
Dlnother	-3.067	(1, 0, 1)	-3.750	-3.000	-2.630	0.029	stable

Note: c, t, and p represent the constant term, trend term, and lag order, respectively. (1, 0, 1) means that the ADF test has a constant term, and the lag order is 1. (1, 1, 1) means that the ADF test has a constant term and a trend term, and the lag order is 1. The lag order is determined by the minimum information criterion (AIC).

demonstrated an increasing trend over time. In general, both of them may have unit roots; i.e., there are data nonstationary cases. Continuously observing the first-order difference graph (see the lower two graphs in Figure 2), it is evident that the first-order difference in the number of patents traded by Huawei and by other ICT firms has no noticeable growth or change trend.

Furthermore, to accurately judge whether the time series are stationary, this paper uses the ADF unit root method to test the stability and their first-order difference time series. The test results are shown in Table 4.

As Table 4 illustrates, in the original series' ADF test results, the statistics reflected by the p-value did not pass the significance test; i.e., the null hypothesis of the unit root was accepted. Therefore, the number of Huawei's patent trades and other ICT firms was a non-stationary series. After checking the first-order difference series, the p-value passes the significance test at the significance level of 1% and 5%, respectively. Accordingly, the null hypothesis is rejected, indicating that their first-order difference series are stationary; i.e., the patent trading time series of Huawei and other ICT firms are first-order unitary series, so the cointegration relationship between these two can be further tested.

The above results suggest that the number of patents traded by Huawei and other ICT firms is a non-stationary first-order integrated series. However, some linear combinations of the two can reflect the long-term stable relationship, i.e., the cointegration relationship. In this study, the EG-ADF method proposed by Engle and Granger [70] was adopted to conduct the cointegration test. The EG-ADF result shows that the statistical value is  $-3.157$ , and the p-value is  $0.023$ , indicating a cointegration relationship between the number of patent trades by Huawei and other ICT firms.

To explore the specific relationship between them, this paper establishes an error correction model. The results show that the influence of other ICT firms' patent trades on Huawei's patent trades is significant at the 1% significance level, suggesting a long-term equilibrium relationship between them. The final cointegration equation is presented by the following formula:

$$\ln hw = 1.132 \ln other - 4.921 \quad (6)$$



TABLE 5. Granger causality test results.

	lag 1	lag 2	lag 3	lag 4
Inother is not the Granger cause of Inhw	0.007	0.011	0.018	0.013
Inhw is not the Granger cause of Inother	0.485	0.767	0.467	0.797

Equation (6) shows that the elasticity coefficient of the number of patents traded by other ICT firms to those traded by Huawei is 1.132, which means that, in the long term, every 1% increase in the number of patents traded by other ICT firms will cause a 1.132% change in the number of patents Huawei trades.

The above analysis shows a long-term stable relationship between the number of patents traded by Huawei and those traded by other ICT firms. Yet, whether this relationship constitutes a causal relationship needs to be judged through the Granger causality. Therefore, this paper tests for “the change in the number of patents traded by other ICT firms is not the cause of the change in Huawei’s patent trades” and “the change in Huawei’s patent trades is not the cause of the change in the number of patents traded by other ICT firms”. The test results are shown in Table 5.

In Table 5, the first column is the zero hypothesis of the Granger causality test, and the other columns are the p-value results of the hypothesis test with different lag orders. The test results all reject, at the 5% significance level, that “the change in the number of patents traded by other ICT firms is not the cause of the change in Huawei’s patent trades”. This indicates that the number of patents traded by other ICT firms is the Granger reason for the change in the number of Huawei patent trades. Meanwhile, it cannot be rejected at the significance level of 5% in each lag period that “the change in Huawei’s patent trades is not the cause of the change in the number of patents traded by other ICT firms”; i.e., the change of Huawei’s patent trades is not the Granger cause of the change of other ICT firms’ patent trades. Accordingly, it can be concluded that the number of patents traded by other ICT firms will lead to a change in the number of patents Huawei trades. This demonstrates that there is an information spillover effect in the process of firms’ open innovation practices.

#### IV. CONCLUSION

Open innovation is increasingly the focus of academic and practical circles. However, the existing research mostly centers on innovation participants and lacks investigations of social third-party firms. Therefore, this paper systematically reviews the open innovation research based on changes in participants. Integrating the sociological view, this paper suggests that firms’ open innovation may be an important information reference for social third-party firms, thereby constructing the conceptual framework of the open innovation information spillover effect. On this basis, taking Huawei as an example, this paper practically explores whether its open innovation is influenced by other firms in relation to

two aspects. First, based on the analysis of patent alliances, the Wilcoxon rank-sum test is used to analyze the significant changes in the number of granted invention patents and R&D investments before and after joining WiMAX. The results confirm that Huawei’s open innovation is influenced by other firms. Second, Huawei’s patent trading behavior is further analyzed, and the Granger causality test is used to demonstrate how Huawei’s patent trades are influenced by others. The results of cointegration analysis show not only that there is a long-term equilibrium relationship between Huawei’s patent trades and other ICT firms’ patent trades but also that, according to the cointegration equation, every 1% increase in the patent trades of other ICT firms will cause a 1.132% change in Huawei’s patent trades. The results of a Granger causality test further confirm that the number of patents traded by other ICT firms is the Granger reason for Huawei’s patent trades.

Accordingly, this paper preliminarily confirms the information spillover effect of open innovation. The results of this paper not only expands the research scope of open innovation, but also provides the factual basis for open innovation implementers, social third-party firms and policy makers to consider the information spillover effect in the subsequent open innovation practices. Nevertheless, given that this paper is a preliminary discussion on the information spillover effect of open innovation, the emphasis is on articulating the theoretical framework and verifying its practical existence. The universality of the research results might be challenged by further scholarship; i.e., whether this paper’s conclusions apply to firms across all industries still requires exploration, whereby large sample data could be used in future research to broaden awareness of the open innovation information spillover effect.

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