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Article

Network Analysis of Open Innovation

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Abstract: The way people innovate and create new ideas and bring them to the market is undergoing a fundamental change from closed innovation to open innovation. Why and how do firms perform open innovation? Firms' open innovation is measured through the levels of firms' joint patent applications. Next, we analyze network structures and characters of firms' joint patent applications such as betweenness and degree centrality, structure hole, and closure. From this research, we drew conclusions as follows. First, the structure of collaboration networks has both direct and indirect effects on firms' innovative performance. Second, in the process of joint patent applications, there is a long tail phenomenon in networks of joint patent applications. Third, the number of patents and International Patent Classification (IPC) subclasses together constitute a meaningful measure of the innovation performance of firms.

Keywords: joint patent application; the structure of collaboration; open innovation; long tail

1. Introduction

1.1. Research Question

The way people innovate and create new ideas and bring them to the market is undergoing a fundamental change [1]. Open innovation is not necessarily activated by factors that weaken closed innovation, such as the growing mobility of highly experienced and skilled people, the growing presence of private venture capital (VC), and decreasing required time for products and services to get into markets, but can only be implemented when wise responses are made to those traditional factors that have hindered coupling between technologies and markets—mainly, the Arrow information paradox, death valley [2], or chiasm [3]. Now, open innovation—including open source, outsourcing, and crowdsourcing—is activating not just at firm level but open innovation of national innovation system or global open innovation by such as an intermediate country [4–7].

In this study, reasons for firms to perform open innovation and their method of doing so will be concretely investigated. This study's research question is as follows.

Does the network structure of joint patent applications by firms moderate the effects of open innovation to the innovation performance?

To answer this research question in an objective manner in this study, first of all, firms' open innovation will be objectively measured first through the measure of firms' joint patent applications. In addition to this, the effects of open innovation level to open innovation structure, the effects of open innovation level to innovation performance, and the effects of open innovation structure to innovation performance will be analyzed. In the end, the research question will be answered. We want to know the effects of open innovation structure, such as moderating effects, which were not analyzed by other researches [8].

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1.2. Research Scope

For the study mentioned above, first, the subjects of analysis were selected among patents in the patent database available in the United States Patent and Trademark Office (USPTO). We use patents data to analyze open innovation objectively even though this approach can have limits in comparing with control group. Among the patents that belong to H03 and H04 under the International Patent Classification (IPC) of the World Intellectual Property Organization (WIPO), those that were applied for between 2000 and 2011 were set as the subjects of analysis. The number of patents included in the analysis was 340,119, and the number of applicants that participated in the patents was 5449. Among them, the top 500 patent applicants and Samsung, Apple, Nokia, and Research In Motion were set as the subjects of intensive analysis. The subjects of patent analysis were selected to examine the area of core technologies for smartphones that are currently leading the second IT revolution throughout the world. For in-depth analysis beyond quantitative analysis, the top 500 firms were selected. In addition, those firms that were ranked first and second in smartphone market shares worldwide as of January 2014 and those firms that were ranked first and second in the drop of market shares over the last three years were chosen as the subjects of individual in-depth analyses.

2. Materials and Methods

2.1. Joint Patent Applications

At first, we should look into diverse contexts of the open innovation of Intellectual Property Rights (IPRs) including patents. Basically, according to industries and firm sizes, the effects of intellectual property rights on innovation and economic performance are different [9]. A patent among IPRs is the legal right of an inventor to exclude others from making or using a particular invention as an incentive for innovation [10]. Thus, even though at first glance the two concepts, such as open innovation and IPRs, seem irreconcilable, open innovation and patent have deep relation like a two-edged sword [11]. Patent can be used to assist in the management of open innovation in a number of ways such as the necessary codification of an invention or technology, patent commons on diffusion of patented technologies, and cross licensing even though it has limits compared to the open science model [11,12]. However, making patents accessible royalty-free did not result in any significant increase in diffusion as measured by citing patents in clean and green technology [13]. In recent years, even though policy discourse has placed much emphasis on the patenting of the outcomes of academic research, it could not confirmed that among several forms of IP (patents, copyright, open source IP, and non-patented innovations) patents are the most effective route for knowledge dissemination of the so-called open innovation channel in the economy [14].

Patent applications encompass valuable information about the inventive activities of firms such as the degree of open innovation by firms from collaborative assignees as defined by the USPTO [15]. By analyzing visualizing patent statistics through patent applicant network analysis, network construction among joint patent-applying firms that participated in joint patent applications and the effects of the construction were studied [16]. In firms who have open search strategies—those who search widely and deeply—the benefits of openness are subject to decreasing returns, which indicate that there is a point at which additional open innovation becomes unproductive [17–21]. Companies are increasingly rethinking the fundamental ways in which they generate ideas and bring them to the market [22]. Therefore, as those who performed funding innovation, generating innovation and commercializing innovation are different in innovation performed by a firm based on its in-house R&D as the applicants or assignees of a patent developed through open innovation in particular are shown to be multiple firms or identities [22–27]. Thus, the measurement of levels of open innovation through patents can be divided into the measurement of the breadth of open innovation, which refers to how much is open innovation performed through various channels, and the measurement of the depth of open innovation, which refers to how intensively open innovation is performed. In particular, when open innovation is analyzed through patents, the ratio of the number of joint patent applications of a firm to the total number of patent applications of a firm, that is, the ratio of open

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innovation patents (ROI) corresponding to the breadth, and the number of applicants per patent of a firm, that is, the intensity of open innovation patents (IOI) corresponding to the depth.

Open innovation is considered to occur mainly when the actor of the patenting of ideas and the actor of external or internal licensing are different from each other; that is, when there are two actors within the entrance of the knowledge funnel [1,28]. There are two directions of open innovation, namely, inside-out open innovation, (cases in which patents made within a firm are licensed out to create larger markets and profits) and outside-in open innovation (cases in which a firm license in external patents to create larger markets and profits) [7,29]. Open innovation in the stage of joint patent application is distinguished from other existing open innovation channels in that the first part of the knowledge funnel is entered jointly with others. Even among open innovation studies regarding various aspects of open innovation—such as open innovation in value networks, open innovation in Small and Medium Enterprises (SMEs), and open innovation in consumer electronics—joint patent applications are yet to be studied [30–32]. All three open innovation process archetypes—outside-in, inside-out, and coupled—focus on firms' activities performed within company boundaries [33–36].

The innovation performance will increase when the level of open innovation goes up in the case of firms with low levels of open innovation but will decrease when the level of open innovation goes up in the case of firms with sufficiently high levels of open innovation [30,31,37–40].

Open innovation has two aspects such as OI benefits and OI cost. OI benefits include diverse opportunities to meet new markets and technologies, in addition to the benefits of Table 1. OI costs include uncertainty and complexity, in addition to transaction cost of Table 1.

Table 1. The effect of open innovation.

	Contents	Characteristics	Related Papers
Shape of OI	An inverted U-shape	The effect of OI in any industry in raw OI is positive. The effect of OI in any industry in active OI is negative.	[17,30,31,37–42]
Benefits of OI	Internal technology, which is not used is externalized External technology, which is useful and exists outside internalized	New revenues from spin-off, license, sale/divestiture Cost and time savings from leveraging external development	[22,43–45]
Cost of OI	Transaction cost	The cost, which needs to arrive at cooperation	[45–52]

Thus, if OI increases in high OI industry such as industry belonging to H03, 04 patents, which are a combination of IT and system technology, a kind of open innovation between IT and other industry. Thus, we build H 1-1 and 1-2. The largest patent holder in the world, IBM, altered their corporate policy on the creation and management of patents substantially in 2006, and released about 100 business method patents to the public. The target patents of this research are business method patents, which IBM released. A skeptic could argue that the IP being given up by large firms, such as IBM, is not very valuable to them, and that pledging allegiance to open innovation is merely a convenient way of saying that they are open to taking others' ideas without giving up any of their own patents [11]. The policy of IBM about business model patents exists in same context of H 1-1 and 1-2.

Hypothesis 1-1-1: The ratio of joint patent applications to the entire patent applications of a firm—that is, the ROI of the firm—will negatively affect the firm's innovation performance.

Hypothesis 1-1-2: The number of applicants per patent of a firm—that is, the IOI—will negatively affect the firm's innovation performance.

2.2. Network of Patents

In various fields, such as the World Wide Web or citation patterns in science, the independence of the system and the identity of its constituents, the probability P(k) that a vertex in the network interacts with k, other vertices decay as a power law, following $P(k) \sim k^{-\gamma}$, which indicates that

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large networks self-organize into a scale-free state, which is a feature unexpected by all existing random network models [53,54]. The power law is observed in various social phenomena such as the rise in financial data when trading behavior is optimal, distribution of wealth in society, and cognitive lock-in [55–58].

Hypothesis 1-2-1: At least a majority of the joint patent application networks of the 500 largest firms should be located in the largest component of firms' joint patent application networks.

Hypothesis 1-2-2: At least a majority of the 500 largest firms should be located in the joint patent application network structures within the 500 largest firms as well as in the entire subject joint patent application network structures.

Hypothesis 1-2-3: The current global leading smartphone firms, Apple and Samsung, and those firms that were the global leading smartphone firms until recently, Nokia and BlackBerry, should show different characteristics in the joint patent application network structures within the 500 largest firms, as well as in the entire subject joint patent application network structures.

If the power law is effective in joint patent application networks, the 500 largest firms' networks should belong to the largest component, and at least a majority of the 500 largest firms should naturally belong to the largest network. Therefore, Hypotheses 1-2-1 and 1-2-2 should be valid. Furthermore, two firm groups that create results contrary to each other can be inferred to have joint patent application network structures that are contrary to each other [59–61]. Therefore, Hypothesis 1-2-3 should be valid.

The centrality of the dominant is measured by using Freeman's concept of "betweenness" [62,63]. The important idea here is that an actor is central if it lies between other actors on their geodesics, implying that to have a large "betweenness" centrality, the actor must be between many other actors via their geodesics [64]. In a similar yet different manner, the degree centrality of any group can be defined as the number of nongroup nodes that are connected to group members [65]. A firm's network centrality in an alliance network affects the "twin tasks" in exploration—novelty creation on the one hand and its efficient absorption on the other [66]. Patent or paper citation and patent application networks, betweenness, and degree of centrality have been shown to result in better innovation performance by firms [62,67–69]. Therefore, Hypothesis 1-3-1 is inferred to be valid.

Hypothesis 1-3-1: Firms with higher centrality should produce better innovation performance.

A structural hole, which means the degree of connectivity or the lack thereof between a firm's partner, indicates that the people on either side of the hole have access to different flows of information [67,70,71]. Innovative firms that bridge structural holes get a higher performance boost, which suggests that firms need to develop network-enabled capabilities accruing to innovative firms that bridge structural holes [72]. In fact, from the perspective of the structural hole theory, ego networks—in which a firm's partners have no links with each other—are prepared to form networks in which the firm's partners are densely tied with structural holes on the resource-sharing benefits of the network. This reveals a conclusion that is almost diametrically opposite to that reached by knowledge spillover to the same network. There are conflicting positions regarding the effects of structural holes. The hole effect of players rich in structural holes leads to higher rates of return on investment in entrepreneurial motivation research [70,73]. At the same time, ego networks with fewer structural holes might promote trust generation and reduce opportunism, leading to more productive collaboration from the perspective of resource sharing [67,74,75]. There is a trade-off between the benefits of connecting non-neighboring nodes and the cost of the effort to maintain links—including settings in which the costs are nonuniform—which reflects the increased difficulty in spanning different parts of a hierarchical organization [75]. Regarding the firms examined in this study in the area of information communication, including smartphone firms, the scope of connection and modulation that occurs between different firms increases explosively in the process of their cooperation with different technologies and sizes for technology development and collaboration for patent applications [23,76–79]. Therefore, Hypothesis 1-3-2 is inferred to be valid.

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Hypothesis 1-3-2: Firms with larger structural holes will achieve lower innovation performance.

Figure 1b shows a structure with closure represented by A, B, and C. In such a structure with closure, B and C can combine to provide a collective sanction or reward the other for sanctioning A [80] (Coleman 1988). However, B and C in Figure 1a have no relations with one another, but have relations with the others instead (D and E). Because of this, they cannot combine forces to sanction A in order to constrain actions.

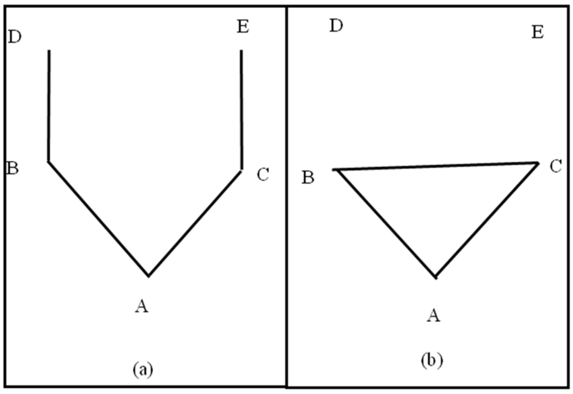

Figure 1. (**a**) Networks without closure; and (**b**) Networks with closure (source: [80]).

Closure has two effects. The first is that information quality deteriorates as it moves from one person to the next in a chain of intermediaries. The second effect is the benefit more emphasized by Coleman—network closure facilitates sanctioning, which makes it less risky for people in the network to trust one another [81]. However, forward citation can be negatively predicted by the closure position in the early and mature stages [82]. According to another study, the effect of closure on a firm's innovation performance has a U shape, which means that, at a low level, closure has negative effects of constrained creativity and innovation [83]. According to Coleman, closure generates positive effects in learning, while closure in a parental network has negative effects [84]. This study infers that the direct effects of closure will be more positive, as indicated by Hypothesis 1-3-3, when more firms implement joint patent applications in the form of closure because it can logically be inferred that collaboration between any two firms that collaborate with a given firm may directly lead to joint patent applications with the given firms.

Hypothesis 1-3-3: Firms with larger closure will achieve better innovation performance.

In Korean SMEs, networking has been an effective way to facilitate open innovation among SMEs [40]. Well-orchestrated companies' networks allow them to sufficiently commercialize their innovations [32]. Strong dyadic interfirm ties can be the basis of a distinctive lead firm's relational capability when it is integrated with a core of strong ties [85]. Thus, even cyber community networks can have positive effects on individual or team performance [86]. The innovation itself, the innovator, and the environment (particularly, the characteristics of networks of innovators), have modulating effects on innovation diffusion; that is, innovation performance [87]. The results of previous studies suggest that the characteristics of firms' joint patent application network structures, that is, centrality, structural holes, and closure, have direct and indirect effects on firms' open innovation. Firms' joint patent application network structures should have modulating effects on the quantitative performance of firms' joint patent applications, that is, the relationship between ROI/IOI and innovation performance [88–92].

Hypothesis 2-1-1: The relationship between ROI and a company's innovation performance is moderated by (degree and betweenness) centrality. Firms that have high centrality in the network of joint patent applications will have lower innovation performance.

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Hypothesis 2-1-2: The relationship between IOI and a company's innovation performance is moderated by (degree and betweenness) centrality. Firms that have high centrality in the network of joint patent applications will have lower innovation performance.

Hypothesis 2-2-1: The relationship between ROI and a company's innovation performance is moderated by structural holes. Firms that have many structural holes in the network of joint patent applications will have higher innovation performance.

Hypothesis 2-2-2: The relationship between IOI and a company's innovation performance is moderated by structural holes. Firms that have many structural holes in the network of joint patent applications will have higher innovation performance.

Hypothesis 2-3-1: The relationship between ROI and a company's innovation performance is moderated by closure. Firms that have closure in the network of joint patent applications will have lower innovation performance.

Hypothesis 2-3-2: The relationship between IOI and a company's innovation performance is moderated by closure. Firms that have closure in the network of joint patent applications will have lower innovation performance.

With regard to the direction of the modulating effects in Hypothesis 2, centrality and closure are inferred to have positive effects and structural holes are inferred to have negative effects for the same reason as that for Hypothesis 1-3.

3. Research Framework and Variables

3.1. Research Model

The research model of this paper is shown in Figure 2. The level of joint patent applications affects not only innovation performance (Hypothesis 1-1) but also the networks of joint patent applications to some extent (Hypothesis 1-2). The latter is only analyzed using qualitative method with attention to the power law of the joint patents applicants. The networks of joint patent applications directly affect innovation performance (Hypothesis 1-3) and modulate the relationship between the level of joint patent applications and innovation performance (Hypothesis 2). Hypotheses that have direct relations with innovation performance such as Hypothesis 1-1, Hypothesis 1-3, and Hypothesis 2 are analyzed by statistical approaches.

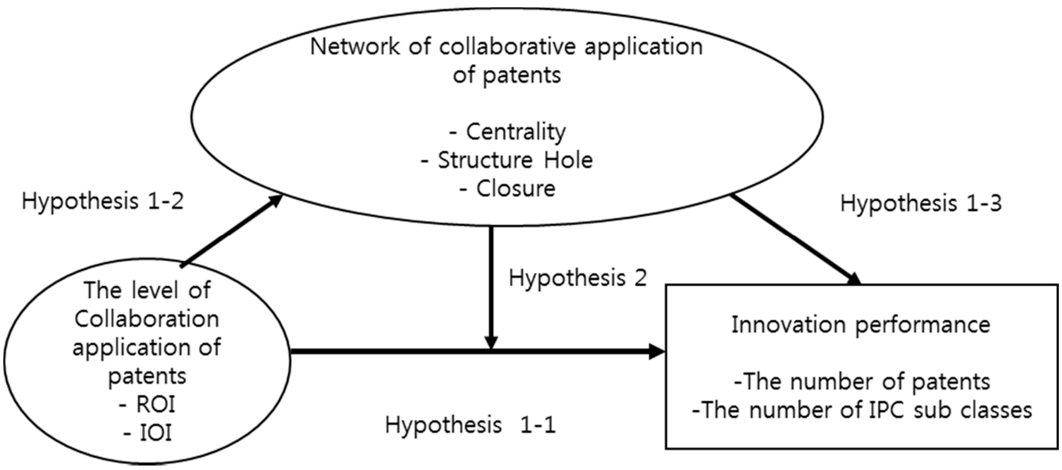

Figure 2. Research model of co-patenting effect on performance.

Based on H 1-1, 1-2, 1-3, and H 2, we mainly want to know the moderating effect of open innovation structure.

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3.2. Variables

3.2.1. Dependent Variables: Innovation Performance

The count of patent applications may not be the most appropriate proxy for innovation performance of a firm because the differences in the qualitative levels of individual patents between important patents such as "standard-essential", and other patents. However, the impression that the patent application at firms is an effective means of product/process protection or a direct promoter of new product sales has been rapidly disappearing as the economic value of patents have rapidly increased since the 2000s [93,94].

The innovation performance of companies has been studied extensively from R&D inputs, patent counts, and patent citations to new product announcements [95,96]. As the knowledge-based economy gradually develops, the ratio of patents to the total amount of knowledge existing in the world continues to increase, and the ranges in which patents overlap with R&D and new products substantially expand throughout all industrial areas are shown in Figure 3 [97]. Thus, we could see that innovation policies to developing a knowledge-based economy policy from Bulgaria, Finland, and Scotland include increasing patents [98].

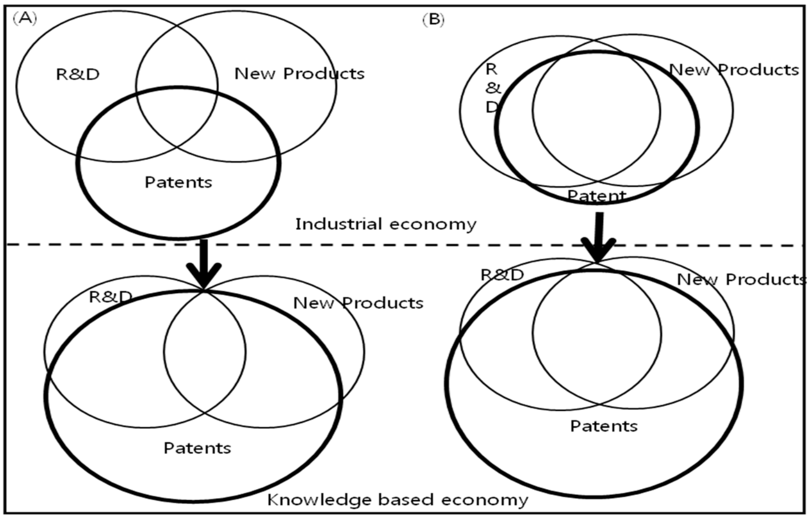

Figure 3. Changing of the relationship between patents, R&D, and new products (source: [1,96,99]).

Thus, the value of patent as the measure of firms' innovation performance has been increasing, as shown in Figure 3.

Of course, it is also true that many problems cannot be avoided when the number of patent is simply used to measure firms' innovation performance.

Thus, we used patent as dependent variables in two ways together such as the number of patent application and the number of subclasses of patent, which is applied by the firm, as in Table 2.

Table 2. The patent as innovation performance.

Variables	Related Papers	Definition	Characteristics
Patent numbers	[93,100–102]	The number of patent which is applied by the firm	The breadth of innovation performance, which is measured by the patent
IPC co-occurrence	[103–106]	The number of subclasses of patent, which is applied by the firm	The depth of innovation performance, which is measured by the patent

Sources: [93,100–106].

Most of all, the number of patents, which is a traditional means of measurement of firms' innovation performance through patents, was set as one dependent variable for the measurement of

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firms' innovation performance, as in Table 1 [93,100,101]. This is the basic measure of innovation performance of firms by patent even though it has several limits.

Many recent studies have been measured the diversity of various of patents as innovation performance [93,103–105]. When multiple IPC codes exist in a single patent and those codes belong to different technology fields, this is called a case of "IPC co-occurrence", by which technological diversity is measured; this kind of innovation is common in Japanese firms [105]. The Herfindahl–Hirschman index of patents (HHI of patents), which describes the concentration of patents across patent classes and measures the concentration level of a firm's technology capability in many patent classes, is negatively related to their market value in the case of U.S. pharmaceutical firms [103]. Another study applied an alternative measure of exploratory innovation from prior research and computed this measure as the number of new three-digit technology classes in which Firm *i* is patented in Year *t*, classifying a technology class as new if the firm had not patented in that class in the past seven years [104]. The number of subclass is a kind of result of a firm's strategy. Thus, any creative firm that does not use open innovation strategy, can have a large number of IPC subclass at any period and oppositely, any open innovation strategy-using firm can have a small number of IPC subclass during that time.

According to the increasing value of patents as measure of a firm's innovation performance, the number of patents, as the length of innovation performance, and the number of subclasses, as the depth of innovation performance of firms, were used together in this study [103–106].

3.2.2. Independent Variables About Network Structure of Joint Patent Applications

a. Centrality

This study made use of the betweenness centrality of a vertex, which is the proportion of all geodesics between pairs of other vertices that include this vertex [107]. If g_{ij} is defined as the number of geodesic paths between *i* and *j*, and g_{ikj} is the number of these geodesics that pass through *k*, *k*'s betweenness centrality is defined as [108,109]:

$$\sum_i \sum_j \frac{g_{ikj}}{g_{ij}},\ i \neq j \neq k$$

The degree centrality, which is an original concept of centrality, is additionally used to measure centrality.

b. Structural holes

The absence of a tie between an actor and the third party is known as a structural hole, which may be exploited by the ego [107]. This study measured structural holes as a constraint using the network constraint by Pajek 3.10 [70,81] and used the ratio of nonredundant contacts to total contacts for the ith firm to measure the structural holes in the ego network of a firm. This is expressed as [67,70,110,111]:

$$\sum_j \left(1 - \sum_q \mathrm{P}_{iq} \mathrm{m}_{jq} \right) / \mathrm{C}_i$$

where P_{iq} is the proportion of *i*'s relations invested in the connection with contact *q*, m_{jq} is the marginal strength of the relationship between contact *j* and contact *q*, and C_i is the total number of contacts for firm *i*. This study measured structural holes using the following formula.

c. Closure

This study measured closure using Pajek 3.10 as follows [112]:

$$7\mathrm{C}_i = \frac{\text{(number of pairs of neighbors of i that are connected)}}{\text{(number of pairs of neighbors of i)}} \tag{1}$$

This was originally used as a clustering coefficient for a single vertex. However, according to the original concept of closure, this formula can be used for the said purpose [80,84,113].

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3.2.3. Independent Variables Regarding the Number of Joint Patents

Collaboration in the patent application stage corresponds to the first part of the knowledge funnel for open innovation. In this study, the level of collaboration in this early stage will be measured through ROI and IOI, as shown in Table 3 [17,30,114,115].

Table 3. Breadth and depth of open innovation measured by joint patent application

Division	Contents	Equation	Meaning and Relation
ROI_i	The ratio of joint patent applications to all patents of Firm *i* The breadth of open innovation of Firm *i* measured through joint patent applications	P_i-$P_{i,alone}$/P_i,	Breadth of open innovation
IOI_i	Average number of applicants per patent of Firm *i* The depth of open innovation of Firm *i* measured through joint patent applications	A_i/P_i,	Depth of open innovation

P_i is the total number of patents of Firm *i*,; $P_{i,alone}$ is the number of patents applied for solely by Firm *i* among the patents owned by Firm *i*; and A_i is the total number of applicants of Firm *i*. (Source: [15–17,29,99,116–118]).

4. Results

4.1. General Facts about Networks of Joint Patent Application

In Figure 4, the total number of nodes that constitute the total network—that is, the number of patent applicants—is 5444. The number of components constituted by these nodes is 299. Among the components, the largest one consists of 2970 nodes, the second largest one consists of 659 nodes, and the third largest one consists of 244 nodes. The 2970 nodes of the largest component are mostly individuals, and the 659 nodes of the second largest component are mostly firms. As such, 2970 is not individual-type assignees in patents data, but the number of individual applicants among the total of 5444 applicants. Node sizes on the network show the numbers of patent applications made, which are diverse, ranging from 1 to 12,907.

In Figures 4 and 5, the 500 largest firms are shown in blue. As seen in Figure 5, few of the 500 largest firms are located in the giant component. It is inferred that they are located in the 2nd component, and some of them are located in the 3rd component. Therefore, Hypothesis 1-2-1 was dismissed. Thus, it cannot be confirmed that only the power law is valid in joint patent application networks. On the contrary, it can be inferred that a long tail phenomenon appears in which not only the patent application activities of some huge firms, but also those of various firms and individuals, coexist [119,120].

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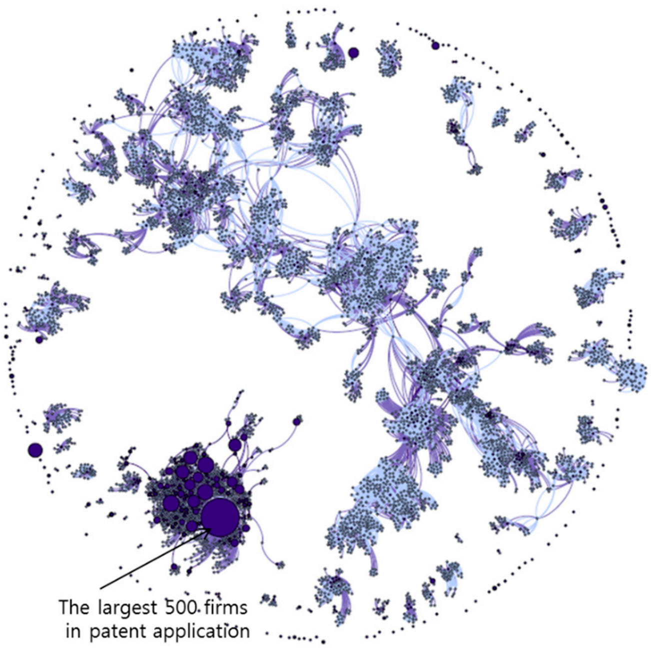

Figure 4. Total network.

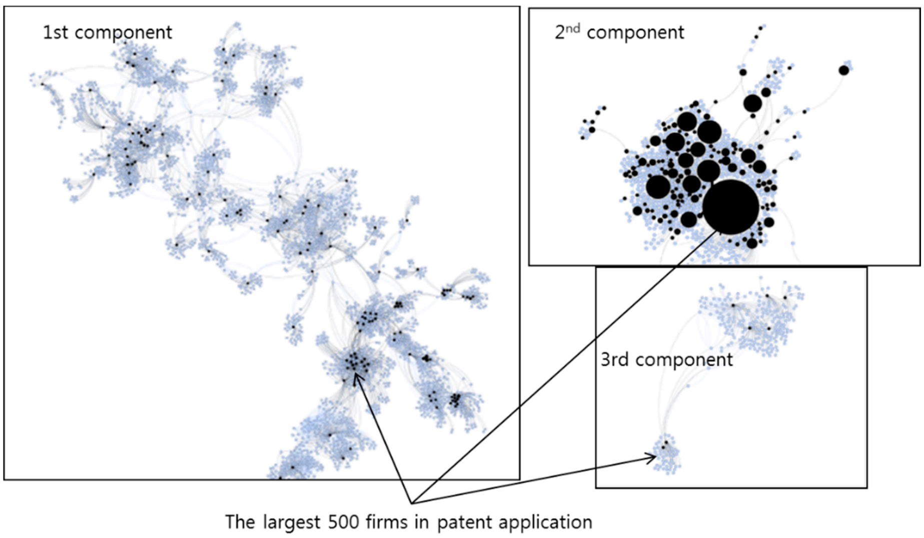

Figure 5. Three major components.

Next, to review the 500 largest firms, 562 nodes—as an approximate value—were examined. These nodes constituted a total of 272 components. The largest component consisted of 124 nodes (22.06%), and the second largest component consisted of 36 nodes. Note that 234 firms or 41.6% of all nodes had no network with the firms included in the 500 largest firms. Therefore, Hypothesis 1-2-2 was dismissed. In Figure 6, different circles represent different components. It can be seen that differing forms of collaboration appear among the 500 largest firms. While 124 firms centering on Samsung actively collaborate with each other in the research and development stage, 234 firms that exist around the former firms in the form of points show a phenomenon extremely contrary to the foregoing by having no cooperation with any firms included in the 500 largest firms at all.

These 500 largest firms applied for a minimum of 50 patents and a maximum of 12,907 patents, which indicate that substantial differences exist in their research and development activities. Therefore, drastic differences in collaboration can be inferred to be relevant to the differences in research and development activities.

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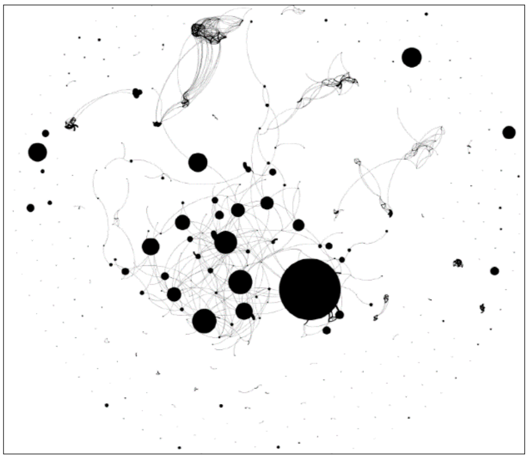

Figure 6. Network in the largest 500 firms in patent application.

When the four firms are divided into two groups based on degree centrality, as shown in Table 4, among the characteristics of their joint patent application networks using the analytic hierarchy process (AHP) method, Apple and Research In Motion, with small numbers of joint patent applications, are classified into a group and Samsung and Nokia, with relatively large numbers of joint patent applications, are classified into another group. Therefore, Hypothesis 1-2-3 is dismissed. Apple has made no joint patent applications with the 500 largest firms or in any of its networks. This is because Apple rarely cooperates with other companies in the research and development stage; therefore, it rarely performs open innovation in the research and development stage. This is contrary to Apple's open innovation in the production stage because Apple performed a total of 54 cases of open innovation through the acquisition of firms in the production stage by implementing mergers and acquisitions (M&A) with various companies ranging from Network Innovations in 1988 to SnappyLabs in January 2014 [34]. As shown in Appendix A, Samsung has applied for joint patents not only with the companies included in the 500 largest firms but also with various other firms in its entire networks, thereby showing a very active open innovation in the research and development stage. Samsung, unlike Apple, has implemented approximately six cases of M&A-type open innovation [34]. As shown in Appendix B, Nokia has applied for a limited number of joint patents at a limited level with four firms included in the 500 largest firms and seven firms in its entire networks. On the other hand, similar to Apple, Nokia has very actively implemented M&A to the extent that it implemented 47 cases of M&A with various firms in contrast with its joint patent application [34]. Lastly, Research In Motion has not applied for any joint patent with any of the 500 largest firms, but it has applied for joint patents with a limited number of firms and individuals in its entire networks, as shown in Appendix C.

Table 4. Networks among the 500 firms and the total of Apple, Nokia, Research in Motion, and Samsung.

Firm	Degree Centrality	Betweenness Centrality	Structural Hole	Closure
Apple	In 500 = 0	In 500 = 0	In 500 = 0	In 500 = 0
	Total = 0	Total = 0		
Samsung	In 500 = 19.0	In 500 = 0.0194	In 500 = 0.28618	In 500 = 59.00
	Total = 104.00	Total = 0.00632	Total = 0.12714	Total = 59.00
Nokia	In 500 = 4	In 500 = 0.00061	In 500 = 0.63460	In 500 = 1.00
	Total = 7	Total = 0.00031	Total = 0.47467	Total = 3.00
Research In Motion	In 500 = 0	In 500 = 0	In 500 = 0	In 500 = 0.00
	Total = 5	Total = 0.00018	Total = 0.32791	Total = 1.00

4.2. Regression Results

Using information on the 562 firms that have made a significant number of patent applications, including the 500 largest firms, the correlations between the variables used in this study were analyzed. The number of IPC subclasses was shown to have significant correlations with all variables such as IOI, ROI, degree centrality, betweenness centrality, structural holes, and closure. As shown in Table 5, the number of patents had statistically significant correlations with all variables except closure. Therefore, the correlations between the dependent variables and independent variables in this study can be considered significant.

Table 5. Correlations between variables.

		No Patents	No IPC	IOI	ROI	Degree Centrality	Between Centrality	Structural Holes	Closure
No patents	Pearson correlation	1							
No IPC	Pearson correlation	0.689 *	1						
IOI	Pearson correlation	−0.165 *	−0.421 *	1					
ROI	Pearson correlation	−0.185 *	−0.449 *	0.884 *	1				
Degree centrality	Pearson correlation	0.290 *	0.118 *	0.541 *	0.440 *	1			
Between centrality.	Pearson correlation	0.720 *	0.522 *	−0.104 **	−0.087 **	0.422 *	1		
Structural holes	Pearson correlation	−0.161 **	−0.263 *	0.000	0.261 *	−0.506 *	−0.223 *	1	−0.367 *
Closure	Pearson correlation	0.037	−0.085 **	0.511 *	0.345 *	0.813 *	0.087 **	−0.367 *	1

Note: N = 562; however, structural holes analysis includes N = 229. * Correlation is significant at the 0.01 level (two-tailed). ** Correlation is significant at the 0.05 level (two-tailed).

Hypotheses 1-1, 1-3, and 2 can be tested through Tables 4–6. In summary, as shown in Table 6, Hypothesis 1-1-1, and 1-1-2 were accepted entirely, and in the case of Hypotheses 1-3-1 and 1-3-3, they were accepted, but 1-3-2 was accepted only when structural holes were added to IOI, and it was not accepted when structural holes were added to ROI. Therefore, Hypotheses 1-2-1 and 1-2-3 were accepted but 1-2-2 was not. In addition, moderating effect-related hypotheses should be reviewed in terms of increases in adjusted R^2. In the case of the ROI model under Hypothesis 2-1, the adjusted R^2, which was 0.200 when the model only had ROI, increased to 0.323 and 0.434 when degree centrality and betweenness centrality were added, respectively, and finally, to 0.504 and 0.448 when ROI* degree centrality and ROI* betweenness centrality were added, respectively. This indicates that the model, including modulating effects, had a considerably greater explanatory power compared to the simple model. In the case of the IOI model under Hypothesis 2-1, the adjusted R^2, which was 0.176 when the model only had IOI, increased to 0.344 and 0.406 when degree centrality and betweenness centrality were added, respectively, and finally to 0.405 and 0.424 when IOI* degree centrality and IOI* betweenness centrality were added, respectively. This indicates that the model, including modulating effects, had a considerably greater explanatory power compared to the simple model. The adjusted R^2 of the simple ROI model under Hypothesis 2-3 was 0.205, but that of the model with ROI*closure modulating effects added was 0.379. This indicates a drastic increase in the explanatory power of the model. Similarly, the adjusted R^2 of the simple IOI model under Hypothesis 2-4, which was 0.197, increased considerably to 0.257 when IOI*closure modulating effects were added. Hypothesis 4-2 was not accepted because only ROI*structural holes showed some positive modulating effects in the relevant regression equation.

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Table 6. Results of moderated regression analysis for the number of IPC subclasses.

Variables	Step 1-1		Step 1-2							
	ROI	IOI	ROI Degree	ROI Between	IOI Degree	IOI Between	ROI Structural Hole	IOI Structural Hole	ROI Closure	IOI Closure
Constant	34.667	29.822	34.117	36.676	33.808	31.074	19.315	18.452	34.713	30.279
A.C.A.P.										
- ROI	−11.903 ***		−16.081 ***	−12.764 ***			−15.485 ***		−11.880 ***	
- IOI		−10.985 ***			−16.871 ***	−11.341 ***		−12.781 ***		−11.609 ***
N.A.C.P.										
- Centrality										
• Degree			10.139 ***		12.040 ***					
• Betweenness				15.247 ***		14.770 ***				
- Structural hole							−1.642	−5.382 ***		
- Closure									1.967 ***	3.995 ***
A.C.A.P. N.A.C.P.[a]										
-Centrality										
• Degree										
• Betweenness										
- Structural hole										
- Closure										
F	141.673	120.660	135.111	216.357	148.327	192.802	137.228	96.159	73.134	69.924
Adjusted R^2	0.200	0.176	0.323	0.434	0.344	0.406	0.544	0.455	0.205	0.197
			Step 2							
Variables			ROI*Degree	ROI*Between	IOI*Degree	IOI*Between	ROI*Structural Hole	IOI*Structural Hole	ROI*Closure	IOI*Closure
Constant			32.606	36.724	24.978	30.998	15.034	11.728	35.009	28.233
A.C.A.P.										
- ROI			−7.939 ***	−11.996 ***			−8.446 ***		−10.853 ***	
- IOI					−8.993 ***	−10.270 ***		−4.243		−10.299 ***
N.A.C.P.										
- Centrality										

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● Degree	18.583 ***		13.709 ***					
● Betweenness		15.290 ***		8.662 ***				
- Structural hole					−2.648 ***	−2.267		
- Closure							12.758 ***	7.606 ***
A.C.A.P.								
N.A.C.P.[a]								
-Centrality								
• Degree	−14.322 ***		−7.612 ***					
• Betweenness		−3.805 ***		−4.318 ***				
- Structural hole					2.071 ***	−0.321		
- Closure							−12.569 ***	−6.761 ***
F	191.334	152.540	128.272	138.807	94.248	63.886	115.110	65.583
Adjusted R^2	0.504	0.448	0.405	0.424	0.551	0.453	0.379	0.257

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, [a] A.C.A.P. = amount of joint patent application patents; N.A.C.P. = network structure of joint patent application patents.

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5. Discussion and Additional Research Topics

5.1. Discussion

First, structure of open innovation gives moderating effects. By proving hypotheses 2, we found that structures of open innovation give moderating effects at open innovation effect. Structure of open innovation should be considered in addition to the level of open innovation.

Second, according to hypotheses 1 and 2 together, open innovation effects can be changed by the open innovation structure even though in high open innovation condition. In fact, we analyzed hypotheses 1 to find out the effect of structure to open innovation effect. In particular, the fact that the structure of joint patent application networks has both direct and indirect modulating effects has been identified through this study. Therefore, to examine collaboration between firms for open innovation, network structures should be considered simultaneously. Although IOI and ROI have negative effects on firms' innovation performance, centrality and closure have direct positive effects, as well as indirect negative effects, to reinforce the effects of IOI and ROI. In line with this, although structure holes were shown to have a partial direct negative effect, they have indirect positive modulating effects on ROI when the dependent variable is the number of IPC subclasses. Therefore, when establishing open innovation strategies, firms should consider the structure of collaboration as well as the level of collaboration itself [121–123].

Third, networks for collaboration in patent applications among applicants that apply for small numbers of patents are more developed than those among applicants that apply for large numbers of patents. This proves that, in the process of patent applications, SMEs actively perform technological innovation activities through joint patent applications. Maybe there are long tail effects at these[124,125].

Fourth, in this study, the diversity of subclass areas of patent applications by each firm was identified to be sufficiently usable as an indicator of firms' innovation performance in terms of increases in the area of IP properties in studies of certain industrial areas. Along with the number of patents, which is a quantitative indicator of IP, the diversity of areas of IP properties owned by firms is a useful measure for innovation performance of firms [97,126–128].

5.2. Additional Research Topics

This study analyzed data on patent applications by all firms in the USA that applied for patents at a certain period in a certain area. Thus, we have manifest limits in this research, and we need to perform the following research.

In-depth case analyses are required as follow-up studies to examine the reality of open innovation in the process of joint patent applications that center on concrete cases of firms, concrete shapes of resultant firms' innovation performance, and related expenses. For a case study, a control group should be analyzed to understand the pure effects of open innovation structure.

These follow-up studies should identify the concrete forms and characteristics of collaboration at the entrance of the knowledge funnel, network structures in this process, the direct relationship between the network structures and firms' performance, as well as the effects of the network structures on firms' collaborative activities. Especially, we should find any special benefits and cost of open innovation in research steps compared to development, partnership in business, or M&A to find the strange aspects of open innovation of R&D, except joint patent application [102], through an intensive case study on the open innovation at the entrance of knowledge funnel.

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Appendix A

Table A1. Samsung Network in the 500 Largest Agents.

Joint Patent Application Firms in the 500 Largest Firms	Number of Joint Patent Application Patents
Electronics and Telecommunications Research Institute (Daejeon, Korea)	137
Korea Advanced Institute of Science and Technology (Daejeon, Korea)	85
Seoul National University Industry Foundation (Seoul, Korea)	75
SK Telecom Co., Ltd. (Seoul, Korea)	60
KT Corporation (Seoul, Korea)	60
Hanaro Telecom Corporation (Seoul, Korea)	59
Postech Academy Industry Foundation (Pohang, Korea)	33
Sungkyunkwan University Foundation for Corporate Collaboration (Seoul, Korea)	11
Samsung Electro-Mechanics Co., Ltd. (Suwon, Korea)	10
Georgia Tech Research Corporation (Atlanta, GA, USA)	9
Tsinghua University (Beijing, China)	6
Palo Alto Research Center Incorporated (Palo Alto, CA, USA)	4
Toshiba Corporation (Tokyo, Japan)	1
Matsushita Electric Industrial Co., Ltd. (Osaka, Japan)	1
Hitachi, Ltd. (Tokyo, Japan)	1
Sanyo Electric Co., Ltd. (Osaka, Japan)	1
Pioneer Corporation (Kawagoe, Japan)	1
Regents of the University of California (Oakland, CA, USA)	1
Fraunhofer Gesellschaft Zur Föerderung Der Angewandten Forschung E.V. (Hansastraβe, Germany)	1

Appendix B

Table B1. Nokia Network in the 500 Largest Firms and Total Networks.

Joint Patent Application Patent Firms	In 500th Firms	Total Network
Nokia Siemens Networks Oy (Karaportti, Finland)	14	
Infineon Technologies AG (Munich, Germany)	2	
STMicroelectronics Corporation (Geneva, Switzerland)	1	
Commissariat à l'Énergie Atomique Et Aux Énergies Alternatives (Paris, France)	1	
RF Micro Devices Inc. (Greensboro, NC, USA)		1

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Appendix C

Table C1. Research In Motion Network in Total Networks.

Network Firms in Total Structure	Number of Joint Patent Application Patent	Institutions
A Corporation Organized Under the Laws of the Province of Ontario (Toronto, ON, Canada)	7	Firm
McMaster University (Hamilton, ON, Canada)	5	Firm
Ascendent Telecommunications Inc. (Redwood city, NC, USA)	3	Firm
Certicom Corporation (Mississauga, ON, Canada)	1	Firm
Ontario, Canada	1	Individual

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