Proceedings of the 52nd Hawaii International Conference on System Sciences | 2019

Dynamics of assignee networks: a new approach for measuring the impact on patent value based on network analysis

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Abstract

This article outlines a network approach to the study of impact factors of patent value. Firms protect their property right of each innovation as the assignee of the patent. Advanced technological capabilities constitute a major resource for firms trying to achieve and maintain competitive advantages. Firms are also assessed by the overall value of its intellectual properties, especially the patents. Researchers have been trying to quantify patent value and study the related influence factors. Among all the characteristics of patents, citations represent the knowledge flows between innovations. This information can be used to measure and track the significance of each patent. The activity of a firm citing patents from other firms during a patent application indicates its R&D intention and interest, creating a strategical link between the assignees of the involved patents. In this study, a new approach of studying the impact of an assignees role on patent value by network analysis is proposed. Our analysis showed that in-degree centrality and betweenness centrality of an assignees position in the interaction network have a significant impact on its patent value, while the effect of out-degree centrality is inconclusive. This approach provides a perspective of assessing the overall patent value of a firm, which can serve as a reference for managerial purpose of allocating firm resources and investments.

1. Introduction

It is widely recognized that technological innovation is one of the key drivers of sustained economic growth of firms, industries, and countries [1]. The quantity and quality of a firm's innovations represent its advanced technological capabilities to achieve and maintain competitive advantages. R&D strategies therefore play a significant role in a firm's business plans. Applying patents through authorities is the major strategy for firms to protect their R&D investment on property rights. Firms claim their rights and potential technological benefits as the assignee of the patents. Therefore, the patent portfolio represents a firm's technological capabilities, which should also be reflected in the valuation of the firm by the market [2].

Previous studies have investigated a variety of ways to evaluate patents based on the characteristics and statistical measurements of patents themselves. Recent research found that the citations data convey information about the cumulative nature of the research process, as well as information about the consequences [3]. However, the basic statistical counts of citations do not reveal the technological complexity included in a patent. They are not suitable to compare technological value across fields either [4]. The activities of citing (i.e. backward citation) and being cited (i.e. forward citation) by other patents form a unique citation network for each patented innovation. Instead of the statistical metrics of citations, the patent citation network can be used to construct relationships among patents. It identifies the origins of the innovative idea and predicts the technological knowledge flows [5, 6]. It further helps determine the innovations significance position in an evolving network of modern technology, which directly relates to the value of the patented innovation. Therefore, a growing trend can be observed in the use of citations network to estimate the patent value [7, 8, 9].

Though various researches have been done on the impact factors of patent value, it is difficult to test the accuracy directly because of the scarcity of directly observable measures of a single patent's value [10]. Moreover, the importance of a technological innovation has to be revealed by the market performance of the firm over time. Firms are evaluated by their overall performance and resources. It is impossible to isolate the impact of one patent on a firm's valuation. Therefore, many researches choose to investigate the influence factors of patent value based on the information of a patent portfolio at firms'level [11, 10, 12].

As discussed, it is an important issue for firms to build a proper patent portfolio with a high value.

URI: https://hdl.handle.net/10125/60112
ISBN: 978-0-9981331-2-6

Successful R&D investments on patents require firms to maintain a good awareness of modern technology development. Technological patents are created by individual or a group of inventors. The firms, as the patent assignees, are usually the real beneficiaries. The innovation process is increasingly based on interactions, collaborations, and networks of various factors [13]. The activities involved in the innovation process can be indicated by the interactions of firms/assignees.

In our study, we propose a different perspective of evaluating patents. Technological innovations are developed through a dynamic process which requires a variety of learning, collaborating, and competing. The static attributes of patents only represent a small portion of patent characteristics. The dynamic interactions through citation relationship form a network between the assignees. It reveals the importance of an assignees position in the industry. An assignee who takes a significant position in the network is more likely to control the essential patented knowledge of the technology, thus having influence on other assignees research outcome. In other words, the patent portfolio of this assignee has a higher value. The assignee interaction network is built based on both the forward and backward citation activities. In the network, assignees are the nodes, citing and cited-by actions are the edges with opposite directions. The edge weights indicate the number of times the interaction occurs. Network analysis is performed and the results demonstrate that it is a feasible approach to assess the patent value of firms in related industries, which can serve as a reference for decision makers on potential investments and resource allocation.

2. Theory and hypothesis

In this section we provide the background for studying patent citation networks, explain our methodology, and outline the hypotheses we want to test.

2.1. Patent citations

Citations data have long been used as reference to ”help the historian to measure the influence of the article – that is , its ’impact factor’” [14]. Patent applicants are obligated to cite prior art as the evidence of the patents claims of originality. Older patents, scientific literature and publications can all serve as prior art of a patent. Some researches showed that non-patent references bring in systematic noise [15]. However, most researchers believe that patent citation information is more reliable than those in academic publications because citing prior art is a legal responsibility of patent applicants [16, 17]. Moreover, the examiners from the patent office can provide additional citations to form a more complete citation index of a patent application [15, 18].

The action of being cited by other patents is also called *forward citing*. Previous studies reported a close relationship between the use of forward citation and the patent impact [19, 20]. Albert *et al.* compared the citation intensity of 77 Kodak silver halide patents to the expert evaluations of technical importance of the patents. The results showed a strong correlation [21]. Another research by Benson and Magee identified 28 technological domains in which they were able to gather the specific metrics of the technological state. They found that forward citations are positively related to the rate of improvement of the technology over the subsequent ten-year period [22].

On the contrary, the publications that a patent is citing are counted as its *backward citations*. The studies on backward citations show inconclusive results on their role in reflecting patent impact [23, 24]. Trajtenberg *et al.* found that more trivia inventions rooting extensively on previous technologies generally have more backward citations than fundamental inventions [23]. However, another research showed that backward citations have a statistically positive association with the probability that a patent will stand up in court [25].

The major type of citations in a patent application is patent material. Although non-patent materials are considered as proper citations of patent application, some research argued that non-patent materials, which are mainly scientific articles, are a noisy measure of science linkage between invention and scientific research [26, 27]. The cited articles are rarely a knowledge source of the innovation[18]. So in this paper, we focus on forward and backward citations with patent type only.

The activities of forward and backward citation naturally form a network representing knowledge flow between innovations. The network also reveal the relationship between the patent assignees who are considered the innovation owners and sponsors. Assignees of related industry are learning, collaborating, or competing with each other. The knowledge flow between innovations can be used to analyze the assignees industrial reputation and performance. For example, Huang *et al.* used citation data to identify the strength of the relationship between companies by studying the strength of bibliographic coupling [28]. The information of the assignee relationship in the innovation process enables the analysis of the influence from assignees on patent value.

2.2. Patent value

Former researchers have developed various patent index as a reference of predicting potential patent value. The ideal candidate should have at least three features [29]: positively correlated with the patent value in the literature, retrievable from patent databases, and able to signal a potential market for the innovation. Forward citations, grant decisions, families, renewals, and legal dispute meet the requirement of all the features and have been the most widely used patent value index [30]. A variety of empirical researches have been conducted by using different choices of patent value index. For example, Maurseth demonstrated that patents that receive citations across technology fields survive longer than other patents [31]. Allison, et al. studied the characteristics of most litigated patents and found that litigated patents are of higher value than those have not been litigated[32]. In this study, we use dynamic network analysis to predict litigation possibility.

2.3. Network theory

Network analysis is an approach used to study the exchange of resources among actors (i.e., individuals, groups, or organizations) [33]. The connection between actors defines an interactive relationship. Networks, typically the social networks, are composed of actors as nodes and the relationship between actors as the corresponding edges. Social network studies focus on network structure and relationship. The interactive relations between actors form the network structure. The network structure determines the level of efficiency with which information is transferred. Each actor takes a part of the complexity of the network structure, which defines the position of the actor in the network. From the position of each actor, we are able to investigate the actor's behavior and predict its performance.

The social network theory is widely applied in research on innovation. For example, Bolconi *et al.* studied the Italian networks of inventors with common team-membership in patenting [34]. A case study performed by Cantner *et al.* on the network of innovators in Jena showed that the network positions are a crucial factor in explaining the innovative performance of the actors [35].

Degree is simply a measure of the number of neighbors that a node has. The degree can be interpreted in terms of the immediate risk/benefit of a node for catching the information flow through the network. So nodes with higher degree centrality possess more informal rights and influence. They can exert influence on the whole network through the nodes connected to them, and have a higher chance to access resources [36]. There are two types of degrees for directed network: in-degree and out-degree. In-degree measures the number of links directing to the node while out-degree is the number of links that the node directs to others. Typically, we are interested in in-degree which are determined by other nodes in the network, while out-degree are created by the node itself.

Let $A = (a_{i,j})$ be the adjacency matrix of a directed graph. The in-degree centrality x_i of node i is given by:

$$x_i = \sum_k a_{k,i}$$

In-degree centrality means how many assignees have cited this assignee's patents. A higher number of forward citations of one patent reflects the essential influence of that patent in this technology field. So we propose the hypothesis

Hypothesis 1 Assignees with more litigated patents have higher in-degree centrality than those with less or no litigated patents.

Closeness centrality is calculated as the sum of the length of the shortest paths between the node and all other nodes in the graph. Thus the more central a node is, the closer it is to all other nodes.

Suppose $d_{i,j}$ is the length of a geodesic path from i to j. The network has n nodes. The closeness centrality is defined by

$$c_i = \frac{1}{l_i} = \frac{n}{\sum_j d_{i,j}}$$

The technological value of a patent is largely reflected in forward citations. Therefore this study only proposes a hypothesis on in-closeness centrality.

Hypothesis 2 Assignees with more litigated patents have higher in-closeness centrality than those with less or no litigated patents.

Betweenness centrality measures the extent to which a node lies on paths between other nodes.

Let $n^i_{s,t}$ be the number of geodesic paths from s to t that pass through i, and $n_{s,t}$ be the total number of geodesic paths from s to t. The betweenness centrality of vertex i is defined by

$$b_i = \sum_{s,t} w^i_{s,t} = \sum_{s,t} \frac{n^i_{s,t}}{n_{s,t}}$$

where by convention the ratio $w^i_{s,t} = 0$ if $n_{s,t} = 0$. Nodes with high betweenness may have considerable influence within a network by their control over information passing between others. So betweenness centrality should have a significant impact on the patent value.

Hypothesis 3 Betweenness centrality shows significant influence on the litigation counts of assignees.

3. Data

The Bluetooth wireless technology serves primarily as a short-range connectivity solution for personal, portable, and handheld electronic devices, including notebook computers, cellular phones, personal digital assistants (PDAs), digital cameras, *etc*.[37]. We choose Bluetooth technology as the focused industry because it has been attracting research attentions all over the world since the name was proposed in 1997. It is considered as a well developed and relatively mature wireless technology standard.

We collected patent data from the Patent Full-Text and Image Database established by USPTO. The term "Bluetooth" is used as the keyword to search patent titles and abstracts. A total of 2758 US patents are retrieved with 204385 forward and backward citations (in the type of patents only) from the database in the period of 1990 to 2018. Though patents are created by inventors, manufacturers or research institutes usually hold the intellectual property of the patents as the property assignees because of their investment on the research.

We generate the assignee interaction network based on the forward and backward citation activities. The network is composed of assignees as the nodes, forward and backward citing actions as the edges with opposite directions. The edge weights indicate the number of times that the interaction occurs. The assignees who have incomplete patent or citation information are removed from our final data. The final assignee interaction network is large and contains 2527 nodes. Figure 2 shows the core of the assignees interaction network. The center of the network represents the identities who play significant roles in the Bluetooth research field. The nodes are closely connected with high in-degrees. The degree distribution of the assignees demonstrated in Figure 2 shows that the network is essentially centralized.

The litigation status of each patent can be retrieved from InnovationQ Plus. The database provides information on whether a patent is litigated as well as the number of litigation cases which it has been involved in. We count the total number of litigation cases for patents belonging to the same assignee. An assignee with a larger number of total litigation cases has a higher probability to get involved in potential patent litigation.

Certain factors about the assignee itself may have impact of its patent value as well. The information about each assignees patent stock and firm lifespan are collected as control variables. Patent stock of an assignee refers to the total patents owned by the assignee in the field of Bluetooth. The data are collected from USPTO. A higher number of patents owned by an assignee means a larger innovation pool for other peer competitors to cite and learn. Firm lifespan refers to the number of years that an assignee has been in the business or the research of Bluetooth since it was established. InnovationQ Plus, which provides firm information for major companies, is our data source. However, we are not able to retrieve all the lifespan information for our assignees. Eventually, 767 of 2527 assignees have complete information.

4. Results and analysis

We calculated the assignee network centralities according to the definitions. Each centrality category presents a wide range of value since we have a large network with over 2000 nodes. Additionally, the differences in value scale between different centrality categories result from their own definitions. The relative position in terms of node centrality, instead of the absolute value, is of our interest.

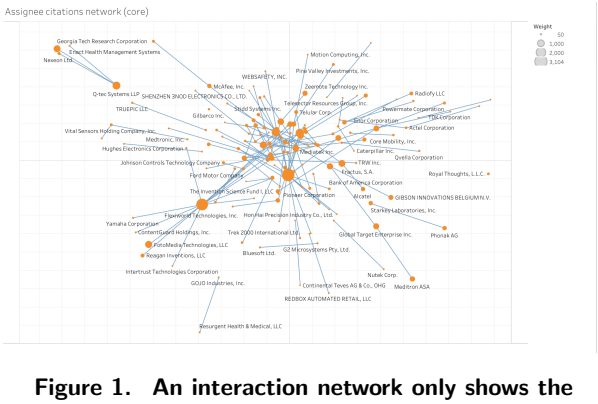

Figure 1. An interaction network only shows the core assignees whose in-degree are 50 or more. The size of each graphic nodes represents the value of its in-degree.

The descriptive statistics of our data are summarized in Table 1. The in-degree and out-degree centralities of the interaction network represent the activities of each assignee reaching out to its peer researchers. We can see

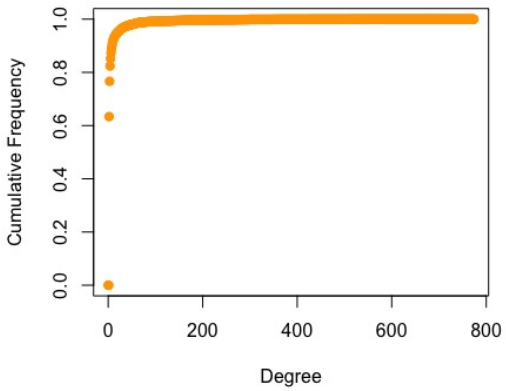

Figure 2. In-degree distribution of assignees in the Bluetooth industry

Table 1. Descriptive statistics.

	Obs.	Min	Max	Mean	Std. Dev.
In degree	2527	0	10280	59.87	368.29
Out degree	2527	0	7380	75.82	394.84
Closeness centrality	2527	0.00017	0.037	0.035	0.0024
Betweenness centrality	2527	0	0.054	0.00012	0.0013
Litigation counts	2527	0	4	0.015	0.16
Patent stock	2527	0	7380	79	407
Firm lifespan	767	1	809	59.633	59.004

that the assignees of the selected technological industry have frequent interactions with other researchers. However, the large variances of all the centrality measures indicate a centralized network structure of the assignees interaction. The information flow exchanges mainly in a portion of the network, while some assignees stay more independent.

We conducted an OLS regression to take all possible network positions into account. The OLS model gives us an overview of how the network structure and node positions affect each assignees probability to be involved in patent litigation. We used the total litigation counts of patents for each assignee as the value index of the assignee's patent portfolio. The degree centrality, closeness centrality, and betweenness centrality of assignees position in the interaction network are the independent variables. The regression results are presented in Table 2.

Table 2. Regression results.

	D. V. : Litigation counts
Intercept	-0.0180
Independent variables	
In-degree	1.58e-4***
Out-degree	7.50e-06
Closeness centrality	0.765
Betweenness centrality	-14.93***
Control variables	
Patent stock	-0.00171
Firm lifespan	0.048
N	767

$^{*}\ p < 0.05, ^{**}\ p < 0.01, ^{***}\ p < 0.001$

The results in Table 2 show that in-degree centrality and betweenness centrality significantly affect patent value under 5% significance level with coefficients as 1.58e-04 and -14.93 respectively. The positive sign of the coefficient of in-degree centrality indicates that the forward citations of an assignee's patents build up its reputation of the industry, thus reflecting higher influence. **Hypothesis 1** is supported by our study.

Few researches have been done on the impact of betweenness centrality but it is straightforward to understand its role in evaluating a node's role in a network. Removing nodes with high betweenness centrality from the network will cause more disruption to the communications between other nodes because they occupy a prominent position through which a large number of paths are taken by the information flow. Our results show that betweenness centrality has a significant negative impact on patent value. **Hypothesis 3** is supported by our results.

Out-degree centrality and closeness centrality do not show significant impact under the selected confidence level. Out-degree centrality shows the backward citation activities between the assignees. It indicates that the assignees have strong understanding on the current development of the technological field. Though a higher out-degree centrality rewards a higher efficiency during the innovation process, it can also show a lower level of creativity. We focused on the in-closeness centrality in our study. It refers to the reciprocal of the sum of the shortest distance a patent to be cited. Closeness centrality also shows the same complex effect on patent value. Our results do not support **Hypothesis 2**. Therefore, we are not able to determine the impact of out-degree centrality and closeness centrality on patent value. This inconclusive results are consistent with

previous researches [23, 24].

From the above results we can also see that patent stock and firm lifespan do not show important influence on an assignee's patent value. This result is not uncommon in the high-tech industries where start-up companies with fewer patent stock and shorter business history show more vitality in initiative and innovative activities.

5. Conclusion

The value of a firm's patent portfolio is an important part of its R&D performance and market valuation. In this study, we propose a new approach of studying the impact of an assignees citation activities on the value of its patent portfolio by network analysis. Previous researches have been focusing on evaluating patents by characteristics of individual patents. However, it is difficult to track the impact of one patent on a firm's performance in reality. Our approach provides a perspective of assessing the overall patent value of a firm by its citation activities. It can serve as a reference for managerial purpose of allocating firms resources and investments. We in this paper focused on the patents in the Bluetooth industry. Future studies can widen the scope of the investigation to other innovation fields which are not limited to high-tech industries.

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