Information **2013**, *4*, 398-410; doi:10.3390/info4040398

OPEN ACCESS

information

ISSN 2078-2489

www.mdpi.com/journal/information

Article

Empirical Analysis on Evolution and Small World Effect of Chinese Enterprise-Enterprise Patent Cooperation Network: From the Perspective of Open Innovation

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Received: 16 August 2013; in revised form: 11 October 2013 / Accepted: 24 October 2013 / Published: 28 October 2013

Abstract: The patent cooperation network which enterprises join is a very important network platform for enterprises' open innovation. However, very limited work has been done to empirically investigate the dynamic change process of the network in China. To address this issue, this paper analyzes dynamic change process of cooperation network of enterprises and the small-world effect of the biggest subgroup according to the data of 36731 items of cooperative patents between enterprises from 1985 to 2010 published by the State Intellectual Property Office of China. A conclusion can be drawn from the analysis results that the biggest subgroup has the characteristics of small-world effect, but the overall network structure also has some defects, which limit the development of open innovation. For the first time, suggestions on open innovation strategies are put forward to provide theoretical reference for both the government and enterprises.

Keywords: patent cooperation network; information mining; open innovation; network structure; small-world effect

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1. Introduction

Open innovation will become mainstream in future development of technology and business. Moreover, enterprises that can successfully implement open innovation will get prosperity and development in the new era. Chesbrough [1,2] put forward open innovative logical thinking, which means combining external creativity, ideas and knowledge with internal research and development. He believed that open innovation is inevitably becoming a new way of technology renovation and making profits at present and in the future [1,2]. With the speed acceleration of new knowledge and rapid spread and communication of professional knowledge globally, the potential creativity and ideas must be utilized soon, otherwise the good opportunity will soon disappear. Some companies have made a lot of long-term investment on research and development. However, finally they realized that the projects they had discarded owned big business interests.

The most typical example is the Xerox Corporation. Xerox developed numerous computer hardware and software technologies, but a lot of items did not get much attention, such as Ethernet and Graphical User Interface [1]. At that time, the main business of Xerox focused on high-speed copying devices and printers, and these two technologies were thought of as unworthy and discarded in the company. However, at the same time, the two technologies were utilized and commercialized by other companies to get great profits, for example, Apple Computer and Microsoft both using GUI technology in their operating system. In recent years, some international companies also begin to formulate some policies to promote the open innovation. For example, if an idea or a thought cannot be adopted in the internal company in three years, the idea would be sold to other companies even the direct competitor, in order to prevent the potential idea becoming a lost opportunity and being buried inside the company. The practice of a lot of companies to explore open innovation has proved that external technology can fill the blank of the internal business or technical gap, and technology of the internal organization can explore new business at an external level. Open innovative logical thinking proposed by Chesbroug [1,2] focuses on technological innovation. Then, Chesbrough [3–5] put forward six business modes of open innovation from the fundamental levels to high levels and the implementation model. This paper discusses the open innovation only from the perspective of technological innovation, and the research in this paper only focuses technological innovation.

Because the time to propose open innovation is short, it will be a new topic for disciplinary study in China, especially in Technological Economics and Corporate Management [6]. An open innovation network can be divided into many forms according to different node types. The applicants contact network based on patent cooperation is one kind of open innovation network. Patent cooperation and joint patent application are the important forms and achievements of open technological innovation. A patent cooperation network of enterprises provides an important network platform for their open innovation. Whether based on the needs of technology or the needs of market, the expandable range of technology and business in the network features in more practical application. Moreover, the technology and business in the network can be combined with new technology and business in other fields and organizations. Therefore, conducting research on the situation of the patent cooperation network of enterprise and the relationship between network structure, open innovation and performance has both theoretical significance and practical importance. The analysis methods and results of this project can provide empirical data and great help for enterprises and research institutions to construct network structure, establish and adjust relationship with network partners and determine the network position to make open innovation strategies. Moreover, the results can help the government to promote the construction of a patent cooperation network and the improvement of this network structure from a macroscopic perspective.

To date, much research has been done in the patent network analysis through aspects of patent citation network, patent collaboration network, patent technical themes collaboration network and so forth [7–9]. Social network analysis has received more and more attention in the patent analysis [10]. This is because in the collaboration network there is a "U" relationship between the centrality of inventor structure and the company innovation [11]. Moreover, most of existing literature has focused on the quantitative statistics on the patents but very limited work has been done to address the network structure and its evolution dynamics [10]. The social network analysis can assess the evolution dynamics about the patent network and hence may provide deep insight into the patent network analysis [12–14]. The application of the social network analysis in the patent network will be a major research area in the near future.

Therefore, for the first time the social network analysis method is adopted in this paper to empirically investigate the dynamic change process of the network in China. Taking the joint patent data published by State Intellectual Property Office of China from 1985 to 2010 as the sample, the paper analyzes the dynamic evolution and network structure of cooperation network of enterprises. The findings of this work will provide a useful theoretical reference for both the government and enterprises to their innovation strategies.

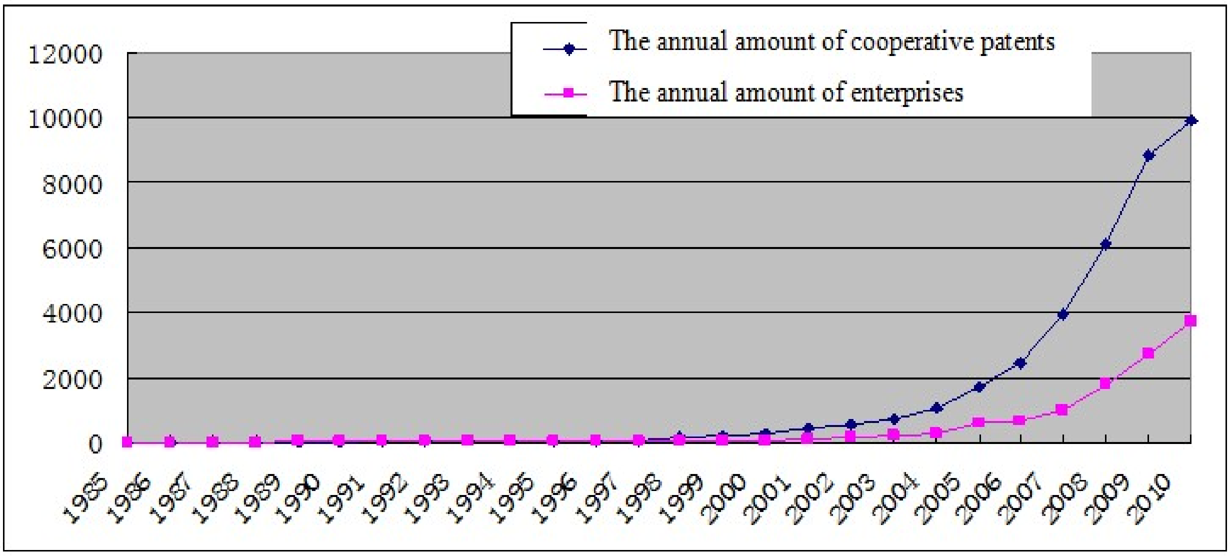
2. Data Collection and Research Method

2.1. Data Collection and Disposal

Patents constitute three categories—patent for invention, patent for utility models and patent for design. Patent for invention shows greater creativity than other two categories. Moreover, the patent in this paper only refers to the patent for invention patent. Patent cooperation between enterprises discussed in this paper only refers to one form, which is joint application for patents of enterprises. The data retrieval was conducted on the net of State Intellectual Property Office. The research targets include the joint application of enterprises (including companies, groups and factories), which belong to patents for invention in mainland China (excluding Hong Kong, Taiwan and Macao). The date of data retrieval was 5 September 2011. The author researched the patents from January 1985 to December 2010 and got 39,351 items of original data. Each patent item shows the information of the publication number, application number, publication date, applicants, classification number, and inventor. The research targets also include the patents of research institutions of enterprise, such as Sinopec Shanghai Research Institute of Petrochemical Technology, and the patents of universities if the university was ranked the third and after the third position in the application, because the author assumed thus patents give the priority to the cooperative patent of enterprises. After being processed with above standards, the sample date account for 36,731 items.

The annual growth of cooperative patents and enterprises are shown in Figure 1. Annual announcement of patents in China before 2000 featured in small and stable amounts. However, the starting phase of rapid growth is from 2000 to 2004; and the boost phase began in 2005. The situation of annual growth of enterprise is similar to the annual growth of cooperative patents. Until 2010, the enterprises which took part in the patent cooperation reached 3733. The proportion of cooperative patents of enterprises in the announcement patents was 0.5% to 0.6% before 1997; the percentage has a rapid increase from 1998 to 2001, which reached 2.45% in 2001; the data in 2005 keep a stable number of 2.55%. The percentage has a rapid growth starting in 2006, and it is 4.55% in 2010. In general, the proportion of cooperative patents of enterprises in the annual announcement of patents is very small. After observation of the annual growth and amount of samples, the sample data are divided into six stages: from 1985 to 2004 every five years is a stage with a total of four stages: 1985–1989, 1990–1994, 1995–1999, and 2000–2004; and the rapid development phase is from 2005 to 2010, which is divided into two stages including 2005–2007 and 2008–2010.

Figure 1. The number of cooperative patents and enterprises.



2.2. Social Network Analysis

At present, the social network analysis has been used in the American patent analysis. However, it is seldom employed to analyze the patent data in China, and little work has reported the investigation on the dynamic change process of the network using social network analysis in China. This is because the USA is the world's economical and political center and the review criteria of the American Patent Office are totally different to the Chinese Patent Office [10]. With the globalization of the world economy, China needs to join the global innovation network to develop its technology. The scholars who used foreign patent databases to conduct data analysis are reviewed below. Xiang [6] used patent reference data and networks of common inventors on NBER (National Bureau of Economic Research) and USPTO (United States Patent and Trademark Office) to construct a network which was established by patent inventors with Chinese nationality who receive technology spillovers from the United States. Further, Xiang [15] adopted The USPTO patent index and DERWENT database, aiming at enterprises in electric system in China, by analyzing patent reference data and common inventors to establish the explicit network and implicit network for enterprises and inventors, as well as the global knowledge spillovers and multinational innovation knowledge network. Wang *et al* [16] constructed an intensity matrix of patent citations of large industrial enterprises in Fortune Global 500, drew the network map of patent citation of leading enterprises, assessed the technology level, identified the core competitiveness and technology competition of enterprises in the industry, and analyzed the relationship of technology development of different industries. Yang *et al* [17], using the database of the U.S. Patent and Trademark Office, based on patent citation network, investigated the relationship between different technical fields. Luan [18] utilized DERWENT database to analyzed technology cluster of Boeing Co. Ma [19] researched the patent application cooperation network of enterprises and analyzed the network of the first patients in alphabetical order from A to H, and compared the evolution of network centrality and centrality potential of this group and the central position of universities on the network of this group. Lei [20] analyzed three evolution phases, cooperation regional center and technology fields of patent applications of coalition of college and enterprise, and the layout evolution of some college and enterprise coalitions which implicated several patents. Liu *et al* [21] took Chinese colleges and universities of “985” Project as the study objects to make a industry-university-research cooperation patent network between “985 colleges and universities” and other colleges and universities and enterprises, in which the authors analyzed evolution of patent cooperation network structure and spatial distribution from 1985 to 2009. Chen and Fang [22] discussed social network analysis method and framework which was associated with patentee network analysis. They conducted the empirical study about patentee network based on cooperation and technology by analyzing the patents for invention from 2005 to 2008 published by the Chinese Academy of Sciences.

Among these research literatures about patent cooperation network of enterprises, only a few papers conducted the empirical study on patent cooperation of university-enterprises, and the research on patent cooperation network of domestic enterprises in China by analyzing large data cannot be found [23]. Moreover, the current literature only focuses on key technology of university-enterprise cooperation and regional condition, but the literature did not cover the relationship between network and innovation. This paper, aiming at patent cooperation network, using social network analysis, discusses the problem of whether the patent cooperation network is conducive to technological innovation of enterprises and the whole network by analyzing practical evolution of multi-disciplinary network and structure features.

3. Results and Discussion

3.1. The Evolution of Network Structure

The indicators of overall structure characteristics of social network include scale, average degree, central potential and network density. These indicators reflect the different aspects of network structure characteristics. In general, these indicators should be combined to analyze the structure characteristics of a network. The average degree means the average of the degree of all nodes in the network, which can explain the average level of external linkage of nodes. NRM average degree indicates standard average degree of nodes, which can be compared in different network scales. Network central potential describes the central tendency of a network, and network density reflects the tightness of links between nodes.

The phase structure characteristics of network are shown in Table 1, and the network revolution is shown as Figure 2. In the process of network development, the number of nodes is increasing rapidly. Except for the stage of 2000–2004, subgroups are isolated from each other in cooperation network, the distribution of network shows the general dispersion and partial compactness, and the absolute average connections and standardized average connections are small when the network density is low. With the rising number in the cooperative group, the network center potential is becoming smaller and smaller. An exception is the stage of 2000–2004, the largest group shares a rather low proportion in the overall network. From the perspective of degree, there were extraordinary core enterprises in the network. Moreover, in the development of network, the relatively low value of some groups changed greatly in each stage.

In the evolution of cooperation network of enterprises, the number of nodes, the number of subgroups and subgroup size are increasing, but there are always three types of cooperative groups in the network: cooperative groups with lots of nodes, cooperative groups with a few nodes, and small groups with two or three nodes. Moreover, the number of large-scale groups is relatively small, while the small groups share a large population. Some large groups own the stable structure and some small groups were not stable. In each stage, some new groups would appear, and some groups would collapse.

From the perspective of business connection of cooperative groups, the cooperation of the stable cooperative groups such as Sinopec, Petro China, Haier Group, and Baoshan Iron & Steel mainly concentrate on inner organizational cooperation and parent-subsidiary cooperation. However, the inter-group cooperation and non parent-subsidiary cooperation are increasing continuously. However, after 2007, several groups of high-tech industries such as electronic communication appeared. The enterprises represented by these groups conducted a lot of cooperation with other organizations and companies, and they showed great openness. From the perspective of technical fields of cooperation, enterprises mainly conduct cooperation in the highly similar technical fields to form the network. Cooperative groups in network mostly belong to the same technical field or the same industry, and the boundaries of technology or industry have not been broken yet.

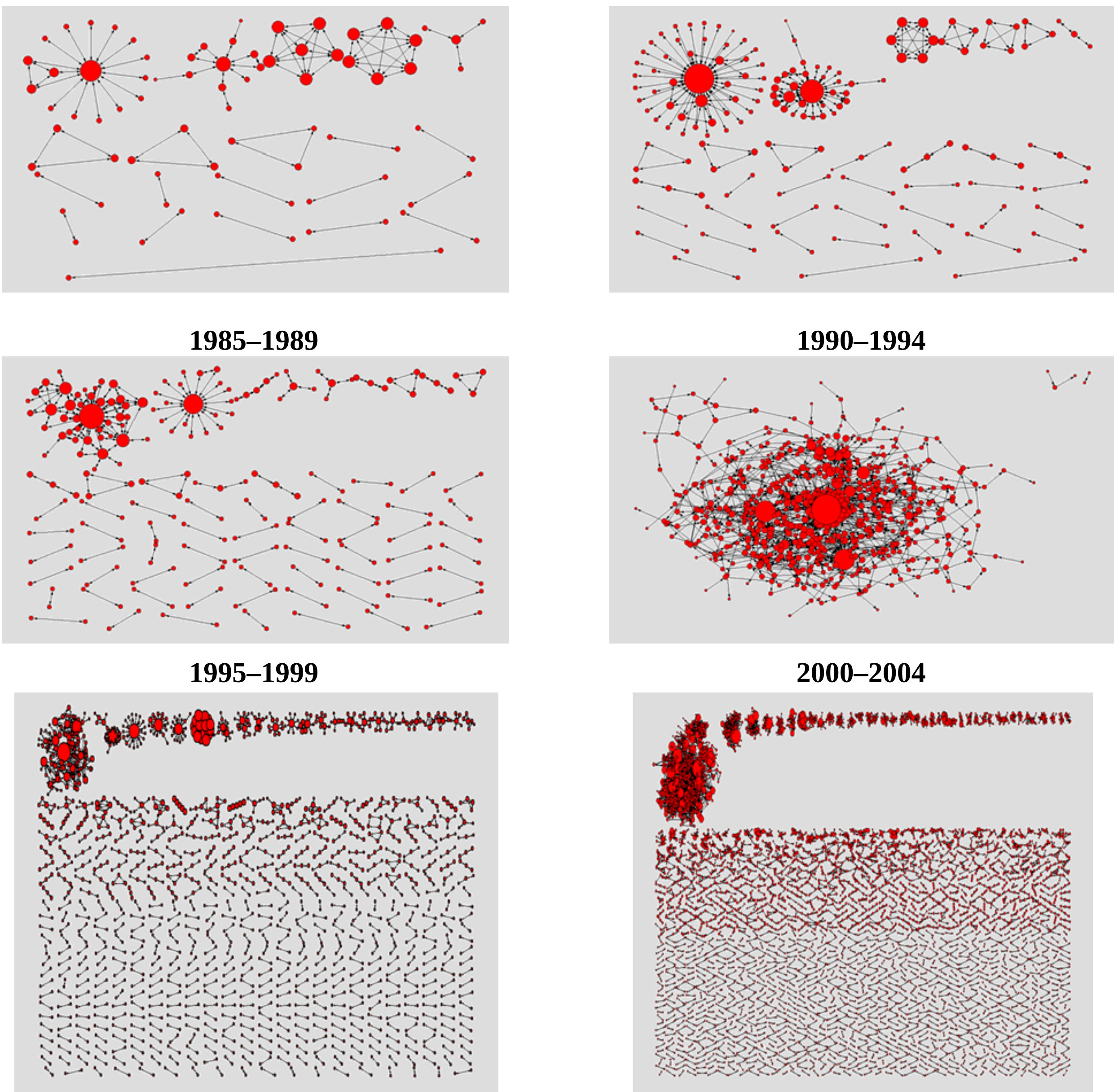
Table 1. Characteristics of contact network of applicants.

Stage	1985–1989	1990–1994	1995–1999	2000–2004	2005–2007	2008–2010
odes	79	168	215	735	1679	5736
Largest connected component ratio (%)	20.253	27.381	20.000	98.912	7.028	15.394
Average Degree	2.177	2.155	1.758	3.540	1.762	2.0321
NRM Average Degree	2.791	1.290	0.822	0.482	0.1050	0.0354
Central Potential	0.1687	0.2597	0.1474	0.1099	0.0240	0.0110
Intensity	0.0279	0.0129	0.0082	0.0048	0.0011	0.0004

Except for the stage of 2000–2004, subgroups in cooperation network are isolated from each other. The distribution of network presents the overall dispersion and partial compactness. The network density is very low. Because of lack of intermediaries (the bridge) between each group in the network, the isolated parts are formed, which also means the structural holes proposed by Ronald Burt. There exist large amount of structural holes in the contact network of applicants. There is a lack of a large number of "intermediaries", which leads information resources to be abandoned, and makes it difficult for a large number of novel and non-redundant knowledge to exert the potential value. Moreover, the flow of knowledge and information in the network will face breakage, which affects the utility of knowledge and innovative performance, as well as the overall innovation when the network grows in a specific stage.

Subgroups in the network present a star-shaped distribution with the core node of an enterprise. The non-core nodes almost isolated each other, and the relation between subgroups depends on these core nodes to a large extent. The nodes will boost the flow of knowledge and information, which plays a very important role in the network. However, the star shaped distribution will increase the instability of the network. Once the core node withdraws, the original groups will break up, or the technology progress will become slow, or the control of valuable information for the node itself will be affected, which will reduce finally the number of groups and the performance of open innovation.

Figure 2. Each phase of cooperation network of enterprises.



1985–1989 **1990–1994**

1995–1999 **2000–2004**

2005–2007 **2008–2010**

3.2. The Evolution of Major Cooperative Groups

The stage of 1985–1989: there were few nodes in this stage. Four isolated subgroups were formed in the network, including two large star-shaped subgroups with the core enterprises of Anshan Iron and Steel Company and China Petrochemical Corporation respectively. The other two subgroups include China Non-Ferrous Metal Corporation and Dalian Lifting Machine Works.

The stage of 1990–1994: the two big subgroups still distributed in star-shape with Anshan Iron and Steel Company and China Petrochemical Corporation as the cores, but the connection of non-core members increased compared with previous stage. The members in subgroup with China Non-Ferrous Metal Corporation as the core almost stayed unchanged. In addition, two new subgroups emerged which took Capital Iron and Steel Company and the Engineering Design Company of Bohai Oil Corporation as the cores.

The stage of 1995–1999: the biggest group is the subgroup with China Petrochemical Corporation as the core member. Hereafter, with its increasing strength, this subgroup remained the biggest subgroup in the network. Anshan Iron and Steel Company relegated to the second in the network, and the relative position began to decline after this stage. Three subgroups in previous stage collapsed in this stage, which are groups with China Non-Ferrous Metal Corporation, Capital Iron and Steel Company and the Engineering Design Company of Bohai Oil Corporation as the cores nodes. Two new subgroups appeared which took Haier Group and Baoshan Iron & Steel (Group) Co., Ltd as the cores, and they become important members in the network.

The stage of 2000–2004: groups in the network formed an interconnected part through some connections. The core nodes of these groups include China Petrochemical Corporation, China Petrochemical Group, Research Institute of China Petroleum and Chemical, Baoshan Iron & Steel, Haier Group, Hon Hai Precision Industry Company, and Qingdao Hisense Communication Co., Ltd, and Wuhan Rongde Industrial Co., Ltd. Moreover, some universities, such as East China University of Science and Technology, Fudan University and Tsinghua University became nodes in the network.

The stage of 2005–2007: Sinopec Corp, China National Offshore Oil Corporation and China National Petroleum Corp as the core nodes to form three groups connected by a small amount of nodes into the largest subgroup, which was called as petrochemical industry cooperation network. Tsinghua University, Zhejiang University and Shanghai Jiaotong University became the important partial nodes of this biggest group. There was an electronic communication network of rail system with very close connection between members, which consisted of CSR Zhuzhou Electric Locomotive Research Institute, Beijing Century East China Railway Technology Co., Ltd, and Shanghai Fudan Communication Co., Ltd. Haier Group, Baoshan Iron & Steel, Hisense Communication and Hon Hai Precision Industry still kept their important positions in the network in this stage. Some large-scale groups emerged in this period, such as China International Marine Containers (Group) Ltd. (CIMC), Founder Group, Panda Electronics Group Company Ltd. (Panda Group), and MiTAC International Corp. As the third applicants for a patent, some universities began to become the core nodes of the cooperation network between colleges and enterprises, and the universities included Peking University, South China University of Technology, Chongqing University, Sun Yat-Sen University and Shanghai University.

The stage of 2008–2010: petrochemical industry cooperation network which consisted of three subgroups with the core nodes of Sinopec Corp, China National Offshore Oil Corporation and China

National Petroleum Corp respectively still was the largest subgroup. However, its scale and density increased greatly compared with the previous stage. The new emerging group with China Mobile Communications Corporation as the core node became the second largest subgroup in the network. The cooperative group of Founder Group and Peking University, Haier Group, Hon Hai Precision Industry, Shanghai Fosun Pharmaceutical (Group) Co., Ltd., Panda Electronics Group, Zhejiang Lonsen Group Co., Ltd., China Banknote Printing and Minting Corporation, and Hengan International Group remained the important groups in the network. As with the last stage, some university-enterprise cooperation networks were formed. The core nodes of these groups were universities, such as Peking University, Southeast University, South China University of Technology, Shandong University, Beijing University of Technology.

3.3. Analysis of Small-World Effect

The "Six degrees of separation" theory was proposed by Professor Milgram of Harvard University in 1967. After that, the small world network received great attention from numerous fields including physics, computer science, sociology, economics and information science. Researchers have shown that many real-life networks, especially social networks presented the small-world effect, for example, the Friendship Network, the Scientific Research Cooperation Network, the Corporate Alliance Network, Internet, American Electric System, the Brain Tissue off Worms, and Hollywood Actors Cooperation Network[24–27]. In 1998, Watts and Strogatz proposed the well-known W-S Small world network model by analyzing the social network model of human beings [28]. The small-world effect is considered to be the most effective way of information transmission of the complex networks. A highly concentrated subnet with several "local connected" nodes and some random long-distance connections which helps produce short paths, can improve the efficiency of information transmission. The small-world effect features a relatively large clustering coefficient and short average path length. Therefore, clustering coefficient (CCi) and average path length (PL) currently are two important indicators of examining small-world effect. Suppose that node i in the net has Ki sides to connect node i to another Ki nodes. So the Ki nodes are the neighbors of node i, and among the Ki sides, there are at most Ki (Ki−1)/2 sides. So the clustering coefficient of the node can be got through the ratio of actual number of sides E(i) of node i to the most possible number of side gets, namely $CCi = 2E(i)/ (Ki (Ki-1))$. The clustering coefficient of the overall network is the average of clustering coefficients of all nodes. The average path length (PL) is the average of shortest path lengths between all nodes in the network, and the shortest path lengths means the minimum number of sides from one node to another.

As shown in Figure 2, due to the missing "intermediary", large and small size but isolated groups were formed in the network, and the network as a whole cannot be connected. Therefore, the biggest connected part (the biggest subgroup) is called as actual network, and its cluster coefficient and average path length (L) are calculated. Compare the actual network with the random networks of the same size, and analyze the small-world effect, as shown in Table 2. By comparing the actual networks and random networks in each stage, the features of small-world effect in three stages before 1999 were not obvious. However, the three stages from 2000, the features of small-world effect were rather obvious. The cluster coefficient of actual networks is significantly higher than random networks, and the average path length of actual networks is close to or slightly higher than random networks, the network's largest group of small world is obvious. From 1995, the biggest connected group in the network is the Petrochemical Industry Network which consists of China Petroleum & Chemical Co., Ltd and China National Offshore Oil Corporation. Its scale is continuously increasing. Information flow in this subgroup is efficient, which will be conducive to promote open innovation of the members.

Table 2. The clustering coefficient and average path length of actual networks and random networks.

		1985–1989	1990–1994	1995–1999	2000–2004	2005–2007	2008–2010
Actual Networks	Clustering coefficient	0.1053	0.0432	0.1792	0.0248	0.1428	0.2888
	Average path length	1.8500	1.9440	2.2570	8.8735	3.8847	7.3578
Random Networks	Clustering coefficient	0.0732	0.0465	0.1005	0.0068	0.0332	0.0046
	Average path length	2.6857	3.8003	3.2171	5.1817	3.8126	5.3184

4. Conclusions and Suggestions

By analyzing the overall network structure and subgroups, there still exist some defects in the spontaneously formed cooperation network: Firstly, from 1985 to now, the distribution of network presents the overall dispersion and partial compactness. Moreover, the network density is very low. Cooperative enterprises in the network mostly belong to a same technical field or a same industry, and the boundaries of technology or industry have not been broken yet. Therefore, because of a lack of intermediaries (the bridges) between each group in the network, the isolated parts are formed. However, the ideal network structure includes some small groups with high internal density, and there are certain intermediaries (the bridges) between each small group. Secondly, the groups present the star-shaped distribution with low density of strong tie of the internal. Thirdly, the number of large-scale groups is relatively small. The stable groups include Sinopec Corp, Haier Group, Shenzhen HaiChuan industrial co., LTD, and Hon Hai precision Industry Co., Ltd, but the duration of the other groups in the network is rather short. Fourthly, in 2010, 3733 enterprises took part in the patent cooperation which belongs to a kind of open innovation. The number of enterprises is very few, and the subjects of open innovation mainly the large enterprises and groups, especially the core nodes of groups. Other enterprises did not fully participate in open innovation.

The existing defects in network limit the information acquisition of open innovation in the technology and business scope of enterprise. In order to make full use of the network platform to improve the performance of open innovation, this paper proposes suggestions for the government and enterprises, as explained below:

Firstly, enterprises should take full advantage of the network platform to promote open innovation. When choosing partners, enterprises can observe network characteristics of the possible cooperative technology fields to choose the partner with the best information and technology advantages, in order to improve the innovation capability. Enterprises can make full use of resources in the network to get more creative information and other business information, in order to inspire the creative ideas. In the process of cooperation, enterprises should constantly adjust the strategies and observe the dynamic development of networks to turn into important nodes in the network, in order to enhance the enterprise the innovation speed and performance. The analysis targets of this paper are the networks in mainland China, and enterprises can conduct similar analysis of the industries involved according to the actual needs, in order to provide some clues for innovation.

Secondly, currently the proportion of patent cooperation in the total patents as well as the number of enterprise participating in is small. The government should propose some favorable policies to encourage more and more enterprises to join in and to transform the competition ideas and creative thoughts. In the field of technological innovation, many enterprises take the patent competition with competitor and try to conduct monopoly to obtain high profits which are produced by innovation. Therefore, the enterprises choose the partnership in a narrow scope. However, the open innovation network will potentially affect the competition views and innovation ideas. On one hand, cooperative relationship in intensive networks even can change the competition views of participants: in an intensive network, an enterprise or organization must adapt to a novel idea that exclusive technological assets to get profits will not be needed in the network because every competitor could be partner. On the other hand, more external cooperation in the network will promote enterprises to conduct technological and managerial innovation early to adapt to the development of the network. Therefore, every successful enterprise tries to turn into the core of the cooperation network, and to explore the cooperation of multi organizations and multi fields to inspire innovation. Cooperation and competition with experienced organizations will improve the efficiency of learning and innovation [23].

Thirdly, the government should take some regulation measures to improve the open innovation network. First of all, the government should guide responding subgroups to form local core nodes with more connection, to change the star shaped distribution with only one core node, and to reduce the limitation of the original core nodes for network innovation. Then, the government should guide or make policies to support the innovation direction of these core nodes, in order to spread information quickly and to allow technological innovation of core nodes to get extensive transmission in the internal and even the external. Finally, the government should guide or support the enterprises to become the bridges (intermediaries). In particular, several big groups mainly conduct cooperation in the industry, so that the dispersed structure gets improved. Accessibility of information will be significantly improved to enable novel and non-redundant knowledge to be performed fully. When choosing the intermediaries to cultivate, the government should combine national science and technology development planning to choose enterprises with original innovation ability, interdisciplinarity ability, and technological integration ability. Open innovation will be the mainstream of technology development and commercialization in the future. The government should pay more attention to the construction of open innovation network. The larger the network size is, the greater the structure becomes perfect, and more smoothly the information flow will be. In that way, the ideas and thoughts will increase more and more, enterprise innovation will constantly break through the boundaries of organizations and technology, and overall innovation performance in the network will be improved.

The limitations of this work are that the evolution dynamics of the patent network in China has been investigated but the forecasting of the patent network evolution is not discussed. Future research could investigate the forecasting of the patent network evolution.

Acknowledgment

The research work was supported by National Natural Science Foundation of China under Grant No. 71072033 and the Philosophy and Social Sciences Planning Project in Zhejiang Province under Grant No. 12JCGL25.

Conflicts of Interest

The authors declare no conflict of interest.

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