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專利佈局之研究：網絡模型的新觀點

Patent Deployment Based on A Network Perspective

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摘要：專利屬於企業研發投入中較易被量化的一種知識產出，利用專利分析可以評估公司無形資產的價值。近年來許多專利分析大都偏向專利指標的衡量。有別於以往的研究，本研究嘗試利用社會網絡的概念與小世界網絡模型，針對 TFT-LCD 產業專利引用網絡進行分析。結果顯示，專利引用網絡為小世界網絡，其小世界網絡特性十分顯著。另外本研究從專利被引用、專利引用他人專利、專利總連結數三方觀察，發現不論何種型態的連結次數分布均呈現冪次分配的型態；若從專利引用次數的成長趨勢來看，我們也可以看出專利的引用具有偏好，也就是說某些專利對於產業技術而言是發展的主流。最後我們針對具有高中介性的專利也就是專利引用網絡中的弱連結做測試，發現 63.75%的專利引用行為都與中介性高的專利有關，當我們去掉這些專利之後會有 50.6%的專利知識得不到交流。

關鍵詞：小世界網絡；弱連結；專利引用；中介性

Abstract: The patent is an indicator of research and development output that can be quantitatively analyzed. A patent analysis can be utilized to evaluate the value of a firm's intangible assets. Up to now, patent-index methods have been widely adopted by various researchers for patent-related analyses. Unlike those, this

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study attempts to use the social network concept and small-world network behavior to analyze the TFT-LCD patent citation networks. The study shows that the patent citation network can be fully characterized by using the small-world model. We also analyze the number of upstream and downstream citations and discover that the number of patent citations is distributed according to the power law. When investigating patent citation growth, we also notice that patent citations are highly selective. In other words, only a few patents represent the mainstream of industry development. Finally, we validate the importance of patents with high betweenness centrality and discover that 63.75% of patent citations are closely related to them. When the patents with high betweenness centrality are removed from the citation network, 50.6% of patent technical information ceases to flow.

Keywords: Small-world networks; Weak ties; Patent citation; Betweenness centrality

1. Introduction

Since the rise of the knowledge-based economy, knowledge has become an asset that businesses desire to develop and protect. The patent is an indicator of research and development output that may be quantified. Alok et al. (1993) pointed out that a patent is a very useful tool for tracking the information exchange between enterprises and their environments. By analyzing patents, we can understand the direction of the knowledge flow and where they are originated from. Therefore, not only do we know how the enterprise uses the patent's technology as a strategic weapon, but we also have visible evidence of how information is diffused, and we can discover the existence of primary or key technologies.

According to statistics by Taiwan's Executive Yuan, 5938 patents were approved by the United States in 2004, and more than the 5928 cases in 2003, ranking Taiwan as the fourth country in the world for approved patents. Taiwan's enterprises have been very proud of the number of patents that they own. However, although the number of Taiwan's patents continues to increase, the amount in royalties that local companies pay to foreigners has not decreased either. In fact, there is a seemingly endless stream of patent lawsuits, indicating that the quality of Taiwan's patents still needs to be improved. On the other hand, according to Moshinsky (2005), 73% of American enterprises worry that, in the coming three years, low-quality patents will cause the cost of patent lawsuits to be even higher than they currently are. Jeffery Hawley, President of the Intellectual Property Owners Association (IPO), also believes that high-quality patents are the key element to lowering patent lawsuits. Therefore, owning patents does not necessarily give an enterprise an advantage. Only owning key and high-quality patents can unleash the advantageous effects of patent deployment.

In order to analyze the patent quality, most researchers choose a certain patent indices as the measurement. Although these patent indices may represent the "innovative productivity outcome" in a more quantitative manner, there exist certain limitations. Many indices are merely used to measure the overall performance of all patents. For example, the total number of patents is quoted as a means of numerical analysis, but with regard to measuring the performance of a particular patent, extremely few good indices actually exist.

Up to now, research on the impact of social networks on patent citations has been limited. The small-world network concept has not been utilized to analyze patents in the literature either. Yoon and Park (2004) and Han and Park (2006) separately used social networks to measure the degree of centrality, and the density of index to measure the inter-connectivity of patents. However, they did not profile the actual features of the patent citations. For example, are patent citations similar to research paper citations? Although Wartburg et al (2005) used the concept of social networks to analyze the multi-stage patent citations networks, his study was limited to only the network locations, and did not have the exact index to mark the individual patent performance, e.g., exactly which patent actually had most influence on the capacity for information exchange within the patent networks. In other words, in the above literature, although the researchers used partial social networks, or methods to analyze patent deployment, they do not focus on the application of social networks to analyze the patent deployment.

In order to compensate for the aforementioned deficiencies, our research is based on a more thorough network point of view to understand the patents' technical position and the extent of their influence. Enterprises can re-examine its patent deployment strategy by analyzing the existing patent citation networks. Thinking of patent deployment from the intellectual property perspective is an important strategic consideration in the commercialization of technology. Besides being able to ascertain a company's patent position, we can also compare and contrast the position based on previous development plans, thus providing new directions for future development. To have a more in-depth understanding of the properties of patent citations, and to investigate the network connections formed by mutual patent citations with the supplement of social network index to measure how individual patents relate to the patent knowledge flow, this research is based on Watts and Strogatz' (1998) "small-world" network and Barabási and Albert's proposed "scale-free" network model. We hope that, by means of emphasizing the network concepts in the research of patent citations, we may open a new direction in the study of patent deployment.

In order to verify the appropriateness of using network perspectives to evaluate patent quality, this research will focus on the liquid crystal display (LCD) industry as a case study of patent deployment. After the United States developed LCD technology in 1968, Japan's Sharp Company began to use it in digital watches and calculators in 1973, thus initiating their utilization in Asia's flourishing consumer electronics industry. Up to now, the global production of thin-film transistor (TFT) LCDs has been concentrated in Taiwan, Japan, and South Korea. The relationships among industries in these three countries have been simultaneously competitive and collaborative.

This paper contains seven sections. The first section is an introduction that describes the research background, motivations, and objectives. The second section discusses prior research on patent analysis, as well as the possible co-relation between patents and knowledge flow. The third section reviews articles relating to small-world phenomena and social network concepts. The fourth section describes the research design and methodology. The fifth section conducts a small-world phenomena analysis of the patent citations network and also investigates the impact of high betweenness centrality on patent knowledge flow. The sixth section concludes our research and discusses its implications for management research. Finally, the seventh section explains this research's constraints and potential future research directions.

2. Network Analysis and Information Flow

Rajeswari (1996) believed that patents can protect research outcomes and are an important indicator of R&D achievement. The patentees want to have exclusive rights until the patents expire. Mogee (1991) believed that patents represent public technical information which can be used to measure the national technological progress and set standards for future inventions. Therefore, one can derive useful technological status and intelligence from this information pool about industrial or national competitiveness. Narin and Noma (1987) pointed out that patent-related information is an "excellence index" to measure an enterprise's technological strength. Ashton and Sen (1988) proposed that patent related information can provide enterprises with unique information in determining their technical positions against competition and how they should manage their technology and product development. Ernst (2003) believed that patent-related information can help business executives to make decisions, and also allow investors to determine a company's future ability to compete.

In order to utilize the knowledge revealed by patent analyses more effectively and precisely, Liu and Shyu (1997) proposed that patent analysis helps the company to formulate the basis of policy for research and development. On the other hand, Abraham and Moira (2001) pointed out that patent analysis is an important method to assess the evolution direction of a specific technology. Gassler et al. (1996) used patent analysis to investigate the levels of mutual dependency among various industrial sectors in Austria.

Many other scholars also believe that patent analysis has a unique value. McGee (1991) pointed out that patent analysis results should have 1) analysis of competitors; 2) technological tracking and forecasting; 3) milestone developments; 4) analysis of national strategy; 5) the discovery of patent infringement and the value of patent infringement monitoring. Berkowitz (1993) proposed that patent information analysis has the following useful values: 1) recognition of invention; 2) recording of invention; 3) filing decision; 4) searches; 5) case strategy; 6) case drafting and revision; 7) foreign filing prosecution; 8) opposition; 9) maintenance; and 10) enforcement.

Related patent analysis has been conducted because industrial executives, national policymakers, and social scientists realize that development in science and technology has a significant effect on the ability of a country or company to grow and compete. Therefore, they increasingly emphasize patent studies (Garg & Padhi, 1998). Generally speaking, patent indices are measured by the quantity and quality of patents. The quantity of patents is usually analyzed by the number of patents approved and the number of applications filed. Patent "quality" is typically analyzed by the number of patent citations, the strength of its technology, the category of the patent, etc. Bernd et al. (2006) proposed that information disclosed by patent indices can be used to evaluate a company's patent strategy. Narin (1995) pointed out that patent indices are usually used to measure the level of industrial R&D efforts. As regarding policy, it can also be used to measure trans-regional R&D policy – for example, to compare regional policy in Europe, Japan, and the United States. It can be used as well to measure the industry's R&D from the points of view of enterprises.

A well-known American patent research organization, CHI Research, is using the following patent performance indices to guide stock investment: 1) number of patents; 2) patent growth percent and percent of company patents in area; 3) citations per patent; 4) current impact index (CII); 5) technology strength, TS); 6) technology cycle title time (TCT); and 7) science linkage (SL). Karki (1997) also developed the following common indices for patent citation analysis: 1) highly cited patents; 2) number of no-patent links (NPLs); 3) technical impact index (TII); 4) Current Impact Index (CII); 5) Technology Cycle Time (TCT); 6) Technology Strength (TS).

Patent analysis assesses citations among patents quantitatively and statistically. From the patent citation network, we may discover key patent technology and important technological groups. Through analysis comparing countries, companies, and different areas of technology and science, analysts can evaluate the patent quality of impact from patent-citation relationships. Therefore, Karki (1997) proposed that patent citation analysis can be applied to: 1) identification of leading technologies among technical activities; 2) measurement of country's patent citation performance; 3) drawing of a technology map; 4) gathering technology news and information; 5) links between scientific areas; and 6) measurement of foreign dependence.

Alok et al. (1993) believed that progress in industrial technology is accomplished by the invention and application of new technologies. Sources of technological innovation may come in part from a company's own technology as well as from external knowledge. Only by combining technologies from both sources can the industry produce a solid knowledge base. Enterprises will use these two sources of information because; 1) inside the enterprise, internal private knowledge is highly sensitive and easily lost; 2) industry must develop its technology very rapidly; and 3) there is a constant threat from external competition. Therefore, continuously examining where the knowledge flow comes from, and where it is going, is a way of assuring the enterprise's ability to compete. However, patents are instrumental in revealing an enterprise's knowledge flow. By using patents, we can understand the directions and sources of knowledge development (Alok et al., 1993). Jaffe et al. (2000) discovered that grouping patterns of patent citations can be used to represent the patent knowledge flows.

Currently, there are many research examples that utilize patent citation flow among industries and nations. Jaffe (1989) used patent citations to explore the influence of university patents and their scientific publications on industrial inventors. Besides, by using patent citation analysis we are also able to identify a wide range of knowledge research outflow. After Fung & Chow (2002) analyzed 244 patent citations from both industry and enterprises, they discovered that 80.7% of companies did not use sources from local industry. Albert and Adam (2003) used patent citation trends to prove that South Korea's inventors tended to use Japanese technology, while Taiwan's inventors used American and Japanese technologies, indirectly verifying where Korean and Taiwanese technology information comes from. By means of technology information analysis, Albert

(2004) proved that, with the establishment in Singapore of R&D departments of multinationals, access to the sources of knowledge has increased for Singaporean inventors. By using patent citations, Park et al. (2005) also found multi-industry trends of technology knowledge flow.

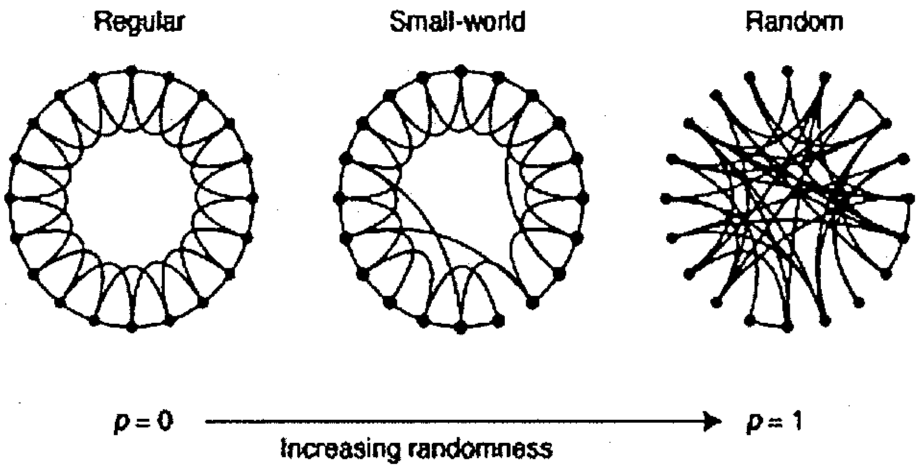
3. Small-World Networks Concepts and Research

3.1 Small-World Networks

Small-world networks were first observed and analyzed by the sociologist Stanley Milgram in 1967, who designed an experiment to explore the structure of a social network and its effects on information exchange. In his original research, he selected 296 stockbrokers in Boston and then asked them to transmit a message through their own social networks. When Milgram examined the transmission results, he discovered that, among all the messages sent to the stockbrokers, virtually all were connected by no more than six degrees of separation. Judging from these results, a socially networked world is much smaller than what we might expect. Although the small-world phenomena were already discovered in 1967, the causes of these networks, and the basis of mathematical models, were not developed until 1998. Watts and Strogatz (1998) first proposed one explanation of small-world network models, while Barabási & Albert (1999) proposed another small-world model from a different perspective.

The small-world network model proposed by Watts and Strogatz (1998) is an intermediate model between the regular and random network approaches. This is done by means of "rewiring" a regular ring lattice to transform a regular network to a randomly connected network, as shown Figure 1. The re-wiring is done by connecting each vertex with an edge, in accordance with different probability values p. When $p = 0$, this indicates that the re-wiring possibility of each edge is 0. As p is increased, the re-wiring probability of each edge in the network is also gradually increased. When $p = 1$, all the edges are re-wired, and a completely random network can be obtained. Between these two network graphs is a small-world network. This kind of network possesses a high cluster coefficient and low-path length characteristic.

Figure 1
Changes in Graph for Edge of Vertex Under Different Re-Wiring Probabilities. Data Source: Watts and Strogatz (1998)



Watts and Strogatz (1998) pointed out that, for the number of vertices N and the initial edge length of each vertex K, the clustering coefficient C and characteristic path length L will change with the value of p. Assuming $C(p)$ and $L(p)$ the clustering coefficient and the feature path length respectively, the values of which we will call. When $p = 0$ and under the conditions of the regular network, i.e., $C(0) \sim 3/4$ and $L(0) \sim N/2K >> 1$, the clustering coefficient and feature path length are at its maximum. When $p = 1$, under a completely random network, both the clustering coefficient and feature path length are at a minimum. In other words, when p is a member of (0, 1), there exists an area in which C and L are both either increasing or decreasing. However, according to the simulation by Watts and Strogatz, it was found that, when p is approximately equal to 0.1, the clustering coefficient in a network is about the same. However, the feature path length closely approximates that of a random network.

This kind of network model overturns modern people's concept of the network. Construction of the network is not completely random and haphazard.

As long as a few random elements are added to the regular network, we can greatly reduce the distance between each vertex but not destroy the feature of a high cluster. This network model happens to match the characteristics of networks with close links to modern-day networking phenomena.

Because of discoveries by Watts and Strogatz (1998), networks became widely studied. Many scholars used various networks as specimens to explore network characteristics. Kogut and Walker (2001) examined financial enterprises in Germany in 1993 and their owners. They found that, in the financial industry, all of their personnel's network connections have small-world networking characteristics. When the enterprises merged and re-organized, small-world networking characteristics remained. Bart & Geert (2004) analyzed the networking of chemical enterprises, the food industries, the electronic industry, and strategic alliances from 1980 to 1986. They discovered that these enterprises' networks also formed a "small-world" network. Joel et al. (2004) took the Canadian investment banking network as a research subject, and found that from 1952 to 1989, the investment banking network also continued to have small-world network characteristics: a minority of important banks possessed a great majority of the links.

Barabási and Albert (1999) proposed another kind of network model, different from the Watts-Strogatz model. This was the scale-free network model. They believed that the real-world network's distribution scale (i.e. the distribution of connection numbers) does not follow the Boltzmann-distribution nor the exponential-distribution but rather a power-law distribution. In such a distributed network, there is a minority of connecting nodes which has a large majority of the connections. A large majority of the connection nodes also has a small proportion of the connections. Because of this common phenomena, any node point in the network, and also other k nodes, has a connection probability $p(k)$ is proportional to $k^{-\gamma}$, where y has been proven to lie approximately within 2.1 and 4.

Barabási & Albert (2002) suggested that the scale-free network model was different from the Watts-Strogatz model in two ways. First, the Watts-Strogatz model assumes that the size of the network, which is the number of nodes N, remains as a constant under any rewiring possibility. Lawrence & Giles (1998) discovered that the number of Internet Web pages grows exponentially with time. Second, the Watts-Strogatz model assumes that when two nodes are connected, they are stochastically independent, but in fact they are not, because for any node with links, the possibility that they are connected to others increases. In reality, the nodes' interconnections have clear preference. For example, a new Web page is more oriented towards Web pages with lots of connections and traffic, and more citations. Often the new page will prefer to link to Web pages that are already well-known and have lots of links. Using a scale-free network with highly selective characteristics (or preferential attachment), Barabási & Albert (1999) calculated the possibility of a node point achieving a connection at different points in time. The probability of a network node achieving a new connection is proportional to its number of connections.

Therefore Barabási et al. (1999) studied the growth of scale-free networks with preferential attachment and described their two characteristics as follows: 1) in the initial growth of the network, there is a very small number of nodes designated by m_0. As time goes on, m ($m \leqq m_0$) existing nodes become connected. In the meantime, the number of nodes also increases. 2) The preferential attachment within the work of new nodes, i.e., the probability of connecting to other nodes, is determined by i, which posses a number of connections k_i as follows:

$$p(k_i) = k_i / \sum_j k_j \quad (1)$$

After time t, the whole network will have $t+m_0$ nodes, and mt connections, among which k_j represents the sum of connections of all node.

Many experiments have proved that some real networks possess scale-free network model characteristics. Redner (1998) demonstrated that document citations which comply with the power law: 47% of the documents were not cited, 80% of the documents were cited less than 10 times, and only 0.01% of the documents exceeded 1000 citations. Also, the older patents have a greater possibility of being cited. Liljeros et al. (2001) investigated 2810 adults between 18 to 74 years old who had sexual relationships in 1996. They discovered that the number of sexual partners also showed a power-law with distribution slope of 1.6

±0.3. Albert et al. (1999) studied the Internet, discovering within the network that a connection between any two documents on average would not exceed 19. No matter the connections between Web pages or the degree of connections between the pages, they all appear to obey the power law.

Based on the above, we conclude that the Watts-Strogatz model does not count for the proper characteristics of a growing network. Besides, within the network it also does not have many connected network nodes. To every node, their connection numbers are about equal. Therefore the Watts-Strogatz network model should be considered an "egalitarian" small-world network model, depending on several stochastically connected nodes which effectively shorten the distance between two nodes within the network. Compared with the Watts-Strogatz model, the scale-free network model accounts for network growth and preferential attachment characteristics, resulting in a small number of network nodes having the majority of the connections. Because of the existence of distributed points, we can always find a shorter distance between any two points in the network. Therefore, we can classify the scale-free network model as an "aristocratic" small-world network.

3.2 Social Networks

Granovetter (1973) presented the "The Strength of Weak Ties" theory. He believed that between every individual, there exists a connection. He had connections classified as one of two types: either strong ties or weak ties. Strong ties generally mean the ties within a group: e.g., relationships among relatives and family, among colleagues, and among task assignments. Such relationships form among individuals who know each other and have strong emotional attachments, and therefore interaction within the group is plentiful and rapid, and information exchange is highly redundant. Based on these reasons, if we remove one link from a group with strong ties, we will not impede interactions within the group.

Weak ties, on the other hand, address relationships between groups. This is a frequently observed relationship with low emotional involvement, and there is no particular conflict of interest. One example might be casual greetings between strangers or unfamiliar neighbors who nod heads at one another in acknowledgment. This type of connection has a profound effect on inter-group information exchange, although it usually is not an important means of communication. However, when this communication is disconnected, it can only result in the entire network breaking up. Therefore, we can conclude that weak ties sustain the integrity of the network and play a crucial role.

In many real-life case studies, it has been verified that weak ties play a crucial role in a real-life network world. Levin (2004) proved that knowledge transmitted through weak ties is not redundant. In other words, all knowledge through weak ties is necessary. Granovetter (1973) found that, among newly hired workers, only 16.7% of workers obtained their jobs through people whom they met frequently. However, 55.6% and 27.8% of people found their jobs through occasional and scarcely encountered people, respectively. Constant et al. (1996) discovered that weak ties through the Internet provide a useful technology to provide solutions to those who are seeking help, regardless of whether they have private connections.

Burt (1992) extended Granovetter's "Strength of Weak Ties" concept to create the "structural holes" theory. This theory addresses two groups which lack connections, thus constituting a "hole" within the network. Burt (1992) believed that enterprises favor using the network as a source of information, and attempt to fill the structural holes between two networks in order to gain resources and benefits. In other words, enterprises in the process of choosing new business partners are apt to capably choose or look for the bridge that can fill the holes between themselves and other enterprises, but not to look for other enterprises which have similar characteristics. Bart & Geert (2004) proved that, when industries are looking for their business partners, they favor enterprises that are a bridge between themselves and others. Such a bridge results in an industrial alliance network which has "small-world" networking characteristics.

If a business can become a bridge between two enterprises, then this enterprise will find a business opportunity between two networks and obtain a way to gain more profit than other competitors. Burt (1992) believed that the network which gives the richest business opportunities is a network which is plentiful in structural holes. If an enterprise is capable of generating a lot of structural holes within a network, and then becoming the bridge between the holes, the enterprise is able to become enormously profitable.

4. Research Design

4.1 Research Methodology

This research investigates patent deployment and a patent's position in the patent networks. The United States is currently the world's largest economy, and many countries are relatively interdependent with the U.S. economy. They therefore all prefer to apply for a patent in the U.S. to order to consolidate their position in the U.S. market. Therefore, this research manually collected the U.S.-approved and published patents of TFT-LCD companies in the U.S. Patent Office (USPTO) database. Using this as a starting point, it then "searched up" for patents that each patent cited and "searched down" for other patents that cited each particular patent. In all, this research analyzed 1298 patent cases approved between 1931 and 2005.

This research first aims to observe small-world characteristics of the patent networks. Watts and Strogatz (1998) calculated and emphasized the feature path length clustering coefficient and observed whether patent networks had small-world networking traits. From the small-world perspective, it is possible to understand the patent citation network, which may have a high clustering property. In actuality, only through a few patents can one transfer different technological information between different technology groups. Secondly, this report studies patent citation usage distribution patterns through indices of degree centrality, calculating the number of patents which this patent cited, the number of times this patent has been cited by others, and the combined number of these citations, in order to verify the edges connected by each vertex. According to Barabási & Albert (1999), the distribution of citations should be in a power-law relationship: a minority of patents have a majority of the connections, and a majority of the patents should have a minority of the connections.

Barabási & Albert (1999) pointed out the vertices in a network because of the priority attachment characteristics, the degree of linking of the vertices by edges, which should increase with time. Therefore it produces the scenario of the "rich getting richer". In order to investigate this kind of scenario, it has to be observed over a passage of time, in order for the changes to be evident. In order to examine this type of exhibited behavior, this research maps the development and progress of the cumulative number of patents being cited, in order to prove that patent citations possess a preference.

Additionally, this research sketches a map of the patent deployment network and searches within the network for the patent with higher betweenness centrality. Because the betweenness centrality is higher, it represents an increased ability to control the direction of the information exchange. We will therefore sketch the patent knowledge network flow. Then, we will connect all of the patents among the patent knowledge network to calculate the proportion of patent knowledge flow within the patent knowledge network. Finally, we examine, after the removal of patents with high betweenness centrality, the effects of this on the patent citation network, in order to judge the importance and contribution of patents with high betweenness centrality on patent information flow.

4.2 Definition of Terms

Characteristic Path Length

The path length is defined as the minimum length between two nodes within a network. The characteristic path length L is defined within a network as the mean value of the minimum path length between two nodes, but the minimum path addresses the number of intermediate points which connect any two points.

Clustering Coefficient

The simple definition of the clustering coefficient C is as follows: every node's neighbor is also the number of neighboring nodes of a particular node's neighbors. Neighbors to a particular node are also neighbors to each other. Let us say that every node has k edges, every k edge is connected between n nodes, and the maximum number of connections equals $n(n-1)/2$. The clustering coefficient is the number of actual existing connections, divided by the maximum possible number of connections. For example: within a network, assume that every node is connected with another 10 nodes. In principle, these 10 nodes will have 10*(10-1)/2 = 45 connecting edges. But in reality, on average, for every 3 nodes, there are only two connecting edges. This clustering coefficient is therefore 2/3.

Patent Citation Growth Trend

This research uses three-dimensional graphics to demonstrate patent citation growth. Among them, the Z-axis is the accumulative number of citations. The X-axis is the year the patent was cited, and the Y-axis is the representative code of the patent cited. For example, the representative code of US 1827530 Patent Registration Number US 1827530 is 1. The representative code of US 2904995 Patent Registration Number is 2, and so on sequentially, according to the year of the patent. The earliest patent has the highest representative code. Finally, we partition the years between 1981 and 2005 into 5-five intervals to observation and analyze the change in the number of citations during these periods.

Betweenness Centrality

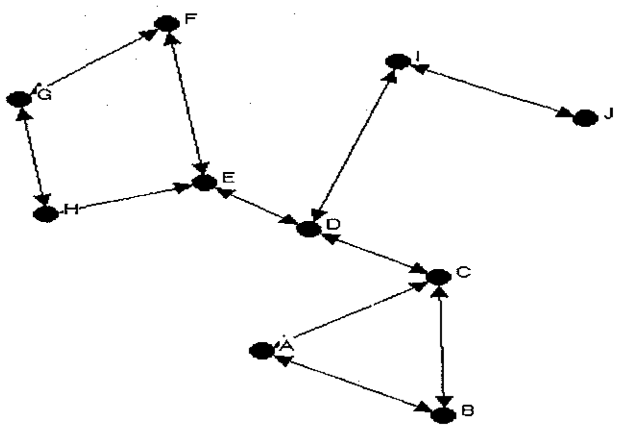
Betweenness centrality is a way of measuring the capability index of a particular node within the network to transfer data between two information groups. Freeman (1978) pointed out that this index is effective in measuring how capable a node point is in controlling information transfer. If in two network groups, there is only one common node, when this node ceases to function or is incapable of transmitting information further, there is no way for the two groups to have any further information exchange. The entire network becomes like a big network hole. In case any node within the network can be connected with other nodes within the network, it can be a weak connection within the group. In Figure 2, Point D is a transmitting bridge possessing abundant information as well as opportunities to transmit information.

Measuring the betweenness centrality of a particular node within the network can be derived using the following formula by Stanley & Katherine (1994)：

$$C_B(n_i) = \sum_{j<k} g_{jk}(n_i)/g_{jk} \tag{2}$$

In this formula, g_{jk} represents the geodesic path from node j to node k. Equivalently, it is the path from j to k that passes through the minimum number of nodes. The term $g_{jk}(n_i)$ is the minimum number of nodes from all the nodes to j and k that pass through i, of which n_i represents a node i within the network. The term g_{jk}(D) represents any connection between (j,k) that passes through D in Figure 2, where g represents the total number of nodes in the network. The purpose of the formula is to calculate the ratio of the minimum number of nodes between any two points passing through the node i divided by the total number of points. Taking Figure 2 as an example, there are two geodesic paths from Point G to Point D, one path through (G, F, E, D) and another path through (G, H, E, D). If we would like to calculate the betweenness centrality C_B(H) of node point H, using the total number of geodesic paths as the denominator, and the minimum number of node paths as the numerator, the betweenness centrality of the H node in the aforementioned example is 1/2.

Figure 2
Betweenness Centrality in A Network



Here we have the standard formula used for non-directional networks:

$$C'_B(n_i) = \frac{2C_B(n_i)}{[(g-1)(g-2)]} \tag{3}$$

This is the standard formula used for directional networks:

$$C'_B(n_i) = \frac{C_B(n_i)}{[(g-1)(g-2)]} \tag{4}$$

To evaluate betweenness centrality, we can use the following formula:

$$C_B = \frac{2\sum_{i=1}^{g}[C_B(n^*)\text{-}C_B(n_i)]}{[(g-1)^2(g-2)]} \tag{5}$$

Degree Centrality

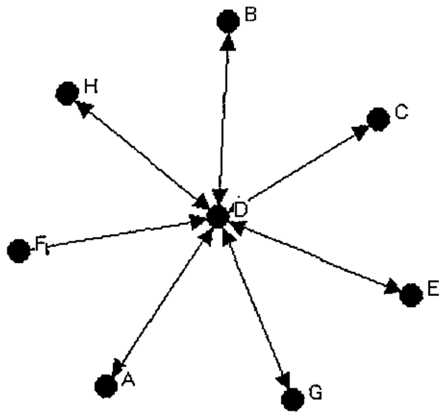
Degree centrality is the most commonly used index to measure which individuals in a group are the most primary central figures. To put it more simply, the degree centrality is the number of connections possessed by each individual node within the network – the larger the network, the greater the number of connections. In a society, the person who has the most prestige usually possesses the most power. As shown in Figure 3, Node D is the most influential in the network group, and thus has the highest degree centrality.

We calculate the degree centrality by using the following formula:

$$C_D(n_i) = d(n_i) = \sum_j X_{ij} = \sum_j X_{ji} \tag{6}$$

$$C'_D(n_i) = \frac{d(n_i)}{g-1} \tag{7}$$

Figure 3
The "Degree Centrality" of A Network



In this formula, the term X_{ij} represents a particular node i that has connectivity with j, while X_{ji} represents whether a node j has connectivity with i. If the network is non-directional, then the connectivity must be mutually recognized by both nodes. The term g represents the total number of nodes in a network. If X_{ij} equals 1, it means that the nodes i and j in the network are mutually related. If X_{ij} equals 0, then they are unrelated.

$$C_D = \frac{\sum_{i=1}^{g}[C_D(n^*)-C_D(n_i)]}{\max\sum_{i=1}^{g}[C_D(n^*)-C_D(n_i)]} \tag{8}$$

The aforementioned formula represents "group degree centrality". This formula is used to measure the difference between the degree centrality of the highest node point and others. If the degree centrality of the highest node is significantly higher than the others, then the group degree centrality is higher. This also indicates that the network's connectivity is extremely centralized.

If the network is non-directional, then its group centrality will be as follows:

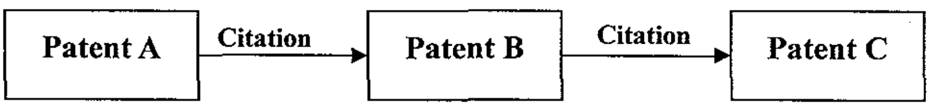
$$C_D = \frac{\sum_{i=1}^{g}[C_D(n^*)-C_D(n_i)]}{[(g-1)(g-2)]} \tag{9}$$

Nieminen (1973) pointed out that degree centrality in the network equals the total number of connections for an individual node. Therefore, we apply such concepts to the patent citation network, making the number of mutual citations equal to the number of total connections. A higher citation number represents a higher connection number. In small-world networks, the degree of connectivity is usually used to depict a particular node point's total number of connections (possessed by a particular node point). Therefore, a higher degree centrality also represents a higher degree of connectivity.

Patent Knowledge Movement

Patent citations are a good representation of the patent knowledge flow. In order to identify all related citation behavior, this research examines all the patents that were cited, and pairs them with their citations one-by-one. For instance, using Patent A as the starting point to find the patent that has cited Patent A, we arrive at Figure 4's patent B. We then use Patent B as the starting point to find Patent C, which has cited Patent B. In this way, we can continue until there are no more patents left. In case, within the patent knowledge flow, there is a certain patent that has a high betweenness centrality, we assume that this patent has taken advantage of its high betweenness centrality to transmit knowledge. In Figure 4, the arrows convey the direction of movement. Therefore we find that, if among patents, once this citation behavior exists, it indicates that two patents are connected, regardless of the direction of the arrows.

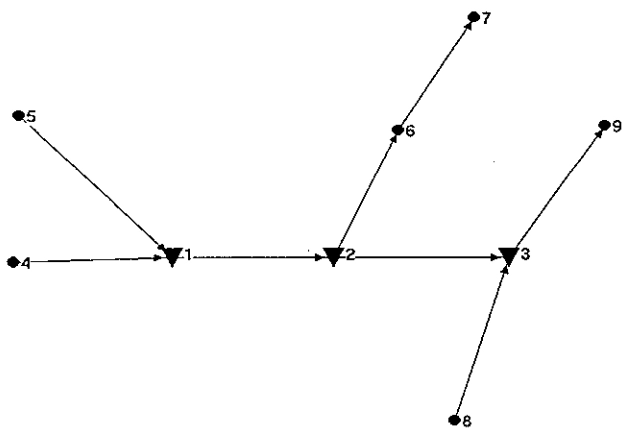
Figure 4
The Patent Citation Behavior



Patent Knowledge Direction Network

Since a high-betweenness centrality patent has a superior ability to convey the information, the majority of the patent citation network's knowledge would pass through such patents. This research therefore selects patents with high betweenness centrality and uses their relationships as the primary conduit in the patent knowledge flow network. As shown in Figure 5, inverted triangles show patents with high betweenness centrality, while circles are ordinary patents. If one wants to transmit the knowledge of Patent 4 to Patent 9, we believe that the intended network provides the necessary knowledge flow effectively.

Figure 5
Patent Knowledge Flow Network



5. Information Analysis and Results

5.1 Watts-Strogatz Network Model

This research follows definitions of Watts and Strogatz's characteristic path-lengths (1998) and clustering coefficients to calculate these parameters, and then uses Kogut & Walker's proposed small-world performance index (2001) SW $=(C_{Actual}/ C_{Random})/ (L_{Actual}/ L_{Random})$, in order to measure its small-world properties. When SW >> 1, network links actually forms the small-world network. Lastly, we use these results and compare them with those of Watts & Strogatz (1998) for the power grid network, the movie actors' network, and the C. elegans network, as shown in Table 1.

Table 1

SW in Different Kinds of Networks

Network Pattern	C_{Actual}/ C_{Random}	L_{Actual}/ L_{Random}	SW
Film Actor Network	2925.93	1.22	2396.90
Power Grid Network	16.00	1.51	10.61
C. elegans Network	5.60	1.18	4.75
Patent Citation Network	58.06	0.077	754.02

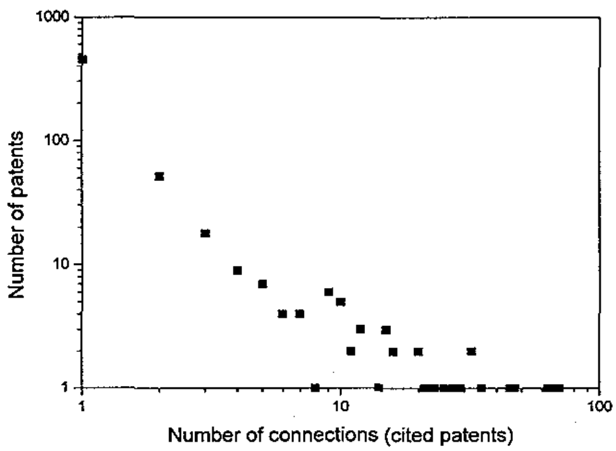
Data Source: Kogut, B (2001); This Research

Based on the results in Table 1, we find patent citation networks to be similar to the movie actors' network, the power grid network, and the C. elegans network. Not only do they possess small-world characteristics, they are excellent examples of a small-world network. This also indicates that this patent network flow expedites the communication through a short path, which reduces the patent knowledge diffusion time.

5.2 Scale-Free Network Model Analysis

First, this research uses the number of times a patent is cited as the degree of connectivity to depict its distribution, as shown in Figure 6. From the following graph, patents that are cited show a power-law distribution trend, meaning that the number of patents with higher connectivity is much lower than the number of patents with lower connectivity. In fact, according to this research study, there is only one patent with such a high degree of connectivity, possessing as many as 70 links. By the same analogy, there are 10 or more connected patents that have been cited 10 times or more, representing 5.5% of total cited patents. Patents cited only once or twice comprise 95.4% of all patents which were cited. The number of patents being cited and their distribution clearly demonstrates the phenomena that only a small number of points has many connections, and a large number of points has only a small number of connections.

Figure 6
Distribution of Patents Cited



In Figure 7, we use the number of patents citing other patents as the degree connectivity to study its distribution. According to Figure 7, the distribution of patent citation numbers appears to again be in the form of a power-law distribution. In this distribution, patents that cite other patents a lot are significantly fewer than those that cite only a few patents. There is only one patent that cited 30 other patents, and only 2.5% of the patents cited more than 10 patents.

On the contrary, we observe that the number of patents that cited other patents less than 2 times comprised 88.3% of the overall patents. Based on such observation, we can infer that the TFT-LCD industry's technology is rapidly growing. Very few manufacturers who continue to utilize the technology incrementally evolved from the old technology. Each country's technical experts continue to develop novel methods to produce TFT-LCD technologies.

Figure 7

Number Distribution of the Degree of Citing other Patents

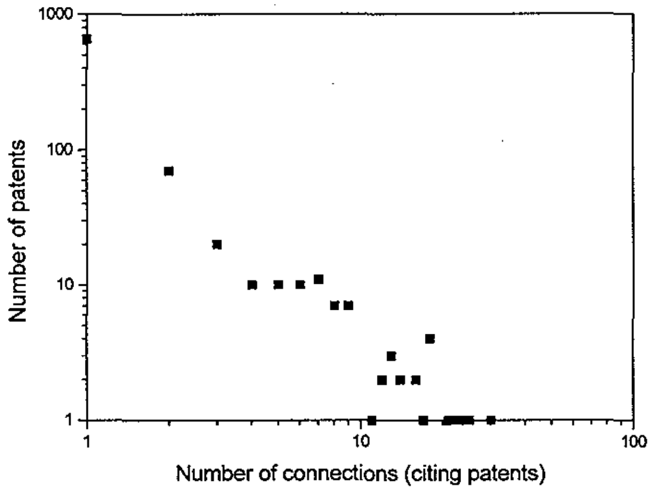
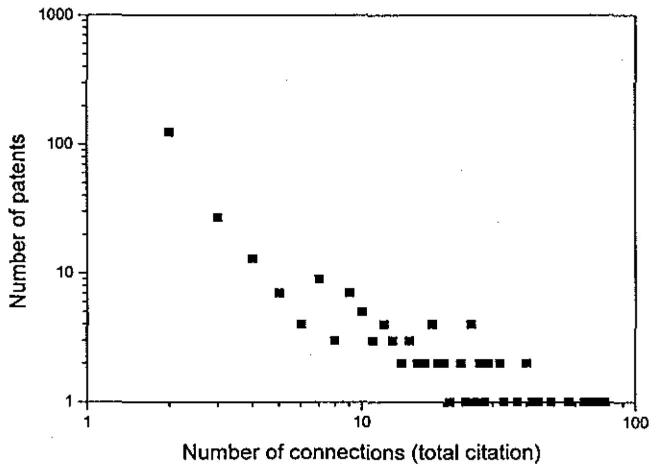


Figure 8

Total Degree of Connectivity Distribution



Finally, this research uses the total number of patents cited by others, and the total number of patents citing other patents, as the degree of connectivity to plot Figure 8. The Figure 8 shows that the degree of connectivity is distributed according to the power-law as well. It statistically concludes that the patent with the highest degree of connectivity has 77 connections. In the same way, we calculate that only 4.6% of the total number of patents has a degree of connectivity greater than or equal to 10. We once again confirm the phenomenon that only very few patents have a high number of connections.

5.3 Patent Citation Growth Trend Analysis

In this section, we analyze the growth trend of patent citations. This research divides the overall patent citation period into 5 different time periods. From the figure, we can find the growth trend in each time period and its relationship to growth trends in other periods. Finally, we use the figure to find out the profile of the patent citation trend over time, as shown in Figure 9.

1981-1985

During the period from 1981-1985, the number of patent citations was scarce, and only a few earlier patents were cited.

1986-1990

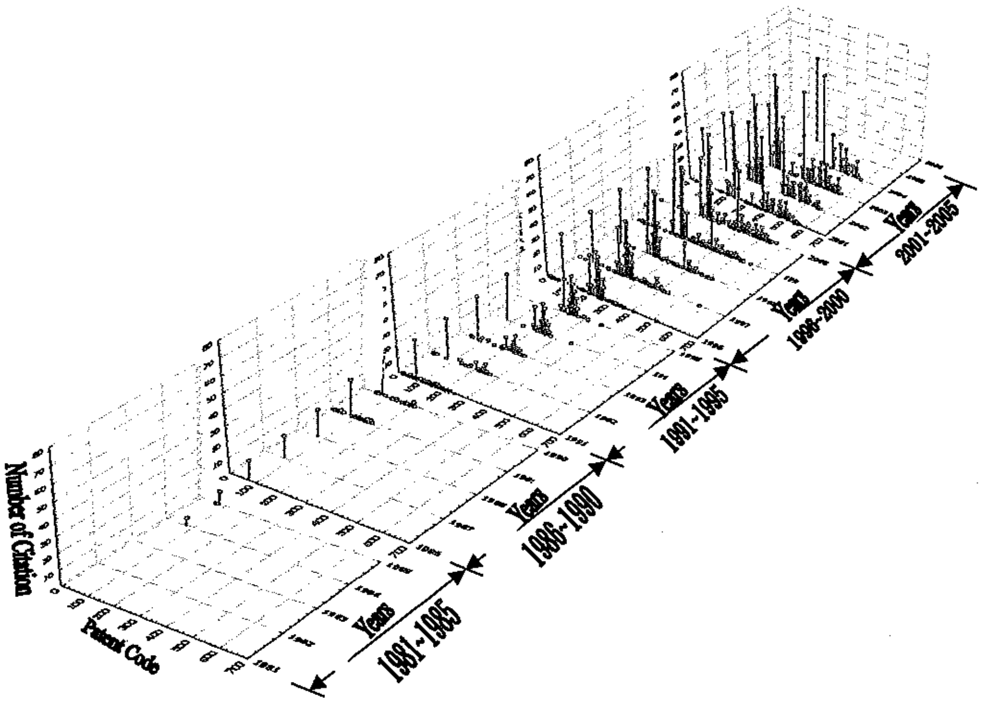
During the period from 1986-1990, the number of citations increased from 10 to 30 among those patents which had already been cited in previous period. For other patents that started to be cited in 1989, since they were newcomers, their number of citations is significantly fewer than that of older patents.

1991-1995

During the period from 1991-1995, it can be very clearly seen that in 1991, the number of citations further increased. This indicates that the impact of those patents which were cited previously has started to show. Nevertheless, the number of their citations is typically not high. Patents which were frequently cited in previous periods continue to be cited, but the average number of citations has reached a plateau.

From 1992-1995, we observe that additional influential patents were generated. Overall, the number of times that patents were cited increases significantly as a function of time. Based on this, we can conclude which patents possess a higher impact on this particular industrial technology. Those patents served as the "gatekeeper" for the technological entry-threshold. Many new patents had to borrow ideas from or benchmark themselves to those highly influential old patents.

Figure 9
The Patent Citation Growth Trend Relationships (1981-2005)



1996-2000

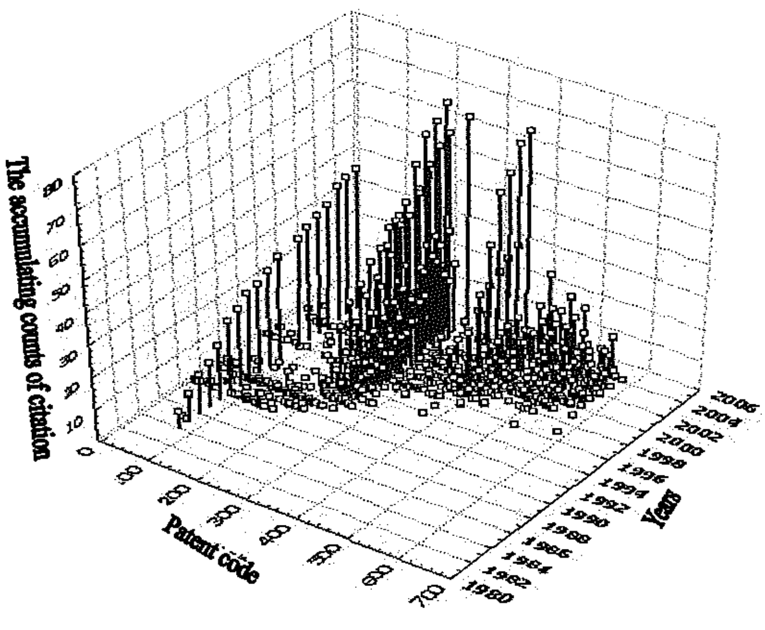
From 1996-2000, many patents gradually generated their impact. Both older and newer patents were cited by others. It was because the TFT-LCD industry expanded rapidly during this period that even less popular patents were cited occasionally. The fierce industrial competition due to the addition of Taiwan and South Korea into the competition had motivated the TFT-LCD technological advancement to gradually shape 3 primary technological trends as of 77, 200-260, and 380-385. These 3 groups of patents were essential in leading their respective areas.

2001-2005

During this period of 2001-2005, the citation numbers of those key patent technologies formed in the previous periods gradually slowed down. Nevertheless, those patents with superior technological potentials continued to grow, such as Patents 200-260, 380-400. Even during this final time period, we observe the growth in citing patents of 400-500, which shows their future growth potential.

Figure 10 shows the entire evolution profile of mutual patent citations during the period of 1985-2005. From the figure, we may identify the areas of those primary patents that were cited extensively. The primary areas of the cited patents are in areas of 70-80, 220-270, 375-390. In addition, patent citation number growth trends are also illustrated here.

Figure 10
Patent Citation Evolution from 1981-2005

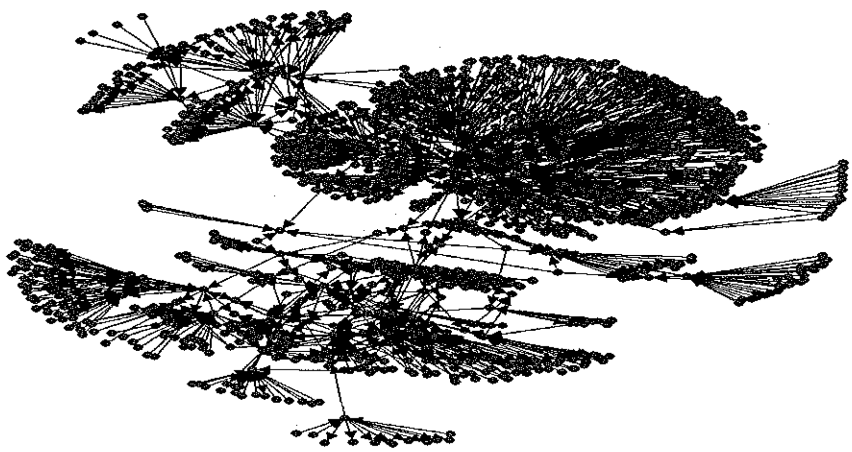


By analyzing each time period and its overall evolution, we can conclude that the well-cited patents have dominated the formation of the patent citation networks. We believe that the reason to have such high preferential attachment in the development of the TFT-LCD industry is because many critical technologies had been developed and patented to form a technology barrier which must be cited by later developed patents. This is the main reason why the key technical patents received so many citations. On the contrary, we also observe that many patents were scarcely cited. And even after many years, their citation numbers never increased. We believe that such patents cannot become critical patents which form technology barriers to other developers.

5.4 Network Diagram Analysis

As mentioned previously, this research uses patent mutual citation relationships to plot a network diagram. Figure 11 depicts the overall picture of a patent citations network. It includes patents that have been cited and that have cited other patents. We observe that the majority of citations focused on a few key patents. This indicates that patent citations or patents being cited are not randomly chosen. Every patent receives a different degree of attention.

Figure 11
Patent Citation Network



5.5 Analysis of Betweenness Centrality

The betweenness centrality indicates that within the network, information flow depends upon certain critical nodes. If, within the network, certain nodes have a higher betweenness centrality, this implies that this network relies on them to facilitate the information flow. From the perspective of the patent citation network, patents with high betweennness centrality are positioned at the focal point of the technical knowledge flow. Without such a patent in the citation network, it will be difficult to enable the technical knowledge exchange throughout the industry, which also prohibits the further technology development.

Therefore, we are conducting research to better understand the betweenness centrality in the patent citation networks. After careful analysis, we discover the patent citation network's overall betweenness centrality to be around 51%. Among them, 102 patents' betweenness centrality is greater than 0. Those patents with betweennness centrality greater than 0 have the capability to influence the technical knowledge flow in the patent citation networks.

There is a huge difference between those patents with the highest and the lowest betweenness centralities. These representative 102 patents make up a large proportion of all patents. It would be difficult to single out which patents actually have a greater impact. Therefore, this research accumulates the betweenness centralities of 102 patents to form the denominator, and uses each patent's betweenness centrality as the numerator. Then, according to Plato's rule, we add all the numerators of the betweenness centralities until they reach 80% of the total impact. This requires 24 patents and the results are shown in Table 2.

From this table, we can identify the structural holes formed by critical patents from Taiwan, the U.S., Japan, and Korea for technology flow within the citation networks. Those structure holes also represent weak ties for the technology flow. To those earlier patents, the top 24 patents have extended their influence by citing them. To those later patents which cited these 24 patents, they become the source of the most crucial technical knowledge.

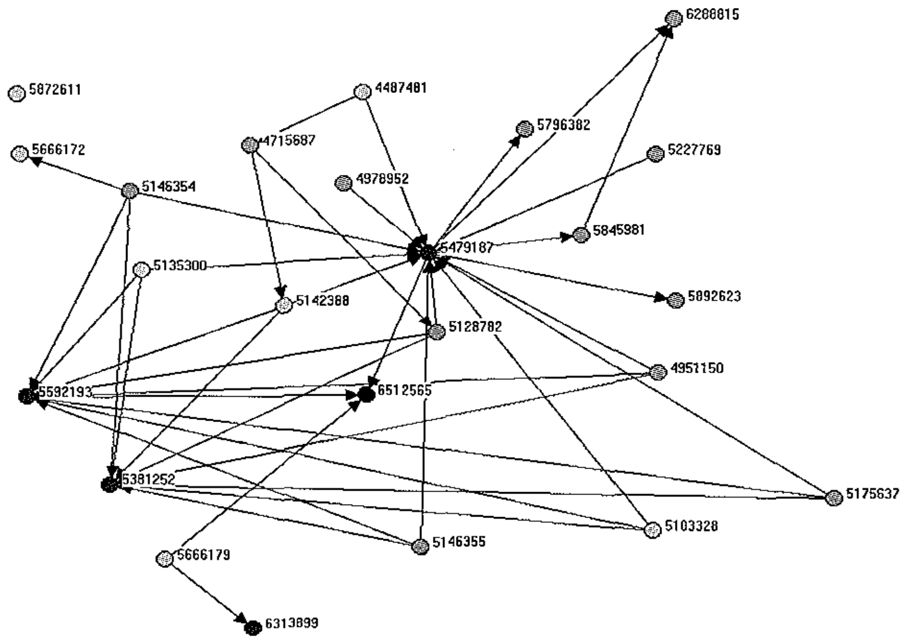
After identifying patents with higher betweenness centrality and removing the lower ones, we graph only those nodes with high betweenness centrality and name it as the patent knowledge flow networks, as shown in Figure 12.

Table 2
High Betweenness Centrality Patent List

Serial Number	U.S. Patent Number	Country of Patent	Company	Betweenness Centrality	Year
1	5479187	TW	Chunghawa Picture Tubes, Ltd.	8587.895	1995
2	5845981	US	Philips Electronics North America Corporation	3568.403	1997
3	4487481	JP	Epson Corporation	2431.633	1984
4	5142388	JP	Futaba Denshi Kogyo K.K	2057.306	1992
5	4978952	US	Collimated Displays Incorporated	1750.378	1990
6	5128782	US	(N/A)	1707.833	1992
7	6512565	KR	Hyundai Display Technology Inc.	1592.333	2003
8	5796382	US	International Business Machines Corporation	1513	1998
9	5227769	US	Westinghouse Electric Corp.	1274	1993
10	5146354	US	Compaq Computer Corporation	1225	1992
11	5135300	JP	Mitsubishi Denki Kabushiki Kaisha	1117.5	1992
12	5892623	US	Philips Electronics North America	1071	1999
13	6288815	US	Philips Electronics North America Corporation	1058.402	2001
14	6313899	TW	Chi Mei Electronics Corporation	930.85	2001
15	4951150	US	Foresight, Inc.	768.267	1990
16	4715687	US	International Business Machines Corporation	749.333	1987
17	5103328	JP	Sharp Kabushiki Kaisha	688	1992
18	5175637	US	Raychem Corporation	685.2	1992
19	5381252	TW	Chunghawa Picture Tubes, Ltd.	625.6	1995
20	5146355	US	Litton Systems Canada Limited	584.467	1992
21	5666172	JP	Kabushiki Kaisha Toshiba	564.5	1997
22	5872611	JP	Sharp Kabushiki Kaisha	520	1999
23	5666179	JP	Sanyo Electric Co., Ltd.	488.433	1997
24	5592193	TW	Chunghwa Picture Tubes, Ltd.	487.324	1997

Data Source: This Research

Figure 12
Patent Knowledge Flow Network



In this figure, Patent 6512565 is a Korean patent, Patents 5381252 、5479187 、5592193 and 6313899 are Taiwanese patents, and Patents 4487481 、5135300 、5142388 、5666172 、5666179 、5872611 are Japanese. The rest of the patents are American, except for the Japanese Patent No. 5872611. This Japanese patent does not connect to the patent knowledge flow network, which the rest of patents are all connected to.

This research further analyzes the effectiveness of knowledge flow through the patent knowledge flow networks. We discovered that among 1465 patents in the network, which consists of approximately 63.75% of the total, will pass through the network 934 times. In other words, among all the patent citations, there is 63.75% related to patents with high betweenness centrality. If these highly influential patents did not exist in the patent citation network, the patent knowledge flow network would be disconnected, resulting in a lot of patent knowledge not being able to prevail or to be further developed.

To further verify the relationship of high betweenness centrality patents versus the patent knowledge flow network, this research adds other patents which do not have high betweenness centrality, as shown in Figure13. After removing directly related patents from the patent knowledge flow network, only patents without high betweenness centrality remain. Only 49.4% of the patents remain connected, rendering 50.6% of the patent knowledge unable to propagate. The patents with connections that remain will have a broken network and disintegrate into 6 sections. As shown in Figure 14, the color of each section represents a different network group. We therefore can conclude, when we have removed the high betweenness-centrality patents from the network, that will make it difficult for much patent knowledge to further propagate, and also will postpone the development of later patents.

Figure 13

Patent Citation and Patent Knowledge Flow Relationship

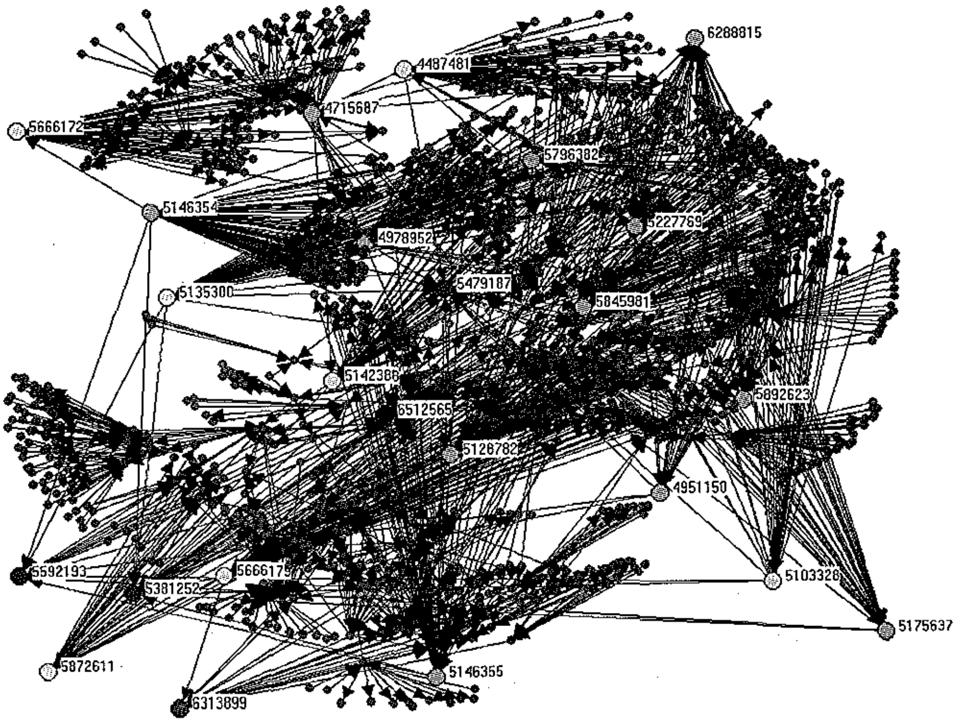
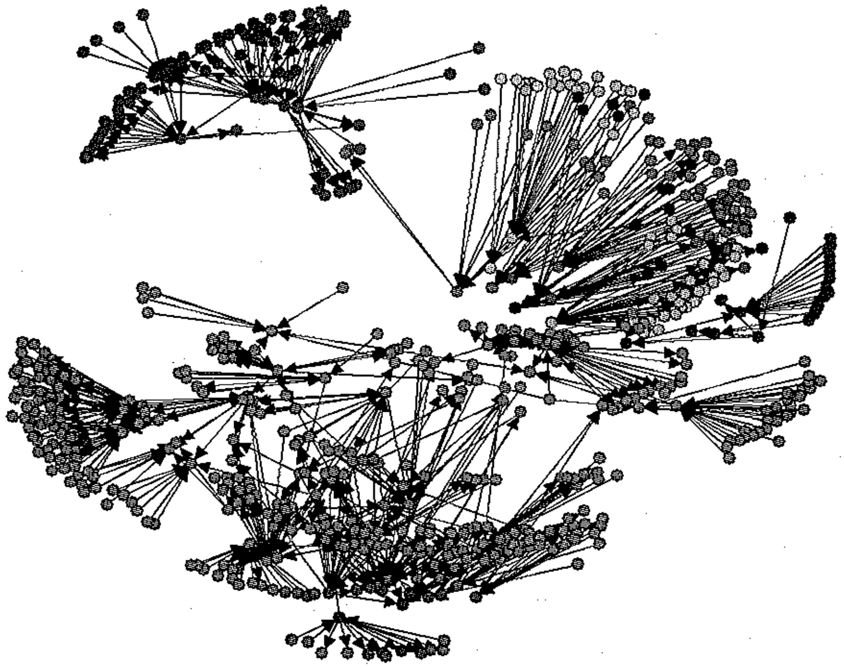


Figure 14
The Network With High Betweenness Centrality Nodes Removed



6. Conclusion and Implications for Management

Based on our analytical experiments conducted in the previous section, we summarize our research results from the perspectives of the small-world networks, patent citation growth trends and the degree of betweenness centrality:

Small-World Networks

Patent citation networks have the more distinct small-world network traits as other modern-day social networks. Even though patents tend to cite each other in their own technological category, the patent knowledge flow may still propagate via patens with effective geodesic paths. Business executives, therefore, must not only pay attention to technology development, but also be aware of those patents which offer geodesic paths in the overall patent deployment to search future technology development opportunities.

Scale-Free Networks

Based on the investigation of up- and down-stream patent citations and the total number of patent connections, we conclude that that the distribution of knowledge flow through patent networks follows the power-law. Unlike the previous normal and Boltzmann distributions, this distribution is unique in having a small number of nodes with a large number of connections, and a large number of nodes with a small number of connections. Because of such connections, we can identify the most highly cited patents, which have the highest technical quality and can make the greatest impact to businesses from the least effort.

Business must aim at developing patents with superior technological impact. Randomly filing patents has the effect of "sowing lots of seeds in a field to grow an army" and building a thick and high wall to protect businesses from IP infringements. However, if the patents are not of crucial value, enterprises will face costs of maintaining the patent rights that are higher than the actual royalties from the patent. Even though it is very difficult for us to judge the quality of a patent when it is being created, we can still estimate or judge, from the current patent networks, the possible influence of our patent on the patent network, compare it with the company's prior patent deployment, and find the differences made with the company's current internal development policy.

Patent Citation Growth Trends

Through observation and analysis of the patent citation numbers, we discover that some patents are selectively cited instead of being blindly cited. When a patent in the patent network is highly influential, then this patent has a high economic value. We know for sure that such superior patent technology would form the basis of industry infrastructure knowledge and also become the main source to stimulate further technological development. Business executives ought to implement the above principles to achieve goals for building the mainstream industrial standards and to develop such patent technologies to maximize their profitability.

Betweenness Centrality

Patents with high betweenness-centrality in a patent citation network have the major influence on patent knowledge flow. This type of patent technology can form a business knowledge transmission hub. A patent knowledge network, if it lacks these patents, will fall apart, and the propagation of knowledge will stop. This research discovers that 63.75% of patent citations are related to patents with high betweenness centrality. Without these patents, there would be breaks in the patent knowledge flow. When we eliminate these high betweenness centrality points in the network, only 49.4% of the patents are connected, and in addition they are poorly connected. The remaining 50.6% of patents are unrelated to other patents. In other words, there are 50.6% of patents that are unable to be connected.

7. Research Limitations and Suggestions for Further Research

Our primary research objective in this work is to develop a new method to analyze patent performance which is different from previous patent index measurement methods. By utilizing the existing network models, our proposed concepts and methods can be used regardless of the size of the sample space. In analyzing the network operations, we only need to identify the relationship between individual nodes, or between individual paths. Regardless of the size or number of links in the network, or of the time sequence in which the nodes appear, as long as the nodes are connected during a certain time interval, its status can be calculated to obtain the betweenness centrality and the degree of betweenness centrality.

Despite this research aims to establish a patent network that can be quantitatively analyzed, however, as the number of patent interrelationships can be large and complex, this research for ease of calculation only selects some nodes from representative Taiwanese patents to assess their upstream and downstream connections. In prior research work, there were also constraints imposed by the size of the sample space. For example, in Yoon and Park (2004), while analyzing high-tech patent growth trends, it was thought to be extremely challenging to analyze a large sample of patents. Future research may try to enlarge the patent search sample space in order to paint a more thorough picture of the patent citation network diagram. From our research which uses the patent network to discover which patents have greater impact and enable greater knowledge flow within the network, these patents can then be used as an example to guide further industrial research and development.

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