The Longitudinal Study of Highly-Impact-Technology Enterprises in the ICT Industry: A Social Network Perspective

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ABSTRACT

Patent citation can be viewed as an indicator for technical impact and technical invention. Highly cited patents represent the "prior art" of many issued patents and are likely to contain significant technological advances. Enterprises that produced these highly cited patents may influence industrial technological development. Because the technologically intensive industries require technology innovation to constantly adapt to the changing environment, any enterprises can disrupt the market and produce high impact technologies. This study aims to explore highly cited technologies in the ICT industry and uses social network analysis and knowledge-based characteristics to investigate the transitions of highly-impact-technology enterprises. The longitudinal analysis of technological leaders examines competitive tendency in specific fields to anchor the positions of the enterprises. This study proposes a different viewpoint to analyze highly-impact-technology enterprises based on social network perspective and knowledge-based characteristics.

Keywords: *Highly-Impact-Technology Enterprise, Information and Communication Technology Industry, Knowledge-Based Analysis, Longitudinal Study, Patent Citation Analysis Social Network Perspective*

INTRODUCTION

The information and communication technologies (abbreviated as ICT) industry is technology-intensive, attracting much attention globally for its constant unpredictability. Interest in ICT industrial networks emerged as companies in the industry have become more dependent on each other. Furthermore, the fragmented structure of the ICT industry resulted a wide scope of enterprises range from service providers to manufacturers of physical goods (Gabriels-

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son & Gabrielsson, 2004). Products such as software, mobile phones, IT systems and communication network providers all fall within the wider ICT industry. Given the dynamic nature of ICT technology network structure, it is essential to consider the transition of highly impact technologies. This study aims to examine whether there are significant differences in highly impact technologies in ICT industry. Enduring technology innovation is regarded as an important issue in the ICT industry, and the enterprises directing highly impact technologies might lead to greater influences on the industry for them. Therefore, understanding the development of the highly-impact-technology enterprises is critical.

Grant and Tan (2013) indicated that the capacity to operate the global network of relationships is useful to the extraordinary technological and process innovations. As business firms increasingly operate as part of highly distributed ecosystems, developing inter-organizational activities are expected to create greater efficiencies in the use of resources and increase profitability (Markus, Sia & Soh, 2012). Research on IT resource management through network arrangements has been prominent and plentiful, particularly conceptualizing inter-organizational IT relationships (Niederman, Alhorr, Park & Tolmie, 2012). Networks are institutions that feature goal-directed exchange of resources and activities for a specified set of outcomes. In the IT field, understanding the industrial network structure assists enterprises' developing the effective inter-organizational IT resource management which is essentially an intensive, collaborative, and often highly political process with strategic decision making (Lacity & Willcocks, 2008). Managers understanding how highly impact technology resource is distributed in the industrial network will enable them to clarify how resource management is being enacted in practice (Chong & Tan, 2012). Simultaneously, through observing the technological position of enterprises in the ICT network may provide more effective ways of managing IT resource that will deliver the results desired or better.

Highly impact technologies are of particular concern for technology-intensive industries. The World Intellectual Property Organization (WIPO) indicated that 90% to 95% of technological inventions can be found in patent, which serves as an important information source. Through patents, firms are granted exclusive rights to prevent or exclude other companies from making, using or selling their inventions. Firms conduct patent analysis to identify key technologies in which their technological portfolios and competitive landscapes built and assessed (Chen & Chang, 2010). Therefore, patent analysis can be employed to delineate the patterns of technological development and assess the competitive advantages of the firms in academic and practical intelligence.

Patent analysis has been widely used as an approach to technological management (Huang & Yang, 2013). Its advantage is that patent data is available for a rather long period and provides detailed technological information. Patent citation method has been proposed in the literature to measure the interrelation among innovations (Alcacer & Gittelman, 2004; Lo, 2010). Citation impact is an accepted measure of retrospective technological impact and can be viewed as an indicator for technical impact and technical invention. Additionally, highly cited patents have been linked to inventor awards and high-value inventions, representing the "prior art" of subsequently issued patents and are likely to contain significant technological advances. For example, Carpenter, Narin and Woolf (1981) found that patents related to IR 100 invention awards (now known as the annual 'R&D 100 Awards') are cited twice as often as typical patents. Therefore, the enterprises which master highly cited patents may have significant influences on industrial technology developments.

A number of researches have noted that patent citations trace out technological building relationship among inventions (Chang, Lai & Chang, 2009). The important featuring characteristic of patent for technology invention is their citations showing which former patents have been contributed to this patent and providing the context of technology accumulation. Patent citation has been widely used in bibliometric study to evaluate technology development and map technological trajectory. For instance, based on an analysis of scientific citations in patent documents, Acosta and Coronado (2003) investigated the links between science and technology to study the relationship between science and technological development in Spain. Hall, Jaffe and Trajtenberg (2005) suggested that of all patent related indicators, patent citation is a more adequate indicator to evaluate market value. In addition, patent citation analysis can be used to combine social network theory. Many studies have integrated patent citations and social networks. For example, Daim, Rueda, Martin and Gerdsri (2006) combined bibliometrics with patent analysis to classify semiconductor technology and to forecast emerging technologies. The results indicated that technology development can be observed or measured by patent citation, including direct and indirect citation. Recently, several studies also attempt to obtain technology development contexts by patent citation analysis (Chang et al., 2009). Thus, the purpose of this study is not only to use citation-based methods to investigate the highly-impact-technology enterprises development, but also employ constructed patent citation network to quantitatively analyze the enterprises' position in the ICT industry.

The leading roles of several patentees seem to be a law of nature and these patentees are regarded as leaders in the underlying field (Bas, Bouklia-Hassane & Cabagnols, 2010). The analytical unit of the leading roles could be at various levels, from individual to country. Ernst (1999) has identified key inventors as those with high patenting activity and high patent quality rating. Later, Pilkington, Lee, Chan, and Ramakrishna (2009) extended Ernst's approach to help to identify key enterprises which are considered to be highly productive firms and are also widely cited. This study attempts to further observe the network structure of highly-impact-technology enterprises in the ICT industry and answer our research question "What are the highly-impact-technology enterprises' positions in the ICT industrial network?" NodeXL software is employed for conducting the network analyses in the study.

The study utilizes the USPTO (United States Patent and Trademark Office) database to obtain the patent information of the ICT industry from 01/01/2000 to 12/31/2011. The highly cited patents are acquired by patent citation analysis. The study regards those enterprises that possessed these highly cited patents as the highly-impact-technology enterprises and attempts to explore the transition of the highly-impact-technology enterprises in the ICT industrial network. The study observed the transition of enterprises across three time periods: 2000-2003, 2004-2007 and 2008-2011. Furthermore, knowledge is the foundation of an enterprise's innovation. In order to understand the knowledge-based characteristics of these highly-impact-technology enterprises in the ICT industry, the study also explored the framework of Pilkington et al. (2009), which was proposed at a firm level. With the results of patent citation network analysis, the study presents the positions and knowledge-based characteristics of highly-impact-technology enterprises in ICT industry.

In spite of the various studies on patent citation analysis for technology development, it is insufficient to use highly cited patents and social network to conduct the longitudinal analysis from the enterprise perspective. Additionally, although prior studies have identified technology structures and made the projection of technological trends in ICT industry through the use of patent data (Lee, Kim & Park, 2009), few studies have investigated the technological position from the viewpoint of highly-impact-technology enterprise and unfolded the knowledge-based characteristics of these enterprises simultaneously. The study contributes to the literature by (1) longitudinally analysing the difference of highly impact technologies in ICT industry (2) observing the technological position of highly-impact-technology enterprises in the ICT industry, and (3) uncovering the knowledge-based characteristics of highly-impact-technology enterprises.

RESEARCH METHODOLOGY

The Information and Communication Technology (ICT) Industry

The ICT industry is characterized by its fast growth and change. Studies have shown that the industry contributed about an average of 0.5% to the world's total annual economic growth (Colecchia & Schreyer, 2002). Over the past two and a half decades, the ICT industry has experienced massive structural changes, including the breakup of AT&T, the PC revolution and the Internet revolution. These structural changes broadly resulted in a significant vertical disintegration and unbundling of innovation activity in the ICT industry. Besides, the ICT industry is typically highly international and the manufacturing processes are often outsourced globally. This outsourcing has led to the ICT industry having a fragmented structure. For example, no company produces all components of its products by itself; companies need to consider and depend on other companies' manufacturing, sales and R&D processes. The ICT industry relies heavily upon constant innovation of technology, research and development. The pressing schedule of innovation along with the need to go global explains why ICT companies tend to eagerly pursue advanced technology development.

In this research, the patent data of the ICT industry were selected based on the ICT patent classification suggested by Choi, Kim, and Park (2007). They classified the whole ICT industry into telecommunications, consumer electronics, computer/office machinery, and the other ICT sectors. They also suggested the IPC (International Patent Classification) classes for each sector. After matching the IPC classes with the USPC (United States Patent Classification) classes, the study selected 37 USPC classes as the target technology fields for analysis (Table 1). The selected technology fields include communication, computer, semiconductor, display and data processing. Detailed definitions and characteristics of the technology fields, classifications and names are based on the information of the USPTO.

In order to observe the evolution patterns among the highly impact technologies of ICT industry, we referenced the definition of USPC classification announced by United States Patent and Trademark Office and classified each of the 37 USPC code into hardware-related patents and software-related patents. The final concordance results are shown in Table2, which also used in the rest of analysis in the study.

Patent Citation Analysis

Patent citation analysis is a quantitative approach to the relationships between citing patents and cited patents. It is a statistical method for analysing, comparing, and classifying document citations, including number of citations, publication year of cited works and the relationships in and between works. Patent citation analysis is also based on the examination of citation links between different generations of patents (i.e. patents that are issued in different years). When a patent application is filed, its applicant(s) must prove that the invention is novel, useful, and non-obvious to someone with expertise in the same technology. To achieve this, the applicant(s) or examiner(s) cite(s) previously issued patents and research papers as prior art, and explains how the new patent improves on the earlier inventions.

Carpenter et al. (1981) indicated that patent citation counts are a good indicator for an invention's technological importance. Highly cited patents tend to be of both technological and economic importance. This study retrieved ICT-related patents based on three periods: 2000-2003, 2004-2007 and 2008-2011. The patent counts for each period were 157,647, 198,389 and 261,787 respectively (see Table 3). The study further selected the top 1% most cited patents as "highly cited patents" (Alcacer & Gittelman, 2004). The numbers of highly cited patents in each period were 1,537, 1,710 and 2,267, respectively. The citation thresholds in each period were 15, 13 and 11 respectively.

Table 1. USPC class and ICT-related patents

Class	Description
235	Registers
318	Electricity: motive power systems
340	Communications: electrical
341	Coded data generation or conversion
342	Communications: directive radio wave systems and devices
343	Communications: radio wave antennas
345	Computer graphics processing and selective visual display systems
348	Television
349	Liquid crystal cells, elements and systems
353	Optics: image projectors
361	Electricity: electrical systems and devices
365	Static information storage and retrieval
367	Communications, electrical: acoustic wave systems and devices
370	Multiplex communications
375	Pulse or digital communications
379	Telephonic communications
381	Electrical audio signal processing systems and devices
382	Image analysis
386	Television signal processing for dynamic recording or reproducing
438	Semiconductor device manufacturing: process
455	Telecommunications
505	Superconductor technology: apparatus, material, process
700	Data processing (DP): generic control systems or specific applications
701	Data processing (DP): vehicles, navigation, and relative location
705	Data processing (DP): financial, business practice, management, or cost/price determination
706	Data processing (DP): artificial intelligence
707	Data processing (DP): database and file management or data structures
708	Electrical computers (EC): arithmetic processing and calculating
710	Electrical computers and digital data processing systems (ECDDPS): input/output
711	Electrical computers and digital data processing systems (ECDDPS): memory
712	Electrical computers and digital data processing systems (ECDDPS): processing architectures and instruction processing
713	Electrical computers and digital data processing systems (ECDDPS): support
714	Error detection/ correction and fault detection/recovery
715	Data processing (DP): presentation processing of document, operator interface processing, and screen saver display processing
716	Data processing (DP): design and analysis of circuit or semiconductor mask
717	Data processing (DP): software development, installation, and management
719	Electrical computers and digital data processing systems (ECDDPS): inter-program communication or inter-process communication (IPC)

Table 2.Classification of USPC code

Classification	USPC Code
Hardware-related Patents	235, 318, 342, 343, 348, 349, 353, 361, 367, 370, 375, 379, 381, 386, 438, 455, 505
Software-related Patents	340, 341, 345, 365, 382, 700, 701, 705, 706, 707, 708, 710, 711, 712, 713, 714, 715, 716, 717, 719

Table 3. Citation threshold of highly cited patents

	2000-2003	2004-2007	2008-2011
Number of Patents	157,647	198,389	261,787
Number of Highly Cited Patents	1,537	1,710	2,267
Percentage	0.97%	0.86%	0.86%
Threshold of Citation	15	13	11

Social Network Analysis

The past decade has witnessed a new movement in the study of social networks, with the main focus transitioning from the analysis of small networks to those with thousands or millions of nodes, and with a renewed attention to the topology and dynamics of networks (Newman, 2001). This new approach has been strongly driven by improved computing technologies which are available to gather and analyse large-scale data. Such technologies make it possible to uncover the generic properties of social networks. The field of social network analysis has led to several software tools that facilitate analysis and interpretation of cooperation and citation data, explaining the relationships among technology fields, patent applicants, inventors. Social network analysis explores the relationships (“ties”, “arcs” or “edges”) of actors (“nodes” or “vertices”). Historically, the methodology of social network analysis was focused on the relationships among people. However, thanks to the algorithm from graph theory, nodes could be regarded as inventors, individual patents or assignees when the algorithm is applied to the content of patent or research literature. In the same vein, ties could symbolize cooperation or citation links.

Based on the direct citation matrix of patents’ assignees in the ICT industry, a social network is constructed to analyse the transition of highly-impact-technology enterprises. Social networks on the basis of social exchange can be used for understanding how social actors are positioned to influence resource exchange, and which resource exchange is important. In this study, NodeXL software is employed to visualize the social network of assignees in the ICT industry. Network properties are calculated as well, including degree centrality, in-degree centrality, out-degree centrality, betweenness centrality, and eigenvector centrality.

In social network theory, centrality is used to estimate the influence of actors and understand to what degree an actor is able to obtain or control resources. Freeman (1979) proposed four concepts of centrality in a social network, which have been developed into degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. Brass and Burkhardt (1992) also indicated that an institution with higher centrality is more influential in the network.

Degree Centrality

One of the main applications of network analysis is the identification of "important" nodes in the network. The most prominent nodes generally occupy strategic locations within a network. Degree centrality is the earliest idea pursued by network analysts, and is used to acquire the positional features of individual nodes within networks. Degree centrality is also the simplest and most intuitive indicator, measuring the centrality of an individual in terms of the number of nodes to which a particular node connects. Generally, nodes with a higher degree centrality are more central to the structure and tend to have a greater ability to influence others. The conceptual equation of degree centrality is as follows:

$$d(i) = \sum_{j} m_{ij} = 1$$

m_{ij}=1 if node i and node j are linked.

Moreover, for the analysis of the direct citation network, degree centrality can be further defined by two separate measures, the in-degree and out-degree centrality of each node. The in-degree centrality (Ind) and out-degree centrality (Outd) of a given node is defined as:

$$Ind(i) = \sum_{j=1}^{l} m_{ij,in}$$

$$Outd(i) = \sum_{j=1}^{l} m_{ij,out}$$

m_{ij} = 1 if node i and node j are linked, where $m_{ij,in}$ and $m_{ij,out}$ respectively denote one of inward and outward connections of node i and node j within the network. In-degree centrality of a node i is the sum of number of nodes j in the network that connect inwardly (from node j to node i); Out-degree centrality of a node i is the sum of number of nodes j in the network that connect outwardly (from node i to node j). For the investigation of the network characteristics of highly-impact-technology enterprises, the two indicators correspond to the inward and outward linkages of an enterprise as well as the technology acquisitions and exportations concerned. Comparison of the two measures of a given enterprise reveals whether the focal enterprise is a "source" or "absorber" of the high impact technology (Shih & Chang, 2009).

Betweenness Centrality

Although degree centrality is important, it cannot completely represent all statuses. Even a node that has relatively low degree centrality may play a role as a connective bridge that may be of the utmost importance in the network. If this node is removed from the network, some nodes will be disconnected from other nodes. To discuss such situations, betweenness centrality is proposed as a measure of a node's centrality in a network which equals to the number of the shortest paths from all vertices to all others passing through that node. A node having high betweenness centrality implies that said node is located at the shortest path between two randomly chosen groups of nodes, playing the role of intermediary. In other words, nodes with high betweenness centrality are "pivot points in the network" (Yin, Kretschmer, Hanneman & Liu, 2006). In the network of highly-impact-technology enterprises, a particular enterprise with high betweenness centrality has a high probability of brokering highly impact technologies for other enterprises. Thus it might possess competitive advantages in terms of brokerage opportunities. The conceptual equation of betweenness centrality is as follows:

$$b(i) = \sum_{j,k \neq 1} \frac{g_{jik}}{g_{jk}}$$

g_{jk} the shortest path between node j and node k, g_{jik} the shortest path between node j and node k that contains node i.

Eigenvector Centrality

In many cases, a connection to a popular node is more important than a connection to a loner. Eigenvector centrality is based on the principle that the importance of a node depends on the importance of its neighbors. For example, both node A and node B have a degree centrality value of three; however, node A is directly connected to node C, which is the most popular node in the network. Therefore, node A has a higher eigenvector centrality in the network than node B. Eigenvector centrality also indicates the global prominence of a node, as it is calculated by using properties of the entire network. The objective is to compute the centrality of a node as a function of the centralities of its own neighbors. If we rank nodes by their eigenvector centrality, the importance of the nodes in network can be fully understood at a glance.

Knowledge-Based Characteristic Analysis

A knowledge base is the foundation of an enterprise's innovation. In order to understand the knowledge-based characteristics of the highly-impact-technology enterprises in the ICT industry, three important enterprises are expected to select in each periods (2000-2003, 2004-2007 and 2008-2011). The first criterion of selecting the three enterprises is based on the ranking in degree centrality, betweenness centrality and eigenvector centrality. Except for considering the ranking in the three centrality indicators, the second criterion is the enterprise would be excluded if the number of highly cited patent is less than three. Nine enterprises would be selected to explore the phenomena of highly-impact-technology enterprises in the ICT industry. This study further investigated the changes in the nature of the knowledge base. Some characteristics, including attributive characteristics and topological ones, of the knowledge base were adopted from the literature and industrial practice. In the research, four aspects of the attributive characteristics were examined, as follows:

1. **Technology cycle time (TCT):** Technology cycle time is the essential cycle time for generations of technology. TCT is the median time lag that references the year gaps between previous patents as criteria for calculation in years, and of patent prior-art references of a set of patents. The time lag is computed from the granted date of a cited patent of an analytical unit to that of each citing patent. TCT is generally considered as the speed of invention. The smaller the TCT value, the faster the technological turnover;
2. **Science linkage (SL):** Science linkage indicates the relationship between the technologies in an analytical unit and academic research results. After the references to all the granted patents were collected, this study extracted and counted the number of non-patent references. Science linkage is then represented by the frequency of scientific papers referenced in an analytical unit's patents. It is assumed that the higher the rate is, the more the firm's patents are building on basic science and technology. Science linkage serves as an indicator for understanding the effect of science on technology (Nagaoka, 2007);
3. **Patent Pending duration (PPD):** Patent pending duration represents the time duration of the successful patents that have been in the application-grant process. Patent pending duration, also known as application-grant lag, is the average time elapsed between the publication date and the application date of an analytical unit's patents. Low values of patent pending duration mean that the examination process is fast and the patents are granted quickly;
4. **Originality index (OI):** Originality index measures the extent to which the patent is based on broad technological roots, because the patent is more likely to synthesize knowledge across a wide variety of disciplines. The index is based on the technology categories of the inventions. A histogram of the United States Patent Clas-

sification (USPC) categories of an analytical unit's citing patents is used to indicate the distribution of its technological roots. Originality index is built in a Herfindahl formula; a higher index means that the citations come from a more diverse set of monopolistic technologies.

RESULTS AND DISCUSSION

Highly Impact Technologies of the ICT Industry

This study investigated the transition of high-impact-technologies in the ICT industry across three periods, namely 2000-2003, 2004-2007 and 2008-2011. After retrieving highly cited patents, the study identified different high-impact-technologies in these three periods (Table 4). First, during the period of 2000-2003, semiconductor device manufacturing (438), multiplex communications (370), file management and telecommunications (707) were the high-impact-technologies. This implies that the hardware and communication were the mainstream technologies in this period. Second, the major trend in highly impact technology during the period of 2004-2007 is similar to the previous period. However, television (455), static information storage (365), memory (711), support of digital data processing systems (713), and correction and fault detection technologies (714) emerged in this period. This indicates that some other technologies were receiving closer attention. Finally, in the period of 2008-2011, business practice and management (705), image analysis (382) and operator interface processing (715) became highly impact technologies. This reveals that the focus of high-impact-technologies changed again during the last period. Based on these results, we see that the high-impact-technologies in the ICT industry have consistently transformed across periods. Additionally, $\chi 2$ test is employed to verify whether hardware- and software-related patents are significant different among the three periods. The results shows that hardware- and software-related patents are significantly different ($\chi 2$ = 54.505) and p-value is less than 0.01. It implies that the high-impact-technology development in the ICT industry is indeed different in the three periods.

Social Network Analysis of Highly-Impact-Technology Enterprises

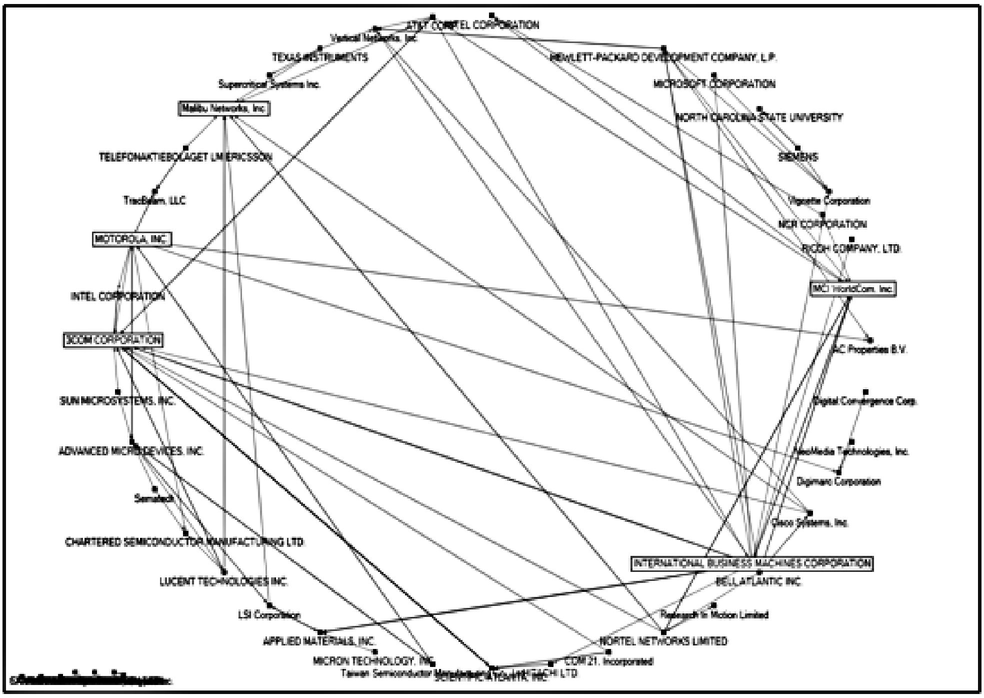
The centrality of a social network can be studied to identify the important enterprises in a technology field and help understand the enterprises' relative positions in the network. For example, the actor with the highest degree centrality in the social network analysis has the most links with others, indicating that it is the most influential in the network. The study used five centrality indicators, including degree centrality, in-degree centrality, out-degree centrality, betweenness centrality and eigenvector centrality to evaluate the enterprises' position in the network. First, in order to understand the transition of the highly-impact-technology enterprises, the social network analysis evaluated by degree centrality is laid out in a circle (top 5 enterprises were labelled) and illustrated in Figure 1, 2 and 3 respectively. Figure 1 shows the results of the period of 2000-2003. It indicated that MCI WorldCom, IBM, 3Com, Malibu Networks and Motorola had the most links with the other enterprises. It implied those enterprises played the high-impact roles in this period. But in the period of 2004-2007 (see Figure 2) the enterprises were changed to Micron, IBM, Current Technologies and Intel. In the period of 2008-2011 (see Figure 3) Microsoft, IBM, Cisco, Embarq and ParkerVision received the most linkages with other enterprises. This result implied that there has been a transition in high-impact-technology within the ICT industry.

To confirm the difference of technology development of the top ten enterprises, $\chi 2$ test is employed to verify whether hardware and software-related patents are significantly different among three periods. Table 5 shows the results of $\chi 2$ test while considering the enterprises' position with five centrality indicators. For example, as the top ten enterprises

Table 4. Top 10 USPC class of highly cited patents

2000-2003			
Rank	**USPC Class**		**Number of Patents**
1	438	Semiconductor device manufacturing: process	348
2	370	Multiplex communications	141
3	707	Data processing (DP): database and file management or data structures	130
4	361	Electricity: electrical systems and devices	87
5	455	Telecommunications	72
6	701	Data processing (DP): vehicles, navigation, and relative location	62
7	345	Computer graphics processing and selective visual display systems	55
8	365	Static information storage and retrieval	53
9	715	Data processing (DP): presentation processing of document, operator interface processing, and screen saver display processing	52
10	379	Telephonic communications	49
2004-2007			
Rank	**USPC Class**		**Number of Patents**
1	370	Multiplex communications	204
2	438	Semiconductor device manufacturing: process	186
3	707	Data processing (DP): database and file management or data structures	137
4	455	Telecommunications	110
5	365	Static information storage and retrieval	83
6	348	Television	75
7	711	Electrical computers and digital data processing systems (ECDDPS): memory	71
8	714	Error detection/ correction and fault detection/recovery	69
9	361	Electricity: electrical systems and devices	65
10	713	Electrical computers and digital data processing systems (ECDDPS): support	59
2008-2011			
Rank	**USPC Class**		**Number of Patents**
1	370	Multiplex communications	269
2	707	Data processing (DP): database and file management or data structures	167
3	705	Data processing (DP): financial, business practice, management, or cost/price determination	147
4	438	Semiconductor device manufacturing: process	145
5	382	Image analysis	143
6	455	Telecommunications	143
7	713	Electrical computers and digital data processing systems (ECDDPS): support	120
8	361	Electricity: electrical systems and devices	106
9	365	Static information storage and retrieval	103
10	715	Data processing (DP): presentation processing of document, operator interface processing, and screen saver display processing	94

Figure 1. Social network analysis of the period of 2000-2003

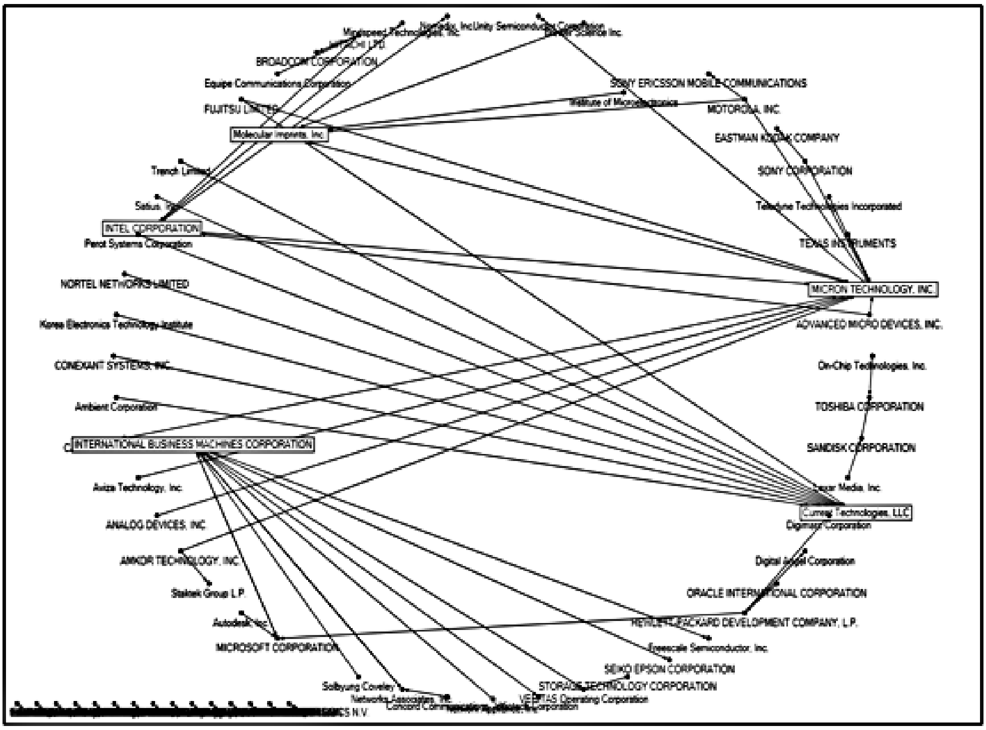


are ranked by degree centrality, the hardware and software-related patents are significantly different across three periods ($\chi^2 = 50.725$) and p-value is less than 0.01. This means the development of hardware and software-related patents, of top ten enterprises evaluated by degree centrality is significantly different. The number of software-related patents increased from the period of 2000-2003 (P1) to the period of 2008-2011 (P3) significantly. Based on these statistical results, further description evaluated by different centralities is discussed in the next paragraph.

The ranking results of degree centrality are shown in Table 6. As the founding years of the enterprises are different, the patents possessed by each enterprise have influenced its position in the social network. The results show that the degree centrality of IBM remains in the top three over the three periods, implying that IBM leads the industry in high-impact-technology and has the most linkages with the other enterprises in the ICT industry. IBM thus holds the greatest influence in the ICT industry's network. Secondly, we found that Microsoft shows a greater influence from the period of 2000-2003 to 2008-2011, suggesting that software-related patents have gradually received greater attention from highly-impact-technology enterprises. Thirdly, many highly-impact-technology enterprises took important positions in the periods of 2000-2003 and 2004-2007, such as MCI WorldCom, HP and Motorola. However, this did not continue in the period of 2008-2011. This shows that the highly-impact-technology enterprises of the ICT industry have changed; hardware-related enterprises have gradually been replaced by the software and communication-related enterprises, such as Digimarc, Apple, Qualcomm and ParkerVision. Software and communication application enterprises were regarded as leaders in the contemporary ICT industry.

Additionally, the in-degree centrality and out-degree centrality of a given enterprise

Figure 2. Social network analysis of the period of 2004-2007

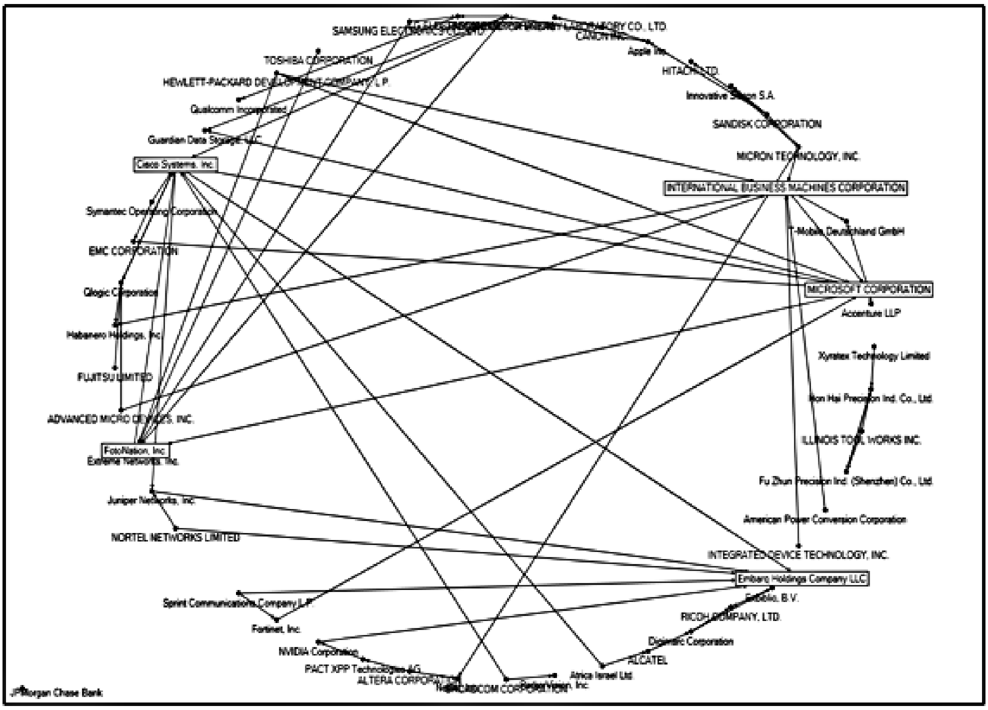


reveal whether the enterprise is a "source" or "absorber" in the social network. The ranking results of in-degree centrality are presented in Table 7. The level of in-degree centrality helps to clarify which enterprises are the sources of highly impact technologies. The results show that IBM remained the top source in all three periods; Motorola and HP were the other major sources in the 2000-2003 and 2004-2007 periods. Communication enterprises such as AT&T and Bell Atlantic were also important sources in the period of 2000-2003. Hardware enterprises such as Intel and Micron were important sources in the period of 2004-2007. Microsoft may be viewed as both an important source and an absorber in the period of 2008-2011. With rather high in-degree centrality, Cisco, Sony and SanDisk were important sources in the period of 2008-2011.

The level of out-degree centrality helps to identify which enterprises are the absorbers of highly impact technologies. The ranking results of out-degree centrality are presented in Table 8. The out-degree centrality result shows that many communication and network-related enterprises, such as MCI WorldCom and Malibu Networks, were absorbers of highly impact technologies from 2000 to 2003. However, in the period of 2004-2007 hardware-related enterprises such as Micron and Current Technologies were absorbers of highly impact technologies. In the period of 2008-2011 software and network enterprises such as Microsoft, Cisco and ParkerVision were absorbers of highly impact technologies. These results reveal that the absorbers of highly impact technologies have shifted from hardware enterprises to software and application enterprises.

In addition to degree centrality, this study also investigated the betweenness centrality of the ICT industry network. The enterprises with the highest betweenness centrality are located

Figure 3. Social network analysis of the period of 2008-2011



at the shortest path between two randomly chosen groups of enterprises, and serve as pivot points in the network. The ranking results of betweenness centrality are presented in Table 9. The results show that IBM is an important technology mediator in the ICT industry across the three periods, implying that IBM persistently played a critical role in the ICT industry. Additionally, telecommunication enterprises such as MCI WorldCom and Motorola were important mediators in the period of 2000-2003. In the period of 2004-2007, hardware enterprises including, Fujitsu and Intel were located at positions where short links existed among other enterprises. Finally, in the period of 2008-2011 Microsoft and Apple had high betweenness centrality, which indicates that software enterprises have been pivots in the recent development of the ICT industry.

After discussing degree centrality and betweenness centrality, the rank of eigenvector centrality is presented in Table 10. First, the study found that MCI WorldCom, IBM and 3COM presented high eigenvector centrality in the period of 2000-2003. However, AT&T, HP, Bell Atlantic and Nortel Network also exhibited high eigenvector centrality in the period of 2000-2003, even though they have low degree centrality in the same period. Second, in the period of 2004-2007 Intel, Molecular Imprints and Fujitsu had high eigenvector centrality, indicating that they connected to other important enterprises in the network to a certain extent. In the period of 2008-2011, FotoNation, HP and T-Mobile Deutschland had high eigenvector centrality and connected closely to other important enterprises in the network.

Knowledge-Based Characteristic Analysis of Highly-Impact-Technology Enterprises

After the social network analysis, this study further explored the knowledge-based char-

Table 5. Results of χ^2 test

Items	Period	Number of Hardware-Related Patents	Number of Software-Related Patents	χ^2 Test
Degree Centrality	P1	198 (56.1%)	155 (43.9%)	$\chi^2 = 50.725$ ($p < 0.01$)
	P2	128 (38.2%)	207 (61.8%)	
	P3	159 (32.1%)	337 (67.9%)	
In-Degree Centrality	P1	98 (67.6%)	47 (32.4%)	$\chi^2 = 9.292$ ($p < 0.01$)
	P2	145 (43.4%)	189 (56.6%)	
	P3	195 (34.8%)	365 (65.2%)	
Out-Degree Centrality	P1	155 (58.1%)	112 (41.9%)	$\chi^2 = 48.87$ ($p < 0.01$)
	P2	79 (31.2%)	174 (68.8%)	
	P3	170 (35.2%)	313 (64.8%)	
Betweenness Centrality	P1	145 (56.4%)	112 (43.6%)	$\chi^2 = 29.994$ ($p < 0.01$)
	P2	125 (37%)	213 (63%)	
	P3	158 (36.69%)	270 (63.1%)	
Eigenvector Centrality	P1	122 (51.9%)	113 (48.1%)	$\chi^2 = 24.963$ ($p < 0.01$)
	P2	100 (54.6%)	83 (45.4%)	
	P3	121 (33.8%)	237 (66.2%)	

Note: P1 refers the period of 2000-2003, P2 refers the period of 2004-2007, P3 refers the period of 2008-2011

Table 6. Top 10 enterprises ranked by degree centrality

Degree Centrality			
Rank	**2000-2003**	**2004-2007**	**2008-2011**
1	MCI WorldCom	Micron	Microsoft
2	IBM	Current Technologies	IBM
3	3Com	IBM	Cisco
4	Malibu Networks	Intel	Embarq
5	Motorola	Molecular Imprints	ParkerVision
6	LSI Corp.	HP	Qualcomm
7	Advanced Micro Devices	Microsoft	Digimarc
8	HP	Hitachi	FotoNation
9	Micron	Motorola	Apple
10	AT&T	ParkerVision	Sony

acteristics of highly-impact-technology enterprises, including technology cycle time, science linkage, patent pending duration and originality index. Based on the criterion we proposed in the methodology, IBM, MCI WorldCom, 3Com, Micron, Intel, Motorola, Microsoft, Cisco and Sony were selected to discuss their knowledge-based characteristics (see Table 11).

First, technology cycle time (TCT) is generally considered to be the speed of invention,

Table 7. Top 10 enterprises ranked by in-degree centrality

In-Degree Centrality			
Rank	**2000-2003**	**2004-2007**	**2008-2011**
1	IBM	IBM	IBM
2	Motorola	Intel	Microsoft
3	AT&T	Motorola	Cisco
4	Bell Atlantic	Micron	Sony
5	HP	HP	SanDisk
6	Nortel Network	Hitachi	Micron
7	Lucent	Advanced Micro Devices	Toshiba
8	LSI	Amkor Technology	Samsung
9	Cisco	Fujitsu	HP
10	Texas Instruments	Sony	Digimarc

Table 8. Top 10 enterprises ranked by out-degree centrality

Out-Degree Centrality			
Rank	**2000-2003**	**2004-2007**	**2008-2011**
1	MCI WorldCom	Micron	Microsoft
2	3Com	Current Technologies	Embarq
3	Malibu Networks	IBM	Cisco
4	Advanced Micro Devices	Molecular Imprints	FotoNation
5	Applied Materials	Microsoft	IBM
6	Scientific-Atlanta	Intel	ParkerVision
7	Vignette	HP	Qualcomm
8	Vertical Networks	ParkerVision	Semiconductor Energy Lab
9	IBM	Toshiba	Digimarc
10	Micron	Veritas	Toshiba

and provides very important information on the management of R&D in firms. For example, the average citation lag of the patent portfolio of a firm may provide important information on how recent patent information is used by the firm for its inventions. A firm that can assimilate prior technological information swiftly and implement its own inventions with speed will have a short citation lag. Ayres (1994) suggested that the notion of the pace of technological progress might also be considered as a sequence of substitutions. Shorter cycle time reflects faster substitutions, indicating faster progress; longer cycle time reflects slower substitutions, indicating slower progress. In the ICT industry, the results show that the TCT value of highly-impact-technology enterprises was smaller in the 2000-2003 and 2004-2007 periods than 2008-2011, implying that the technologies of ICT industry in the period of

Table 9. Top 10 enterprises ranked by betweenness centrality

Rank	2000-2003	2004-2007	2008-2011
1	IBM	Micron	Cisco
2	3COM	Current Technologies	Microsoft
3	MCI WorldCom	Fujitsu	Sony
4	Motorola	Intel	IBM
5	Malibu Networks	IBM	Apple
6	Applied Materials	Molecular Imprints	Micron
7	Vignette	Hitachi	FotoNation
8	Nortel Network	Microsoft	Embarq
9	LSI	HP	Atrica Israel
10	AT&T	Motorola	LG

Table 10. Top 10 enterprises ranked by eigenvector centrality

Rank	2000-2003	2004-2007	2008-2011
1	MCI WorldCom	Micron	Microsoft
2	IBM	Intel	IBM
3	3COM	Molecular Imprints	Cisco
4	AT&T	Motorola	FotoNation
5	HP	Advanced Micro Devices	HP
6	Bell Atlantic	Fujitsu	T-Mobile Deutschland
7	Nortel Network	Amkor Technology	Sony
8	Malibu Networks	Sony	Embarq
9	Vertical Networks	Analog Devices	Guardian
10	Cisco	Aviza Technology	Juniper Networks

2000-2003 presented a more rapidly progressing trend than the period of 2008-2011. MCI WorldCom, IBM and Sony have shorter TCT in the period of 2000-2003. The results further indicated that the technological progress of highly-impact-technology enterprises currently shows a longer TCT and more stable status in the ICT industry.

In regards to science linkage (SL), the frequency of the references by the patents of a firm to the science articles (science linkage) may provide information on the absorptive capability of a firm to exploit knowledge disclosed from academia. Nagaoka (2007) argued that a firm with strong absorptive capability with respect to scientific advances would have first mover advantage in R&D competition and may be able to produce more pioneering inventions. In the ICT industry, some hardware-related highly-impact-technology enterprises, including IBM, Micron, Intel and Cisco, presented lower rates of science linkage in the period of 2000-2003, whereas higher rates were shown in the period of 2008-2011. This implies that in the early period hardware enterprises preferred to exploit knowledge from technological fields, but this trend has changed. Microsoft, a software-related enterprise, showed the highest rate of citing sci-

Table 11. Knowledge-based characteristics of high-impact-technology enterprises

Enterprises	TCT (P1—P2—P3)	SL (P1—P2—P3)	PPD (P1—P2—P3)	OI (P1—P2—P3)
MCI WorldCom	2.82—6.88—N/A	0.75—1—N/A	3—7.5—N/A	0.97—0.99—N/A
IBM	3.61—4.89—6.42	0.67—0.65—0.73	2.67—4—3.3	0.92—0.97—0.97
3COM	2.54—4.9—7.82	0.89—0.78—1	3—4.5—7	0.98—0.97—0.96
Micron	4.92—4.81—6.56	0.6—0.75—0.85	2—2.3—3	0.98—0.98—0.97
Microsoft	4.23—5.27—7.50	0.9—0.79—0.91	3.5—4.5—5	0.97—0.98—0.98
Motorola	3.58—4.63—6.35	0.6—0.33—0.33	2.75—3.5—5	0.97—0.95—0.94
Intel	3.69—5.32—7.62	0.43—0.6—0.81	3—4.3—5.3	0.96—0.93—0.97
Cisco	4.21—6.17—7.52	0.53—0.83—0.84	3—5.3—5.25	0.96—0.97—0.97
Sony	2.75—5.03—6.38	0.53—0.43—0.44	3—4.25—4.5	0.96—0.93—0.95

Note: P1 refers the period of 2000-2003, P2 refers the period of 2004-2007, P3 refers the period of 2008-2011

entific papers in all three periods. These results indicate that these highly-impact-technology enterprises, including hardware and software enterprises, have developed strong absorptive capabilities towards contemporary scientific advances.

In regards to the patent pending duration (PPD), if a firm has a low value of patent pending duration, it means that the firm has more time to generate monopoly rights to explore an invention and to build the barriers of entry from other inventors. Jaffe and Trajtenberg (2002) pointed out that the knowledge, particularly the technological knowledge, forming the foundation for industrial innovation is an extremely important economic commodity. In the ICT industry, we found that most highly-impact-technology enterprises had a lower patent pending duration time in the period of 2000-2003, implying that the technology innovation in this period grew swiftly. However, in the period of 2008-2011 the speed of technology development showed a lower rate, implying that the ICT industry's technology innovation achieved a stable status.

In regard to the originality of patents, a higher originality index means that the citations of patents come from a more diverse set of technologies, whereas they relate to monopolistic technologies. Originality, as suggested by Jang, Lo and Chang (2009), is the indicator of firm's wide variety of citations, implying relative linkage to other innovations. In the ICT industry, the results showed that all highly-impact-technology enterprises presented a high originality index value. This implies that the technologies of ICT industry originated from a diverse set of technologies. Because different environments and technologies create differences in technological development among firms, the result shows that in the ICT industry highly-impact-technology enterprises with diverse originality will create more innovative technologies in other fields.

According to the analysis of knowledge-based characteristics among nine highly-impact-technology enterprises, three important findings can be addressed. First, based on the technology cycle time and patent pending duration, the technological progress of highly-impact-technology enterprises in the ICT industry shows a slow speed of invention and more stable status currently. Secondly, based on the results of science linkage, the highly-impact-technology enterprises gradually had strong absorptive capability to scientific advances. Thirdly, the highly-impact-technology enterprises presented a high originality index value among three periods. The result indicated that the high-impact-technologies of ICT industry originated from a diverse set of technologies.

CONCLUSION

One of the main advantages of patents is that historical data can be retrieved and analysed, thus providing detailed technological information. Highly cited patents represent the prior art of technology and contain significant technological advances. Those enterprises which master highly cited patents may have major influences on industrial technology development. Through social network analysis and centrality, the position of highly-impact-technology enterprises in the ICT industry is presented. This study further observed the transition of highly-impact-technology enterprises in the ICT industry. The results show that the high-impact-technologies in the ICT industry have clearly evolved over a long time period. Many highly-impact-technology enterprises regarded as holding important roles in the periods of 2000-2003 and 2004-2007 did not retain that same status during the period of 2008-2011. Today, the software, communication and application enterprises have achieved leading positions in the ICT industry.

In regard to the sources of high-impact-technology, the results show that IBM remained the number one technology source during all three periods. The communication and hardware enterprises were important sources of the periods of 2000-2003 and 2004-2007 respectively. Microsoft is both a key source and an absorber in the period of 2008-2011. With regard to the absorbers of high-impact-technology, the results show that the absorbers have gradually changed across the three periods from hardware enterprises to software and application enterprises. As for the betweenness centrality, IBM was also an important technology mediator in the ICT industry during the three periods, and can be considered a critical pivot point in the network. However, software and application enterprises were the key pivots in the ICT industry in the period of 2008-2011.

In regards to the knowledge-based characteristics of high-impact-technology enterprises in the ICT industry, highly-impact-technology enterprises presented smaller TCT values in the period of 2000-2003. This implies that the technologies presented a more rapidly progressing trend in the early period. In addition, the rate of science linkage indicated that these highly-impact-technology enterprises have strong absorptive capability with regard to scientific advances. Concerning patent pending duration, the results implied that technology innovation in the early period grew swiftly, but the speed of technology development presents a lower rate at present. This implies that technology innovation has achieved a stable status. Finally, the originality of patents shows that the ICT industry's technologies originated from a diverse set of technologies in all three periods studied, implying that highly-impact-technology enterprises in the ICT industry persistently absorb innovative technologies from other fields.

By means of social network and knowledge-based characteristic analysis, this study obtained a different perspective on the influence, position and knowledge characteristics of highly-impact-technology enterprises in the process of industrial technology development, especially for technology-intensive industries. For example, enterprises with high degree centrality can attract many more other enterprises, expanding the connection scope of the network and mapping a more strategically competitive position. Enterprises with higher betweenness centrality have a greater ability to communicate with different groups of enterprises and facilitate technology transfer. Additionally, based on the multi-level characteristics of networks, enterprises might exist simultaneously in different levels of the network and play different roles. Thus, longitudinal analysis of centrality and identification of technological leaders interpret competitive tendencies in a specific field so as to anchor the positions of the enterprises. Through social network and knowledge-based characteristic research, this study has achieved a better understanding of the evolution of technology development, which is critical for enterprises engaging in technology management.

Concerning the implication of this study, the study performed patentometric analysis at a macro-level view at general assessments of industries as a whole. As enterprises increase the R&D investments to strengthen their business competitive position, they first need a global overview of the major dominators. For instance, the characteristics of an enterprise's are, an enterprise's advantage and when did an enterprise emerge in the industry. Second, longitudinal analysis of technological leaders provides a possible way to understand the changes of the enterprises' positions. The highly-impact-technology enterprises of ICT industry evolve over time and corresponding status may appear, maintain, or disappear respectively. The observation inspired us to deepen the knowledge about the enterprises' characteristics that could explain such transition patterns. For instance, 3Com presented a longer technology cycle time in the period of 2008-2011, reflected slower pace of technological progress, and finally disappeared its role of highly-impact-technology enterprises in the recent period. The findings potentially provide a useful application for the policy makers if they are likely to realize the status of highly-impact-technology enterprises in the future. Finally, the directionality of each knowledge-based characteristic also could be served as one of signals to judge the enterprises' transition in the future.

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