Hybrid Documents Co-citation Analysis: a Suggested Method to Analyze the Interaction between Science and Technology in Technology Diffusion

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Abstract
Given the growing attention paid to technology diffusion with the method of patent citation analysis, scholars and practitioners alike need practices to assist them in better understanding the interaction between science and technology. The main objective of the paper proposing a hybrid documents co-citation analysis, tries to help them in this task with a practical and replicable method. With the patents citing Smalley RE in Derwent Innovations Index as the data source, the paper achieved hybrid documents co-citation network through two procedures at first, then made cluster analysis to get a better understanding of technology diffusion from the macro and micro levels. Furthermore, based on the concordance between network properties and technology diffusion mechanisms, three indicators including degree, betweenness and citation half-life, were created to mine the basic documents in the critical position during the technology diffusion. At last, the paper summarized the hybrid documents co-citation analysis in practise, thus made the conclusion on the interaction between science and technology that they undertook different functions and acted dominatingly in the different period of technology diffusion, although they were co-activity all the time.

Introduction
With the development of technology in the progressing society, the capability of a country, corporation or researcher to keep up with new technologies, monitor technological change and evolution, obtain and use the most appropriate advanced technologies is of vital importance to survive in the competition. Among kinds of methods proposed to technology diffusion, patent analysis, in which patent citation analysis is a mature and objective method, is the most common one for that patent is taken as the proxy of technology. An invention is patented, it must contain the prior art in the patent document, such as the former patent, previous literature or some others. And the more frequently a patent is cited by subsequent patents, the more the patented technology could be diffused, indicating that the technology is more widely applied and more valuable (Jaffe, Trajtenberg, & Henderson, 1993; Narin, Hamilton, & Olivastro, 1997; G. Park & Park, 2006; Stolpe, 2002). So based on the patent citation analysis, the researcher can not only evaluate the importance of a patent, but also trace the trajectory of a certain technology domain. Pei-Chun Lee et al.(Lee, Su, & Wu, 2010) constructed and analyzed patent citation network and patent citation map for the field of electrical conducting polymer nanocomposite; Kihoon Sung et al. (Sung, Kim, & Kong, 2010) took a microscopic approach to measure and evaluate the level of technological convergence using patent citation analysis.
Considering that there are mainly scientific papers and technological patents in the prior art in the patent document. Therefore, scholars usually apply patent-cited document analysis and patent-cited patent analysis. The former is a usable method to identify the contribution of scientific knowledge to technology development, or even to position the scientific base of patented technology(Meyer, Debackere, & Glanzel, 2010; Noh, Kim, Kwon, Yae, & Choi, 2007) ; while the latter one is implemented for the aim of technology diffusion in order to trace the technological trajectory(Chang, Lai, & Chang, 2009; Lee et al., 2010; Sung et al., 2010). For the further facility of analyzing, the paper called scientific paper and technological patent together with a general term document.

However, both the analysis methods have a same disadvantage that they depend on the separation between science and technology with a unidirectional flow of knowledge. So the analyzed result only shows the impact of prior science to subsequent technology or prior technology to subsequent technology. It can't reveal the exact interaction between science and technology, and thus the paper provides a method called hybrid documents co-citation analysis (HDCCA) based on references in patent. This method could meet the following five demands. The first one is to adopt co-citation analysis to find knowledge evolution and knowledge structure (Small, 1973; Small & Griffith, 1974); the second one is about the proxy of interaction between science and technology by paper and patent's co-citation in a patent document (Brusoni & Geuna, 2005; H. Park & Kang, 2009); the third is to use co-citation analysis based on a large number of bibliographic patent information to display the interaction's influence on technology progress with objectivity. And so to the fourth and most important reason for HDCCA, is the concordance between network properties and technology evolution mechanisms, with which the basic documents could be confirmed. At last, cluster analysis in the time zone represents the central paths of knowledge diffusion.

Data

Nanotechnology is an interdisciplinary filed fusing numerous research achievements, which is the typical production of interaction between modern science, such as physical chaos, quantum mechanism, molecular biology and so on, and current technology, for example computer technique, micro electronic technique and some others. So nanotechnology is considered both as academic science and applied technique (Baker & Aston, 2005; Roco, 2005), which is an optimal candidate field chosen to make analysis on interaction between science and technology (Alencar, Porter, & Antunes, 2007). Here the paper retrieved patents citing "Smalley RE" in database of Derwent Innovations Index (DII) as the datum. The reason why the paper takes the retrieving method described above, is that those patents retrieved could indicate technology spread from Smalley RE, known as the father of Nanotechnology. He had published 372 scientific papers in Web of Science and invented 42 patents in DII by the retrieving time.

The searching detail was as follows: in DII, the paper searched the cited inventor "Smalley RE" with Cited Patent Search (Patent search time: Dec. 18th, 2010). But the time was not related with the application time or the issued time of patent, but with the database's update time. At last, the searched patents were carefully reviewed to dismiss those whose inventor's name was the same, and finally a total of 934 patents were left as data source. One thing to note, there was no item "PY"(publication year) in the downloaded bibliographic data, so a further step need to extract the applying year from the item "AD" (application date) to represent the item "PY", which was necessary for further study.

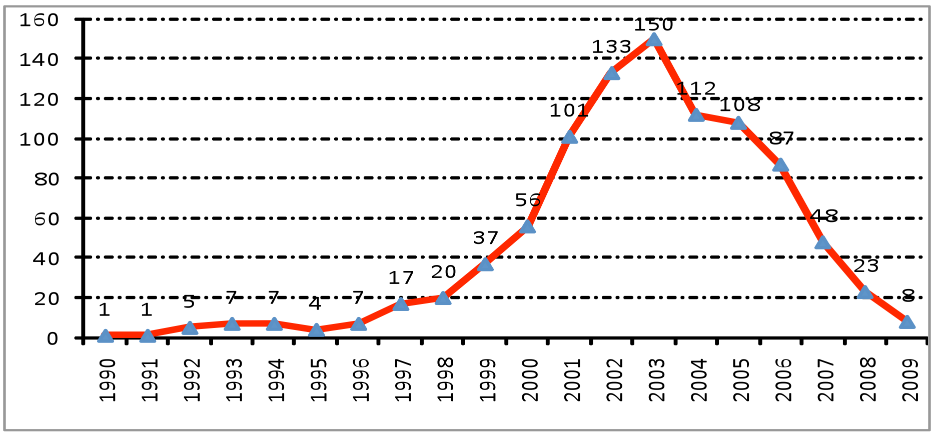

Figure 1. Distribution of analyzed patents over "PY"

According to the Fig. 1, the number of patents increased with the time went on, specially from 1997 to 2003. In 2003, it had reached to the top 150. After that, it sharp dropt. Of course, it might be for the time lag from patent application to patent accessed by the DII, especially for those applied in 2006 or 2009.
In all, direct influence of Smalley existed observably, although it had great change during the lately 10 years. Thus it was still reasonable to study technology diffusion based on patens citing Smalley.

Method

In DII, there are PT, PN, TI, AU, AE, GA, AB, MC, IP, PD, AD, FD, PI, FS, CP, CR, UT and some other items in a patent document. Among them, the item CP, cited patents in prior art, and the item CR, cited papers in prior art, are the basic research objects, which two are called together as citations.
The whole process contained two procedures: one was data pre-processing to acquire Citations co-occurrence matrix; the other was cluster analysis labelled by MC with software CiteSpace II(C Chen, 2004, 2006; C Chen, Ibekwe SanJuan, & Hou, 2010), designed to visualize patterns and trends in scientific literature by Chaomei Chen, the professor of iSchool at Drexel in U.S.A as well as Changjiang Scholar at Dalian University of Technology in P.R.C..

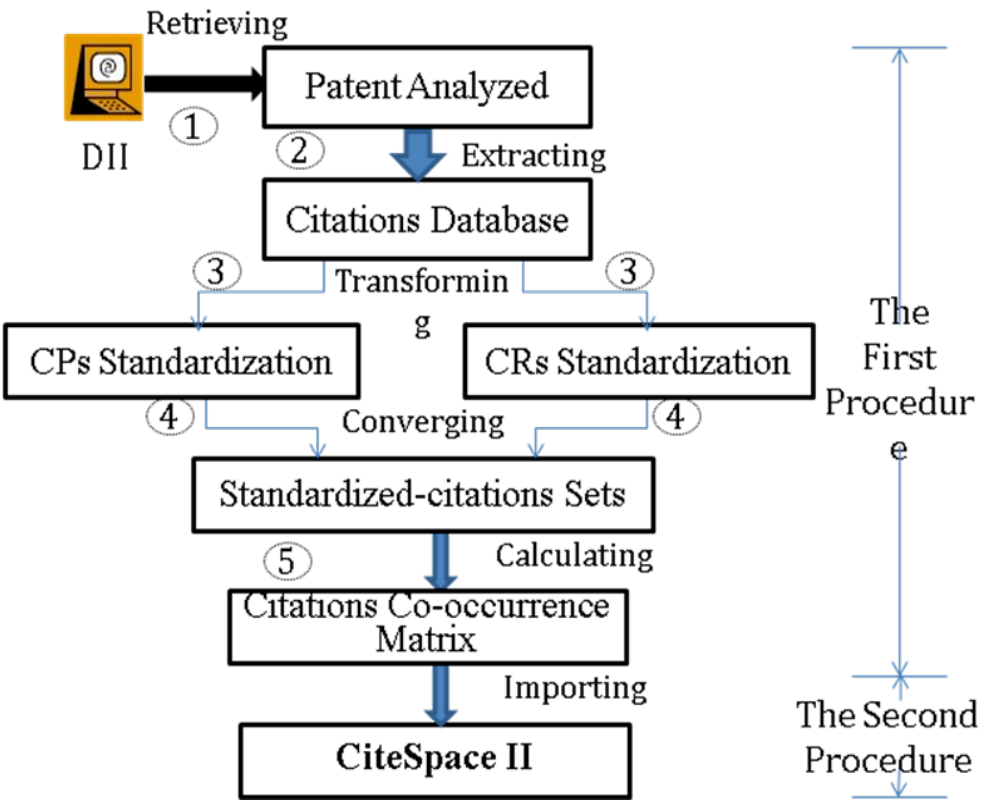

Figure 2. The whole analysis procedure

The first procedure

The first procedure was about data processing including 5 stages, which were the central work author done. The details were as follows.
(1) Patent Retrieving. Based on the above search strategy, the paper retrieved patents in DII and saved as text, then combined all the texts to one text.

(2) Citation Extracting. After stage 1, the paper extracted the references in the patents, including cited patents in the item CP and cited non-patent in the item CR, and then made index with the title of patent.

(3) Data Transforming. The formats of CP and CR were quite different, so they need to be standardized separately.

In the CP, the standard reference contained patent number, assignees and inventors, like this "US5744235-A HYPERION CATALYSIS INT (HYPE-Non-standard) FRIEND S O, BARBER J J, CREEHAN R, SNYDER C E". Of course, not all the references in CP included these three parts.

In the CR, kinds of reference forms existed. Among them, the standard reference should cover author, title, journal, press and page number, like this "M.S.P. Shaffer, et al. "Dispersions of Carbon Nanotubes: Polymeric Analogies". Department of Materials Science, Cambridge University, pp. 24-27.". Also a great many discrepant forms were in existence, for example, ""Unique Slough Resistant SRTM Series ESD Thermoplastic Product Line Offers Reduced Particle Contamination For Demanding Electronic Applications", Hyperion Catalysis International. http:www.fibrils.come5d.htm.", ""Conductive Plastics for Medical Applications" Medical Device & Diagnostic Industry Magazine MDDI Article Index, Jan. 1999, http:devicelink.commddlarchive9901009.html. pp. 1-11.". So for the better analysis in the further work, we converted all the references in CR to a standardized one, such as "Dispersions of Carbon Nanotubes: Polymeric Analogies, 1992, world, V1", "Unique Slough Resistant SRTM Series ESD Thermoplastic Product Line Offers Reduced Particle Contamination For Demanding Electronic Applications, 1992, world, V1". It was worth noting that the title in the standardized format was the critical characteristic, compared to other features that had no specific meanings.

(4) Citation Converging. Depend on the index built in stage 2, the paper converged the contents in CP and CR together to create the standardization-ciation sets.

(5) Similarity Calculating. Here cosine similarity algorithm was adopted to measure the documents' similarity, named as cosine coefficient.

$$\text{Cosine coefficient}=\frac{C_{ij}}{\sqrt{C_i}\times\sqrt{C_j}} \qquad (1)$$

C_i: the amount of document i in the standardization-citation sets; C_j: the amount of document j in the standardization-citation sets; C_{ij}: the times that document i and document j co-occurred in the patents' references.

Then, the paper generated citations co-occurrence matrix for the second procedure.

The second procedure

In the second procedure, the primary work was done by CiteSpaceII to finish the following three functions.

(1) Visualizing the Hybrid Co-citation Network. Importing the citation co-occurrence matrix to CiteSpace II, the software produced the HDCCA map, in which nodes representing documents and lines representing co-citation were the basic elements making concordance between network properties and technology diffusion mechanisms. Particularly, the colour of the line corresponded to the year of co-citation, which could be used as a visual statement of technology diffusion.

(2) Cluster Analysis. Derwent Manual Code (MC) in DII highlights the inventive and significant aspects of the invention, and it is drawn from patent specification by technical scholars to reveal its technical detail and its technology innovation. So MC is analogous to the keywords in scientific papers. For this, we clustered the hybrid documents co-citation network and labelled each cluster with MC calculated with log-likelihood ratio (LLR) algorithm.

(3) Identifying Basic Document. After construction of the hybrid documents co-citation network, network property was subsequently obtained. Although the process of technology diffusion is complex, dynamic and nonlinear, based on the concordance between network properties and technology diffusion mechanisms, we could devise diverse indicators to stress on emphasized mechanisms.

The whole hybrid co-citation network was an undirected and weighted network. Kinds of network properties have different implication in technology diffusion, thus the paper developed three indicators to describe the technology diffusion in order to get the basic documents.

Degree, the times that the document was cited in the data sources, could be used as an indicator to measure the document's influence. In technology diffusion, it implies its diffusing capability. (Degree, in actually, means the number of times that a document was co-cited, but in patent there is no document cited alone.)

Betweenness (betweenness centrality, Betweenness), a kind of metric that measures how likely an arbitrary shortest path in the network will go through the node in the network, could be taken as an indicator to uncover the document's spread. In technology diffusion, it implies its transformative capacity.

$$\text{betweenness}(x) = \sum_{j<k} g_{jk}(x)/g_{jk} \qquad (2)$$

g_{jk} : the shortest path between node j and node k; $g_{jk}(x)$: the shortest path between node j and node k that contains node x.

HL (citation half-life, HL), the number of years that a document receives half of its citations since its first cited in data sources, could be employed as an indicator to reveal the document's potential. In technology diffusion, it implies its reserving capacity.

With the above three indicators representing three mechanisms of technology diffusion, the basic document could be identified, relied on which of the mechanisms were emphasized.

Results and Discussion

In the hybrid documents co-citation network, a large number of documents together formed the co-citation network, so it seemed complicated. For the better visualizing, the paper split the references into 10 slices from 1990 to 2009 with every two years a slice, and then chose top 10% references highly cited in the slice to analyze in the further study.

Here the paper adopted spectral clustering technique to make clusters in the hybrid documents co-citation network, although kinds of cluster algorithms exist, such as K-means, EM cluster and so on. Compared to the above traditional clustering algorithms, results obtained by spectral clustering often had better performance(C. Chen, Zhang, & Vogeley, 2010; Von Luxburg, 2007).

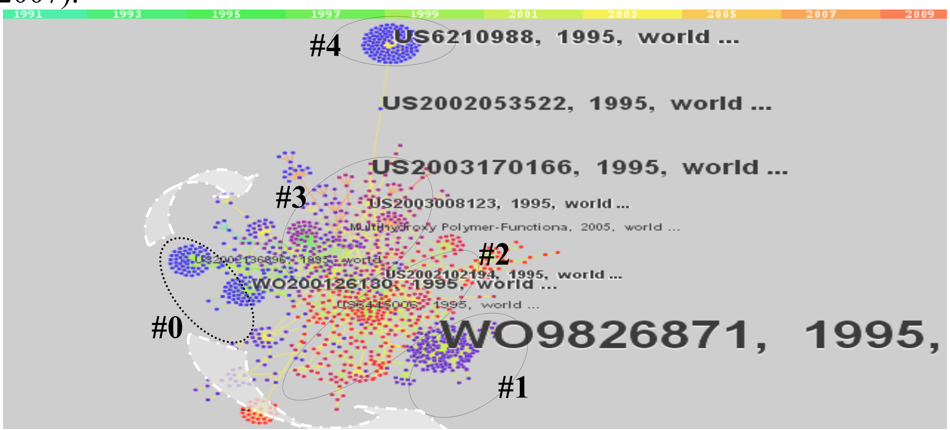

Figure 3. Cluster of the hybrid documents co-citation network

The whole network contained 1,623 nodes and 1,907 lines, and also generated 12 clusters. Furthermore, we merged the neighbouring and relevant clusters into one, and finally 5 clusters were illustrated in Fig.3.

Cluster result

On the whole, the technology diffusion of Smalley from 1990 to 2009 could be divided into five categories, namely, #0, #1, #2, #3, and #4 in the Fig.3. In the Fig.3, the colour of the node indicated the cluster it belonged to.

(1) #0---- e05-u02

On the left of the Fig.3, the cluster #0 was about fullerene type cage structures containing carbon only. The representive documents included: the production of fullerene by evaporating fluid carbon (WO9404461), fullerene molecule for trapping neutrons (WO9624139), fullerene synthesis, purification and separation apparatus (WO9821146), preparation of stable endohedral fullerene (WO9800363) and some others.

Here also a great many scientific articles about fullerene existed, representing with Smalley RE's papers, such as *C_{60}: Buckminster fullerene*, *fullerene with metals inside* and others. Also, fullerenes C_{60} and C_{70} in flames (doi: 10.1038/352139a0), the infrared and ultraviolet absorption spectra of laboratory-produced carbon dust (doi: 10.1016/0009-2614(90)87109-5) and some others, were discussed in the cluster.

(2) #1---- u12-a01

On the bottom right of the Fig.3, it was the cluster #1, which was related to light emitting devices with jump or surface barrier, such as nanotubes, use and manufacture of same (WO9826871), light-emitting device for light fixture (WO2008002318), Klystron for generating electromagnetic energy comprises opposing silver walls (US2007075907), Light emitting device used for emitting light of selected wavelength comprises light emission layer (WO2008101031) and so on.

(3) #2---- b04-c03

Cluster #2 was in the central of the Fig.3, relevant to polymers. Manufacture of nano-polymer was the major subject here, for example, nanowire semiconductor device's manufacture (WO200217362), method of spatially aligning single walled carbon nanotube in selected orientation (WO2003053846), membrane for controlling material transport (US2004173506) , direct observation of reptation at polymer interfaces (doi:10.1038 /365235a0), polypropylene fibers reinforced with carbon nanotubes (doi: 10.1002/app.11160) and so on.

(4) #3---- l04-c12

In cluster #3, semiconductor processing – insulating and passivating layers were the research topics, for instance, electrostatic deposition of grapheme on substrate (US6210988), field effect transistor structure fabricating method (US2006228835), fabricating transistors (US2005167755), Lowering the dielectric constant of an insulating layer(US5744399) and others.

(5) #4---- v05-f01a5

The cluster #4 was labelled with v05-f01a5, which meant tunnel current and analogous devices. Here much attention had paid to tubes for processing objects, especially the patent US7282710, the patent US2005150280, the patent US2005103993, the patent WO2004052489.

Technology diffusion analysis

In the Fig.3, different colours of the lines were corresponding with the year documents were co-cited. So from the changing colours, we could get a better understanding on the technology development diffused from Smalley RE. In the perspective of micro level, the analysis could be summed up as follows.

The first stage was cluster #0 about the analysis on fullerene, which was directly originating from Smalley RE. Then it turned to cluster #1 and cluster #3 in part (shown with arrowhead in the Fig.3). In cluster #1, the technology was diffused to nanotube's manufacture and application to light emitting device, while partly to semiconductor processing in cluster #3.
After that, cluster #1 was flowing to cluster #2, which combined nanotube's application in light emitting device to the field of polymer. At the same time, cluster #3 was linking to cluster #4 for further development.
At last, the cluster #2 and cluster #4 were turning to cluster #3 in the other part for semiconductor processing – insulating.
In different time periods, diffused technology had different research focuses, from fullerene in the beginning to the manufacture of nanotubes, then to the nanotubes' application in light emitting and semiconductor processing, later to polymer and tunnel current, and lately to passivating layer in semiconductor processing or others.

Basic documents

Although there is not a specific definition to basic document or basic patent, the paper tried to adopt three indicators emphasizing different implication in the knowledge diffusion to locate the basic documents which are at a critical position in technology diffusion, and also are cited by the subsequent technology.

(1) Diffusion capability

Table 1. The top 20 documents with high diffusion capability

Num.	*Degree*	*Document*	*Num.*	*Degree*	*Document*
1	89	US6183714	11	57	US6426134
2	87	WO9839250	12	57	US6203814
3	66	Fluorination of single-wall…	13	57	US6445006
4	63	Solvation of fluorinated single…	14	57	US6423583
5	63	WO9805920	15	56	US2002130353
6	62	US6256767	16	55	US5424054
7	61	WO200103208	17	54	WO200248701
8	61	US6128214	18	50	US6790425
9	60	US6232706	19	50	US6221330
10	59	Helical Microtubules of Graphi…	20	50	Polystyrene grafted multi-wall...

In the top 20 documents with high diffusion capability, there were 16 patents, in which patents were applied in The United States Patent and Trademark Office (USPTO) or World Intellectual Property Organization (WIOP). And these patents were chiefly concerned with the method of making carbon nanotube or carbon fibers, such as patent US6183714, WO9839250, US6232706, US6426134, etc.
All these four scientific articles were related with the property of nanotube, including its fluorination, salvation of fluorinated carbon nanotube, helical microtubules of graphitic carbon and polystyrene grafted. Especially the 10th, the paper, published by Lijima in Nature, marked the birth of carbon nanotube.

(2) Transformative capability

Table 2. The top 20 documents with high transformative capability

Num.	*Betweenness*	*Document*	*Num.*	*Betweenness*	*Document*
1	0.41	WO9826871	11	0.09	US2002102196
2	0.20	US2003170166	12	0.09	WO9848456
3	0.20	US6210988	13	0.09	Multihydroxy Polymer-Functionalized…
4	0.19	US2002053522	14	0.09	US2002136896
5	0.14	WO200126130	15	0.08	US6555945
6	0.13	US2003008123	16	0.07	Raman scattering study of double…
7	0.12	US5663971	17	0.07	EP758028
8	0.12	US2002102194	18	0.07	WO9734025
9	0.10	US6445006	19	0.06	Ultrahigh-Density Nanowire Arrays…
10	0.09	US6314019	20	0.06	WO9958748

In the Table 2, it consisted of 17 patents and 3 scientific articles in the top 20 documents with high transformative capability. And the patents were also mainly from WIPO and USPTO, only one from European Patents Organization (EPO). These patents covered a couple of research subject, such as nanotubes, mico-electromechanical system, nanocomposite dielectrics, free-electron laser, molecular-wire crossbar interconnect, electron emission, actuators, etc.

As to the scientific papers, these three ones were also not same in the focus, although they were bound up with carbon nanotube. The 13th was multihydroxy polymer-functionalized carbon nanotubes' synthesis, derivatization and metal loading, while the other ones were related with nanotubes' electronic characteristics.

(3) Reserving capability

Table 3. The top 20 documents with high reserving capability

Num.	*HL*	*Document*	*Num.*	*HL*	*Document*
1	10	Improved conductivity of …	2	10	Smith-Purcell Radiation from …
3	10	Angular Radiation Patterns of …	4	9	Semiconductor Devices …
5	8	Far-Infrared Composite Micro…	6	8	Measurements of Smith-Purcell
7	8	Experimental Investigations …	8	8	The Influence of the Guided …
9	8	Influence of the Guiding …	10	7	Quantum Mechanical Theory…
11	7	Fabrication of Magnetic Micr…	12	7	US4125439
13	7	US4201635	14	7	US5607562
15	6	Investigation of the Mean …	16	6	US4350576
17	6	US4091083	18	6	US4244934
19	6	US3885007	20	6	WO9731691

In the reserving capability, great changes happened, compared to diffusion capability and transformative capability in which the patents were the majority. In general, the scientific papers were relatively small in the share of Table 1 and Table 2, while in the Table 3, they received the bigger portion. So compared to technology patent, scientific papers had larger reserving capability in technology diffusion. Moreover, these papers having longer half-lives may belong to the classical literature(Burton & Kebler, 1960).

Conclusion

The paper proposed the hybrid documents co-citation method, and implemented the ideas into the research work with two procedures. Also based on the datum citing Smalley RE, technology diffusion was traced by the co-citation network in cluster view, with the coloured clusters indicating its different spreading direction. From the Fig. 3, the diffused technology could be divided into five categories: fullerene type cage structures, light emitting devices, polymers, semiconductor processing layers and tunnel analogous devices. Furthermore, the whole technology diffusion originated from cluster #0. In the process of diffusion, a mass of documents existed as the bridge linking different technology domain, such as US2002053522, US2003170166, WO9826871, mainly the technique patents with high betweenness. Through the research in the above, we found that HDCCA might also be used to evaluate the scholar's academic influence.

In order to characterise the dimensions of the interaction between science and technology, papers were taken as a proxy of scientific orientation, and patents as a proxy for technology research. After interaction analysis relying on the HDCCA, the paper briefly summarize as given below.

First, papers representing scientific progress, especially the basic scientific research, constructed the leading research base at the beginning of technology diffusion, particularly in 1990 and 1991.

Second, the effect of the scientific papers were decreasing with the time went on, on the contrary, the impact of technique patents were increasing. But the scientific papers had relatively high reserving capability, compared technique patents having higher diffusion capability and transformative capability.

Third, can applied science be "good science"? Also it was a complicated question to answer. Through the research, we found that the applied science had better interaction with the technique patent, such as the method for nanotube's manufacture in Table 1. Here it was also another reason why the paper chose the patents citing Smalley RE as the research object. Smalley RE won the Nobel Prize for his great scientific discovery C_{60}, detailed described in the paper *C_{60}: Buckminsterfullerene*. It was the typical academic science, but it was only cited 15 times in the technology diffusion, much less than his top cited paper *Length-dependent extraction of single walled carbon nanotubes*. So we considered that in technology development, the applied science is good science.

Forth, science and technology both were crucial in the technology diffusion, but they undertook different functions and acted dominatingly in the different period of technology diffusion. The former was the source of technology diffusion, and provided basic method in technology diffusion, while the cited patent assumed the prototype in the process of technology development.

So science and technology are the two sides of coin, but the coin has a central section where they are interacting all the time.

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