Dynamics of Patent Collaboration – The Case of Nanocomposite Materials

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***Abstract*— Nano-composite materials are reported to be the smartest materials of the century due to the property combinations that were not found in conventional composites. Since nanocomposite materials are at an early phase of their life-cycles, an exploratory analysis on collaborations between actors seem to be important towards the generation and dissemination of the required knowledge for actually benefiting from nano-composite applications. This study analyses the actors' patent collaboration structures and dynamics, and to identify the determinants of collaboration in the sector. Through the use of tech mining method and patent data on nano-composite materials (multi-dimensional nano-composites and single dimensional nanorods), the paper examines whether such collaborations in nano-composite materials affect national systems of innovation owing to its interdisciplinary type and its dispersion across scientific fields. The results indicate that Asian organizations have a significant advantage in developing strong collaborations networks, with the active involvement of large organisations. Linear (mono-linkage) collaborations among actors in the case of multi-dimensional nano-composites were appeared to be an effective model, revealed the stronger bonds particularly in Japan, China and South Korea. Whilst in single dimensional nanorods' case, more distribute and decentralised collaborations were appeared to be most efficient model, revealed the strongest bonds among actors.**

I. Introduction

It has been widely acknowledged that technology development and innovation are a major determinant of economic development and the competitiveness of firms, regions and nations [1]. Nano-composite materials have been considered as a revolutionary discovery in advanced materials and are believed to contribute substantially to innovativeness, economic growth and employment [2] as it shows certain characteristics of a 'General Purpose Technology' like the information and communication technology [3]. It can be applied to various technology sectors as a cross-sectional technology. Nevertheless, nano-composite materials come along with a high technological complexity, making it difficult for firms to access the economic potential of this technology. On the other hand, such nanomaterials are enabling technologies as it improves the quality of existing products and it has important implications of their value chains in terms of their flexibility of application which allows for the exploration of economies of scope (e.g. one type of nanomaterial can be used in a variety of applications that can benefit from the same special electronic, optical, catalytic, chemical or physical properties and the choice exists among the materials to be selected to fulfil a given function). Most applications of nano-composite materials require the skills and expertise of technologically advanced universities, private and public research institutes that have the ability to perform first-rate basic and applied research activities.

As such, the study argues that collaborations in nano-composite materials knowledge production are different from other established technological fields. In this field, new knowledge which is subsequently protected by patents mainly stems from applied research at industry-funded R&D units [4]. In contrast to this, basic research, as it is necessary to advance the field of nano-composite materials, is mostly performed at universities or government-funded research institutes which can actually afford less application-oriented research. Owing to the complexity of such emerging technology and its interdisciplinary nature, collaborations between actors would presumably not be bound to a geographical proximity in attracting a 'critical mass' of nano-composite material competencies. Since nano-composite based commercialised products are at an early phase of their life-cycles, collaborations between public institutes and private companies seem important towards the creation of the required knowledge for actually benefiting from composite materials applications.

This study specifically focuses on patent collaboration dynamics in nano-composite materials innovation system, as strong relationships between private and public actors have gained importance in improving the efficiency of innovation systems. Furthermore, this research provides a comparative study of the differences of innovation systems with regard to two different key nano-composite materials cases. In this study, multi-dimensional nano-composites and single dimensional nanorods are chosen in nanotechnology field. This study also supports and extends its findings with interview data that is collected from various nanotechnology experts. The results indicate that Asian organizations have a significant advantage in the composite materials field in terms of technological collaborations with the active involvement of large entities. Linear or mono-linkage collaborations were found to be an effective model by considering the rapid development of both academic and industrial actors. Nanotechnology centres appear to be an effective place to overcome difficulties related to the multidisciplinary nature of such emerging technology field. The current funding systems appear to be one of the key motivator for organisations to collaborate.

II. Literatur Review and Research Design

Collaborations related literatures are examined to find the gap and to position this study. Collaboration is a course of action in which actors share information, resources and responsibilities in the attainment of a common goal that is jointly planned, implemented, and evaluated by the participants [5]. There are different collaboration models exist including informal collaborations, strategic alliances, joint ventures, partnerships, R&D consortia, licence agreements, coalitions, associations, clusters and networks. Some of the reasons why organisations are encouraged to collaborate are the increased competition, technological complexity and higher R&D investment risks. The determinants that affect inter-organisational collaboration dynamics can be geographical [6-7], technological [8-10], organizational [11-12], economic [13-14] and societal/individual factors [15-16]. Furthermore, some studies focus on how involvement of different types of actors (e.g. academia, industry, intermediaries, and suppliers) affect collaboration mechanisms [17-18]. A number of studies have compared geographical locations [19-20] and the type of sectors (e.g. nanotechnology, biotechnology) [21]. Having examined different collaboration models, we assume that there would be academia-academia, academia-industry and industry-industry collaborations in nano-composite materials innovation, but it is not clear if the form of collaborations consist of small clusters or a network on a large geographical scale.

One of the basic categorisation of networks describes them as centralised, decentralised, or distributed. Accordingly, there can be a network with a dominant central ego to which other nodes are directly linked. This network may not have a very healthy structure as the network is controlled by an individual organisation and the progress of the network may be slow and unstable. The structure of a network is likely to be vulnerable and unstable if there is a single node in it, as it is too dependent on the central ego. A decentralised network can be considered as a more efficient model in terms of knowledge flow compared to the centralised model, as the structure consists of clusters or smaller networks with a higher number of central organisations. The most effective and stable network structure is the distributed network, as risk factors are lower compared to other types of networks. Distributed networks are likely to have lower levels of formalised interactions among comparatively equal organisations and the distribution of knowledge and resources will be more balanced.

The key objective of this paper is to understand and analyse patent collaboration dynamics in a particular nano-composite field. However, it is assumed that there will be various structures where there are central players or multiple dominant actors appearing within the composite materials innovation system. As an analytical framework, the study proposes a collaboration model which consists of five different collaboration network types that were termed for the purposes of this study as mono-linkage, oligo-linkage, central-linkage, decentral-linkage and distributed linkage (see Figure 1). It is expected that there will be various types of collaboration networks in terms of actors and information flow within nano-composite materials system.

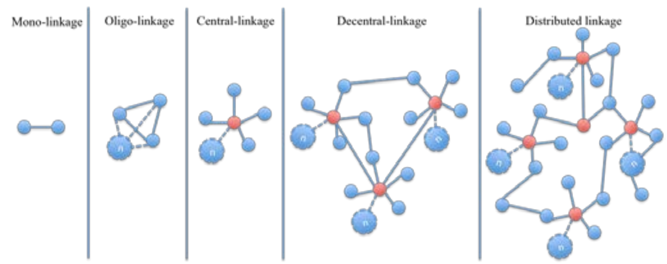

Figure 1: Proposed analytical framework for collaborations types in nano-composite materials technology field

This study applies the proposed model to analyse the nano-composite materials case, where the institutional networks of nano-composite technology are being examined in terms of the structure by which organisations are linked to each other and what the national and regional differences are with regard to the various collaboration types as described (i.e. mono-linkage, oligo-linkage, central-linkage, decentral-linkage and distributed linkage), and what the collaboration characteristics are. To fulfil the purpose of the study, it attempts to answer the following fundamental questions: 1) what the collaboration structures are in respect to the actors involved in nano-composite materials; 2) how the leading actors are linked to each other and how effective their collaborative network is.

A technology mining method [22], is used to analyse the patent data. Technology mining can be used to determine relations between actors and technologies within a given innovation system. Patent and scientometric analyses were based on large and general nanoscience and nanotechnology database retrieved from Thomson Innovation patent database. Subsequent analysis was performed using dedicated technology mining software VantagePoint and Thomson Data Analyser (TDA). The software automates mining and clustering of terms occurring in patent abstracts and patent descriptors, such as authors, affiliations, or keywords that it recommends. This makes the results increasingly valid and reliable; as this data mining software allowed the data to be cleaned further to eliminate unnecessary patent documents and duplicates. Table 1 shows an outline of research methods used in this study. Gathering valid patent data, efficient analysis of large data sets, and handling and interpreting the outcomes of the analysis is crucial for the accuracy of the results.

Table 1: The outline of research method

Quantitative Work	Qualitative Work
- Patent database selection - Patent search - Patent data optimization - Patent data analysis - The outcome of patent analysis	- Selection of interviewees according to the patent analysis - The design of interview questions according to patent analysis outcome - Gathering key factors for identifying collaboration dynamics

Patent data were extracted by using relevant keywords and all the classification codes including 977 by USPTO, B82 by IPC, Y01N by ECLA, and 3C082 by Japanese F-Terms. After collecting the patent dataset, there were still certain steps exist that need to be taken to optimise the data set. However, duplicates are very rare in the data since DWPI is used in the patent data collection phase. For those remaining irrelevant documents, VantagePoint and TDA were used to eliminate them and to achieve the required results. After optimizing the dataset, 1,792 nano-composite materials and 1,466 nano-rod patents were obtained. The patents were analysed with the data covering all the granted and applied patents.

The obtained results were imported into VantagePoint and Thomson Data Analyser (TDA) and, to validate the results further. The duplicate results were eliminated and variations of company, inventor, institute, and university names were unified where they appeared as separate patent assignees. After the dataset was prepared, various functions offered by the software were utilized to generate the required analysis. To validate the patent analysis, we conducted face-to-face semi-structured interviews with leading experts who worked in these composite materials. These experts largely spanned the entire value chain, from blue sky research at universities to producers of novel materials and the products that contain them. They were asked questions related to key aspects of the innovation system: 1) sources and strength of nano-composite materials research, 2) collaboration structure and levels, 3) technology transfer and commercial dynamics. Follow-up calls and emails were also carried out for any needed clarifications.

III. Results

A. The case of multi-dimentional nano-composite materials

Nano-composite materials (ceramic-, metal- and polymer-based nanocomposites) have emerged as suitable alternatives to overcome limitations of micro-composites and mono-lithics. The structure of nanocomposites usually consists of the matrix material containing the nano-sized reinforcement components in the form of particles, whiskers, fibres, nanotubes, etc [23]. They are reported to be the materials of 21st century in the view of possessing design uniqueness and property combinations that are not found in conventional composites. The nanocomposite would assume 2.5% of the fill material while a conventional composite may require 20% or more. It can be seen that the nanocomposite presents significant improvements in fracture strength and toughness, high temperature strength and creep resistance compared with its micro counterpart and to the monolithic matrix component. The applications of nanocomposite systems are numerous, comprising both the generation of new materials and the performance enhancement of known devices such as fuel cells, sensors and coatings. The polymer-based nanocomposite materials are in the forefront of applications due to their more advanced development status compared to metal and ceramic counterparts, in addition to their unique properties. Although the use of nanocomposites in industry is not yet large, their massive switching from research to industry has already started and is expected to be extensive in the next few years [23].

As mentioned 1,792 patents had been granted for nano-composite materials, among of them are 3,459 inventors, 1,400 organisations, and 30 countries. The significant increase in the number of patents started from 2002 and the peak for patenting activity was between 2005 and 2009. The gradual increase in patent documents promises the high commercialisability of this technology. As shown in Table 2, the leading country and organisation profile is articulated. The Chinese and Korean-based public institutions are playing a key role in nano-composite technology development and help ensure China and Korea lead in patenting the technology. From Table 2, it can be seen that academic actors in both the countries perform an important function, for instance, China's top four players and Korea's two players are all universities except Samsung. In the US, Samsung leads its position. This is due to the fact that Samsung often patents its inventions both in the US and Korea at the same time. The statistics of the percentage of granted patents within the last three years supports the top rank of China as 34% of their nano-composite patents have been granted within the last three years, which is the highest number compared to other countries. The second rapid increase has taken place in Korea with 20%.

On the other hand, private organisations in Japan lead in nano-composite technology, among of them are Sumitomo, Hitachi and Mitsubishi with a slow growth in last three years. The leading organisation in China is Chinese Academy of Sciences (CAS). The Chinese nano-composite leader CAS, as a late mover, was granted its first patent only in 2000 while most other companies involved in this field became so in the late 80s (see Table 2). However, CAS overtook other actors in the field within quite a short time period. As mentioned before, academic actors play a substantial role in the nano-composite materials technology. Their successful involvement in this area is very important for the technology diffusion process as academic institutions collaborate with private companies as they try to create spinoffs to commercialise their patents. When looking at the general profile of corporate actors, the dominant involvement of the electronic industry can be seen, which is, of course, due to the extensive applicability of nano-composite technology to electronic devices and materials.

Table 2: Patent profile in nano-composite technology field

Number of Records	Country	Top Organizations	Year Range	% of Records in Last-3 Years
904	CN	CHINESE ACAD SCI [87]; UNIV SHANGHAI JIAOTONG [30]; UNIV SICHUAN [25]; UNIV DONGHUA [25]	2000 - 2011	34% of 904
297	JP	SUMITOMO SPECIAL METALS CO LTD [33]; HITACHI LTD [22]; MITSUBISHI GROUP [14]; NISSEI JUSHI KOGYO KK [14]	1989 - 2010	6% of 297
229	US	SAMSUNG ELECTRONICS CO LTD [9]; BRIDGESTONE CORP [5]; UNIV CALIFORNIA [5]; JANG B Z [5]; DANA CORP [5]; ZHAMU A [5]; GENERAL ELECTRIC CO [5]; CABLE COMPONENTS GROUP [5]	1989 - 2010	12% of 229
191	KR	KOREA INST SCI & TECHNOLOGY [20]; SAMSUNG ELECTRONICS CO LTD [19]; KOREA RES INST CHEM TECHNOLOGY [13]	1990 - 2011	20% of 191
66	EP	BEKAERT NV SA [3]; STARCK GMBH&CO KG H C [2]; SANDVIK INTELLECTUAL PROPERTY HB [2]; ETH ZUERICH [2]; METALLOCERAMICA VANZETTI SPA [2]; XEROX CORP [2]; MAX PLANCK GES FOERDERUNG WISSENSCHAFTEN [2]; FRAUNHOFER [2]	1991 - 2010	12% of 66
65	DE	INST NEUE MATERIALIEN GEMEINNUETZIGE [5]; LEIBNIZ INST NEUE MATERIALIEN GEMEINNUET [5]; FRAUNHOFER [5]	1992 - 2010	9% of 65
28	TW	IND TECHNOLOGY RES INST [7]; ZH KOGYO GIJUTSU KENKYUHIN [5]; CHUNG SHAN INST SCI&TECHNOLOGY [4]	1998 - 2010	7% of 28

In the case of nano-composite materials technology, all of the collaborations appear as linear (mono-linkage network) structured. As shown in the collaboration map of the nano-composite field, the strongest collaboration appears to be in between Sumitomo Special Metals Co Ltd and Hitachi Ltd (see Figure 2). These two organisations share have the highest number of collaborations with 12 patent collaborations, both of which are corporate organisations within the realm of nano-comnposite technology. No countries appear to have a cluster but the collaboration between Japanese corporate organisations are very significant. In fact, the strongest bond is found between Sumitomo Special Metals Co Ltd and Hitachi Ltd. Generally, it can be said that mono-linkages between organisations result in stronger collaborations. This is due to their patent agreement within nano-composite field that both parties share their IP rights. Moreover, as presented in the proposed model considering the number of shared patents produced, this kind of linear structure (mono-linkage) appears to be an effective model due to two factors. Firstly, it is a collaboration between tow industrial players so there is great mutual interest in each other's activities and involvement. Secondly, the size of the organisations is significantly large and it is very balanced in respect to their own industrial activity. This is very important for the nano-composite field given the fact that required investment is high in respect to the related industries such as the semiconductor industry and it requires scientists from diverse scientific fields such as material sciences, electronics, and chemistry.

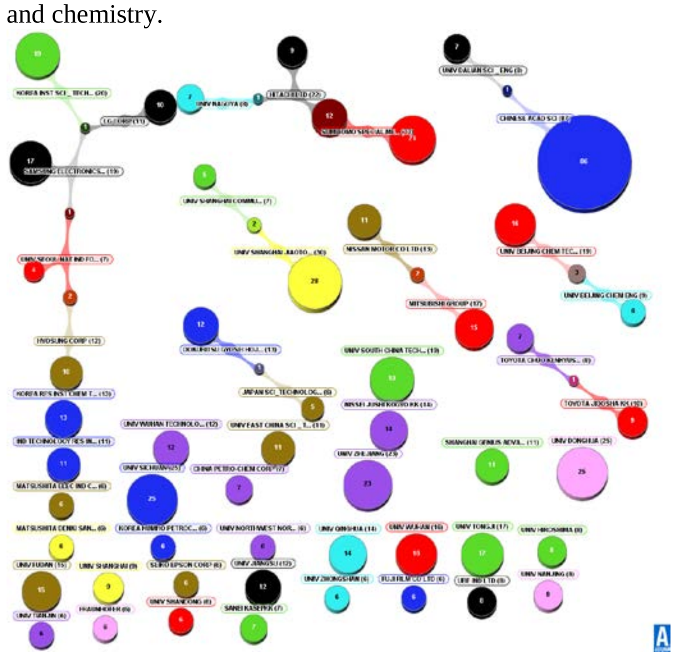

Figure 2: Patent collaboration in nano-composite materials

By looking at the general picture for nano-composite materials patent collaboration dynamics, it is to be expected that Chinese players should have a greater degree of collaborative involvement in patent activity as they hold the highest number of patents. An interesting point is that Chinese Academy of Sciences (CAS) holds the highest number of patents (87), but shares only one of them. CAS does not share their IP rights which interpretes that they commercialise nano-composite technology by their own initiatives. This kind of collaboration may indicate a focused R&D group as there are no substantial collaborations with neither private nor public actors from across the country and regions.

B. The case of single-dimentional nano-composite materials (nanorods)

Nanorods are single-dimensional rod like nano-composite materials where each of their dimensions range from 1–100 nm, and can have applications that include next-generation electronics and sensing elements [24]. Nanorods and nanowires are very similar, and in most synthesis produced together. The real difference lies in their aspect ratios i.e., the ratio of their length to width. This ratio further determines the application of the moiety as either a nanorod or a nanowire. Nanorods are thicker in comparison to nanowires, the latter thus having greater flexibility and both of them having greater flexibility than nanotubes. Such kind of nano-composite material is one of the most mature nanostructures that are available today and so an analysis of the patents in this field is significant as there are more patent applications for nanorods compared to other nanotechnology field [24].

Table 3: Patent profile in nanorods technology field

Number of Records	Country	Top Organizations	Year Range	% of Records in Last-3 Years
696	US	SAMSUNG ELECTRONICS CO LTD [43]; UNIV CALIFORNIA [39]; KONARKA TECHNOLOGIES INC [23]	1996 - 2010	24% of 696
317	CN	CAS [24]; CHINESE ACAD SCI [22]; UNIV ZHEJIANG [17]	2002 - 2011	58% of 317
297	KR	SAMSUNG ELECTRONICS CO LTD [73]; POSTECH FOUND [27]; KOREA INST SCI & TECHNOLOGY [17]	2000 - 2010	36% of 297
124	JP	MITSUBISHI GROUP [22]; DAINIPPON TORYO KK [19]; DOKURITSU GYOSEI HOJIN BUSSHITSU ZAIRYO [13]; RICOH KK [13]	2000 - 2010	24% of 124
46	TW	UNIV NAT CHAO TUNG [9]; IND TECHNOLOGY RES INST [7]; HON HAI PRECISION IND CO LTD [4]; UNIV NAT CHENG KUNG [4]	2002 - 2010	24% of 46
44	EP	SAMSUNG ELECTRONICS CO LTD [5]; KIM J [3]; LG INNOTEK CO LTD [3]; LG ELECTRONICS INC [3]; STORMLED AB [3]	2001 - 2010	34% of 44
28	GB	CAMBRIDGE ENTERPRISE LTD [5]; IMPERIAL INNOVATIONS LTD [3]; RGB CO LTD [2]; UNIV CAMBRIDGE TECH SERVICES LTD [2]; GENERAL ELECTRIC CO [2]; SHARP KK [2]; UNIV OXFORD [2]	2001 - 2010	39% of 28

As mentioned 1,466 patents had been granted for nanorods, among of them are 3,709 inventors, 1,339 organisations, and 27 countries. The significant increase in the number of patents started from 2002 and the peak for patenting activity was between 2008 and 2009. The gradual increase in patent documents promises the high commercialisability of this technology. As shown in Table 3, the Korean based multi-national company Samsung is the leading organisation within the US and Korea. This is due to the fact that Samsung often patents its inventions both in the US and Korea at the same time. The Japanese and Chinese-based actors are also playing a key role in nanorods. As shown in Table 3, it can be seen that corporate actors in both Korea and Japan perform a substantial part of nanorods technology system. The percentage granted patents supports the top rank of China as 58% of their nanorods patents have been granted within the last three years, which is the highest number compared to other countries. The second rapid increase has taken place in the UK with 39%. In the US, University of California leads while Chinese Academy of Sciences (CAS) leads in China. When looking at the general profile of corporate actors, the dominant involvement of the electronic industry can be seen due to the extensive applicability of nanorods to electronic devices and materials.

Looking at the general structure of nanorods patent collaboration networks and clusters (Figure 3), it can be claimed that the structure of Korean innovation systems may begin with a key collaboration between Samsung and other organisations which agree to form the bidirectional linkage. This new formation enlarges and establishes the centralized cluster due to the presence of a dominant player in the system such as Samsung. After the development of centralised clusters, the structure evolves to a decentralized cluster model as the US academic organisation Rensselaer Polytechnic involves. The US cluster appears to be decentralized where both corporate and public actors collaborate to each other and this type of cluster has better characteristics in terms of its stability and efficiency. In japan and China, most of the collaborations are mono-linkage (linear) types where two organisations share their IP rights. Some collaboration appears in Japan and Korea to have oligo-linkage type where the network appears to be expending (see Figure 3).

IV. DISCUSSIONS

The research objective was to investigate patent collaboration dynamics in nano-composite materials using a proposed framework and to analyse the determinants of collaboration in this emerging field by linking the observable innovative output patents to the observable inputs such as investments in research and development in nano-composite materials in terms of funding, personnel as well as the technological strength and specialisation. We were interested in whether collaborations in nano-composite materials presumably be bound to a geographical proximity or a matter of national systems of innovation owing to its globally dispersion and complexity; what the national and regional differences are with regard to the various collaboration types

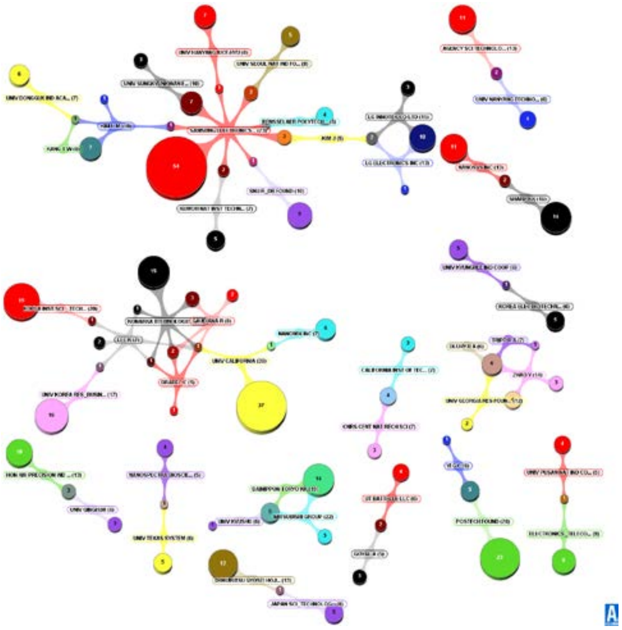

Figure 3: Patent collaboration in nanorods technology

as described in our collaboration framework; and what the collaboration types are.

This research provided the opportunity to construct a collaboration network profile for nano-composite materials technology. This has provided much valuable information, including identification of key actors and regions where nano-composite materials (multi-dimensional and single-dimentional) patents are being produced. An interesting outcome was to see the changing dynamics of involvement by different countries in nano-composite technology. Asian players appear to have very high collaborative involvement in this area. It appears that South Korea, Japan and China are leading in the technology. With respect to the key actors in the field, the electronics industry's ownership of patents is dominated mostly by large organizations. The main reason for this is, large organisations have the capability to provide the large investment necessary for R&D activities and they are aware of the benefits of nano-composite technology in terms of its efficiency and its nature for bringing about incremental innovation characteristics.

A linear or mono-linkages collaboration can be considered as the only effective model for multi-dimensional nano-composite materials technology field, whilst a mix of all collaboration types (e.g., decentralised, distributed, oligo and mon-linkages) were appear to be effective in nanorods technology. Considering the collaboration networks and clusters, it can be said that these vary greatly from one country to another. It was found that the Samsung's centralized network is due to the international externalities of multinational companies. There was a high degree of co-ownership by two Japanese corporate organisations both in the private spheres. However, it was found that the main focus of these collaborations was within the electronics sector. This is of course due to the application of nano-composite technology to semiconductors, batteries and display technologies. It can be noted that the US has a national cluster rather than an international network. Another interesting fact is that the China shows very poor intention to collaborate in the field, although CAS has a very strong patent records in multi-dimensional nano-composites. In China, the number of collaborative organisations should be increased to move it to the stage where there is an innovative cluster to increase the technology diffusion process. This research suggests that the government should take action to bring this about.

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