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An empirical analysis of nanotechnology research domains

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ABSTRACT

Research activities in nanotechnology have been strengthened worldwide since the last decade to provide a foundation for technological advancement by grasping nanoscience and technology opportunities. This paper aims to make a refined classification to understand the whole research spectrum in nanotechnologies. We also provide an insight into horizontal comparisons between the research domains using *tech mining* (Porter 2005) method. The findings show the regional strengths and weaknesses in nanotechnology research domains, indicating that the US has gained much strength in bionanotechnology research relative to other domains, and the other regions (e.g. the EU, Japan, China, South Korea and India) have gained their research strength in nanomaterials, nanoelectronics and nanomanufacturing and tools. The paper contributes to the literature of nanotechnology management by providing a categorization of nanotechnology research and offers a useful insight for academic and industry practitioners in nanoscience and technology fields.

1. Introduction

It has been nearly half a century since Nobel Prize winner Richard Feynman advocated widespread nano-scale research by delivering his famous speech "There's plenty of room at the bottom" in 1959, through which the nanotechnology concept first captured the world's attention. Nanotechnology, a field prioritized and promoted by governments worldwide, comprises one of the fastest-growing research areas in scientific and technical fields in the world (National Science and Technology Council, 2006). Like many areas of scientific and technological exploration, nanotechnology exists on the borders between disciplines and technology domains. Several literatures explore nanotechnology as a multidisciplinary field since it requires multi-disciplined networked research (Meyer and Persson, 1998; Schummer, 2004; Rafols and Meyer, 2007; Islam and Miyazaki, 2009), education and an improvement in the level of human skills performance; it also requires input from, amongst others, chemists, physicists, materials scientists, biologists, engineers and pharmacologists. What has led to a breakthrough in nanotechnology is the rapid development and application of nano-instruments for observing and manipulating matters in the nano-scale and the discovery of new nanomaterials (e.g. carbon nanotube, fullerene) for developing the building blocks of nanoproducts. Nanotechnology thus conforms to a pattern of science-based innovation, where an important revolution in analytical instruments, preceding discoveries and subsequent technological advancement (Rosenberg, 1982) stimulated the exploration of nano-scale structures and the development of nano-scale technologies.

In the 21st century, nanotechnology is being considered as a key technology of molecular or atomic engineering that might have the potential to produce sweeping changes to almost all aspects of human society beyond the scope of conventional technologies (Roco and Bainbridge, 2002). For example, nanotechnology encompasses more distinct areas such as precision engineering as well as electronics, electrochemical systems (lab-on-a-chip devices) and mainstream biomedical applications in areas as diverse as gene therapy, drug delivery and novel drug discovery techniques. Many authors split nanotechnologies in many ways, e.g. top-down nano and bottom-up nano (Kautt et al., 2007; Walsh and Elders, 2003; Binns and Driscoll, 1999). As such, nanotechnology is built upon many sciences and technologies and is inherently complex. In nanotechnology there can be both a *mechanistic version* (more materials science and microelectronics inspired, having new or significantly improved mechanical, electrical and chemical properties or functions) and a *bio-mimetic version* (more biotechnology inspired, having control of biological systems in order to achieve desired and designed outcomes).

Earlier studies inform us well on the long-term time perspective of the technology, its possible impacts and key actors in the development of nanotechnology (Walsh, 2004; Yung-Chi Shen et al., 2009). They inform us little on the evolution of the nanotechnological fields of spectrum. A broad and refined classification of nanotechnology research spectrum could enrich

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the literature of nanotechnology management. As nanotechnology is mostly developed as a knowledge intensive sector, organizations (e.g. universities, public research institutes or company R&D laboratories) have focused strongly on the science and technology part of it. The main purpose of this study is to provide an empirical analysis of the dynamics of nanotechnology research domains, to compare specialization patterns among the leading countries, and to show the evidence of growth rate and interdisciplinarity of domains. In this paper, it also seeks to identify mature and immature domains for nanotechnology research. In the following sections, literature related to this research is reviewed and a general framework of nanoscience and technology evolution is introduced. The research question and methodology are then defined and clarified. Afterwards research analyses, findings and implications have so far been presented and further research activities are proposed.

2. Developing a general framework of nanoscience and technology evolution

Since nanotechnology knowledge is highly dispersed and extends beyond a particular technology sector, no single theory or approach can explain nanoscience and technology evolution dynamics. Theories and studies of technology and innovation management argue that some changes in technology have so pervasive impacts on the economy that they will entail a techno-economic paradigm change (Dosi, 1982; Freeman and Perez, 1988; Nelson and Winter, 1982; Perez, 2000). Possibly a techno-economic paradigm change entails a disruption or renewal of many existing industries as in the case of nanotechnology. Such a possible major industrial transition is likely to take 20–30 years since nanotechnology development appears analogous to that of the two other major general-purpose technologies such as biotechnology and ICT 25–30 years ago (Freeman and Louçã, 2001). Several studies have argued for a possible techno–economic transition led by nanotechnology. Specifically Wilson (2002) argued that the aggressive growth of these two general-purpose technologies cannot be sustained without nanotechnology. Ikezawa (2001) mentioned that nanotechnology provides new possibilities of manufacturing and is likely to say that the bottom-up manufacturing approach is a key to create new nanotechnology paradigm.

The characterizing features and the visionary aspects of nanotechnology make it challenging to analyse the determinants of the innovation process as they are involved in a range of scientific disciplines and technology domains. Besides, the performance of public research institutions and private actors that generate and disseminate nano-knowledge plays a significant role in the development of nanotechnological systems. In this context, the innovation systems (SI) approach (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Edquist, 1997) seems adequate to explore nanoscience and technology evolution framework. Within the SI approach, a technological system requires some unit of study or dimensions of analysis to delineate its boundaries (Metcalfe, 1995; Carlsson et al., 2002). The general framework related to nanoscience and technology evolution does not center on exclusively national (Lundval, 1992), technological

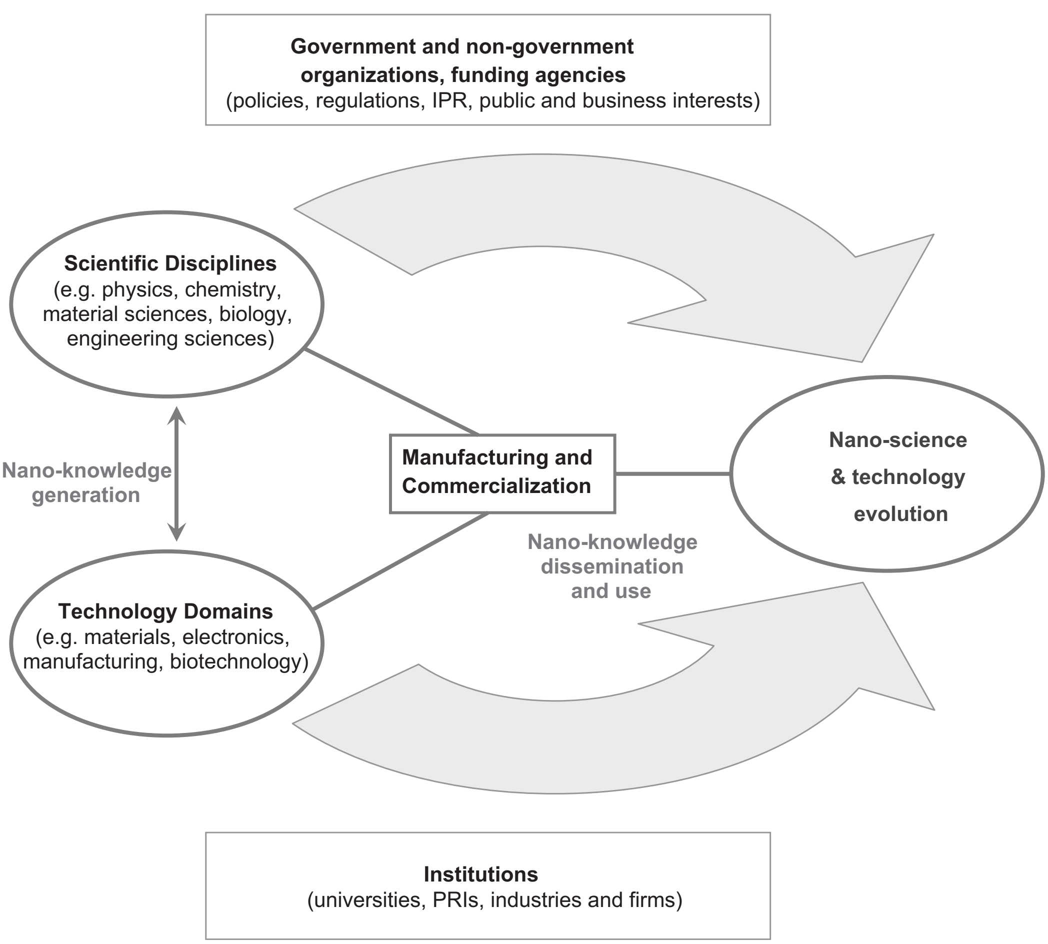


Fig. 1. General framework of nanoscience and technology evolution.

(Carlsson and Stankiewicz, 1991; Carlsson et al., 2002), or sectoral aspects (Malerba, 2002), since things are little unusual in the case of nanotechnology as it is not really a specific technology or product group, nor is there any defined group of scientific disciplines and/or technology domains behind its development. Drawing on national and technological systems approaches and considering additional elements to fill the gaps and adapt the approaches to the specificities of nano-knowledge creation and dissemination, the authors define a general framework within which major elements and the relevant institutions or organizations are embedded to shape the technology evolution. Fig. 1 is an overview of this framework.

Generally, nanotechnology research has been developed mainly in universities and public research institutes where scientific disciplines, such as chemistry, physics, materials sciences and biology are extensively involved in the relevant research to explore nano-science as a scientific curiosity and through government initiatives drives. The basic scientific disciplines connect to different types of technology domains. For example, within electronics, demands for increased performance through smaller components have paved the way to the nano-scale. The driver in materials sector has been the search for new properties in materials. In recent times, performance demands in new materials have also come from biotechnology through the development of regenerative medicine and drug delivery. Similarly, companies complement their activities by interacting with each other and help the technology evolution through manufacturing and commercialization. Under the proposed framework, the regulatory infrastructures (e.g. standards, ethics), public policies and funding allocation system constitute important elements for fostering nanotechnology research across institutions, such as universities, public research institutes and companies. Therefore, institutions are getting involved, initially, for the generation of nano-knowledge to grasp scientific and technological opportunities. The paper also argues that nanoscience and technology evolution is not one directional, rather different technology domains and disciplines interact, and government and institutional infrastructures are supporting them to evolve. Under the proposed framework, we would rather focus on identifying specific research domains through which nano-knowledge generates and then disseminates the knowledge by manufacturing and commercialization.

3. Research method

Bibliometric quantification is an effective way to show the emergence and development of a new technology (Braun et al., 1997). Over the past few years, several attempts have been made to study nanoscience and technology management (for example, two journals called *Research Policy* and *Technological Forecasting & Social Change* were published with their special issues on nanotechnology). The studies over the years can be grouped into several categories, such as: (1) Nanoscience and nanotechnology interactions (Zhou and Leydesdorff, 2006, Hullmann and Meyer, 2003; Meyer, 2000); (2) The realization of nanotechnologies potential (Roco and Bainbridge, 2002, Nordmann, 2004); (3) The productivity of publications and patents in a bibliometric manner (Islam and Miyazaki, 2009; Lee et al., 2009; Zucker and Darby, 2006; Kostoff et al., 2004; Zucker et al., 2002; Braun et al., 1997). Existing studies lack the classification of nanotechnology research domains, which we think can make a worthy contribution to enrich the literatures in nanoscience and technology management. The practitioners in this field can greatly benefit from an examination of the status of entire research domains and the dynamics of nano-knowledge generation and their revealed technology advantages. The *tech mining* method proposed by Porter and Cunningham (2005) is used in this study which draws heavily a significant impact on the analysis in segmenting nanotechnology research spectrum.

Nanoscience and technology comprises a range of scientific fields that cover a large amount of research activities and the application of research is spreading into every industrial sectors. Therefore, an engineering database covering multidisciplinary applied research outputs would be a better choice. Our analysis is based on relevant scientific outputs—nanotechnology-related academic publications from Elsevier Engineering Index (EI) Compendex database covering a 15-year period (1990–2004), using specialist keywords derived from the Nano Science and Technology Institute (NSTI) publications, starting with the first academic articles and tracking almost the entire lifecycle of the technology. This paper attempts to answer the questions: (1) Which areas of nanotechnologies are currently state of the art and how mature are they? (2) How is the involvement of organizations, regions or countries in the development of nanotechnology knowledge? (3) Which areas of research are most important for specific types of organizations and for specific regions? In this paper, *tech mining* method is applied which analyzes the relations between actors and technologies within a given innovation system based on the input data from the article database. Subsequent analysis is performed using a dedicated *tech mining* software VantagePoint, automating mining and clustering of terms occurring in article abstracts and article descriptors such as authors, affiliations or keywords. In addition, VantagePoint helps us to statistically and textually analyze articles, cluster thousands of keywords or specialist terms occurring in abstracts, thus increasing the reliability of the findings and opening up new analytical opportunities for emerging technologies such as nanotechnology. The article abstracts from the database were imported to VantagePoint from which duplicates or empty records, typographical errors (typos) in affiliation name and related geo-graphical information, name variations, inconsistency among each fields from different articles were removed. We double checked the raw records, cleaned our data set and facilitated the subsequent analyses.

4. Classification of nanotechnology research domains

Nanotechnological research has attained much interest recently in the global scientific and technical agenda due to its versatile potential applications. In this section, the quantitative analysis involves the classification of nanotechnology research domains. In order to divide whole nanoscience and technology research articles into distinctive domains, we use article keywords and EI codes defined by Elsevier Compendex. EI codes are standardized and nested structures used to assign every article extracted from the database. Every article may be assigned to one or more EI codes—as interdisciplinary research will fall into several categories and consequently have several EI codes. Every keyword from the articles has also been assigned to relevant research domains. Therefore this categorization scheme is more reliable than the traditional paper-based bibliometric research. Following this method and the interpretations from specialist technical literature, we have decided to divide the entire nanotechnology-related applied research outputs into four domains, for example, *nanomaterials*, *nanoelectronics*, *bionanotechnology, and nanomanufacturing and tools*. Table 1 demonstrates a refined classification of nanotechnology research domains including domain names, short description, examples of EI codes and the relevant keywords. For every domain, detailed lists of relevant EI codes were identified—specific domains corresponded in general to distinctive EI classes (e.g. *nanomaterials*: EI codes 5.x

Table 1
Classification of nanotechnology research domains.

Domain name	Short description	Examples of codes	Examples of keywords
Bionanotechnology	Bionanotechnology concerns with molecular scale properties and applications of biological nanostructures. It can be used in medicine to provide a systematic, as well as a screening, approach to drug discovery, to enhance both diagnostic and therapeutic techniques and to image at the cellular and sub-cellular levels.	Compendex EI code 4.x	Biological nanosensors, nanobiomagnetics, nanocantelevers, targeted nano-therapeutics, nanoreplication, nanoencapsulation
Nanoelectronics	Nanoelectronics focuses nanoscale properties and applications of semiconductor structures and devices, and process technology to explore economic and performance benefits in computing, information and communication system.	Compendex EI code 6.x and 7.x	Nanodevices, quantum dot lasers, nanosensors, nanocrystal memory, molecular electronics, nanorobotics
Nanomaterials	Nanomaterials concern with control of the structure of materials at nanoscale with great potential to create a range of advanced materials with novel characteristics, functions and applications.	Compendex EI code 5.x and 8.x	Nanomaterial, fullerenes, nanocomposite, nanofilms, carbon nanotubes, nanoparticles
Nanomanufacturing and tools	Nanomanufacturing attempts at building more intricate (information-rich, self-assembly) nanostructures. In addition, tools concern its ability to manipulate and characterize materials at the nanoscale.	Compendex EI code 9.x	Nanoprototyping, nanofabrication, nanolithography, scanning tunneling microscopy, atomic force microscopy

Table 2
Publications share in nanotechnology research domains.

Total number of publications by domains - »	1919	24,267	3847	28,019
Year	**Bionanotechnology**	**Nanoelectronics**	**Nanomanufacturing and tools**	**Nanomaterials**
1990	0	2	0	2
1991	0	1	0	1
1992	0	18	2	18
1993	0	18	3	19
1994	9	223	37	280
1995	21	856	148	1034
1996	22	965	129	1158
1997	17	1067	107	1329
1998	34	892	93	1122
1999	37	1241	165	1548
2000	35	1423	171	1757
2001	108	2208	312	2551
2002	214	3113	480	3595
2003	421	4547	741	5178
2004	1001	7693	1459	8427

and 8.x; *nanoelectronics*: EI codes 6.x and 7.x; *bionanotechnology*: EI code 4.x; and *nanomanufacturing* and *tools*: EI code 9.x). There were many individual variances and many of the several hundred sub-classes were excluded from or assigned to other domains. In this way, an exclusive list of EI codes for every nanotechnology research domain was generated and used it to classify nanotechnology research.

5. Horizontal comparisons of nanotechnology research domains

In this section, we focus identifying the leading and emerging sectors of nanotechnology, compare the horizontal discourse development in domains and analyze the distinctive research profiles of individual countries. In addition, we identify diversity and similarity of domains as well as the interdisciplinarity. The variation of nanotechnology applied research outputs is illustrated in Table 2, which indicates that nanomaterials and nanoelectronics domains shows their superiority in terms of publications. The finding also show that overall research output increases slowly from the early 1990s and then increases rapidly since the early 2000s (Fig. 2). Research activity in other two domains such as bionanotechnology and nanomanufacturing and tools is slowly picking up which is instructive in that they are still emerging sectors for nanotechnology.

From the characterized nanotechnology domains, we get a completely different picture when we compare the average growth rate of publications. In bionanotechnology, the average growth rate exceeds 40%, although the total publications share stands below 5%. On the other hand, the average growth rate is not exceeded more than 20% in nanoelectronics and nanomaterials domains, while the total publications share exceeds 40%. The results are illustrated in the Fig. 3, which interprets that biotechnology domain is a rapid growing field for nanotechnology, manufacturing and tools show moderate growth, and electronics and materials domains are indicating the slow growth. The research also forecasts the mature and immature domains for nanotechnology. Fig. 4 forecasts that large sized (in terms of articles volume) domains, for example, materials and electronics domains with slower growth rate are said to be more mature in terms of applied research and look for new applications. While small sized manufacturing and tools and biotechnology domains with moderate to higher growth rate are said to be most promising and emerging fields in the near future.

Fig. 5 compares the regional nanotechnology research activities, although the absolute number varies due to the number of researchers involved in the relevant regions. When

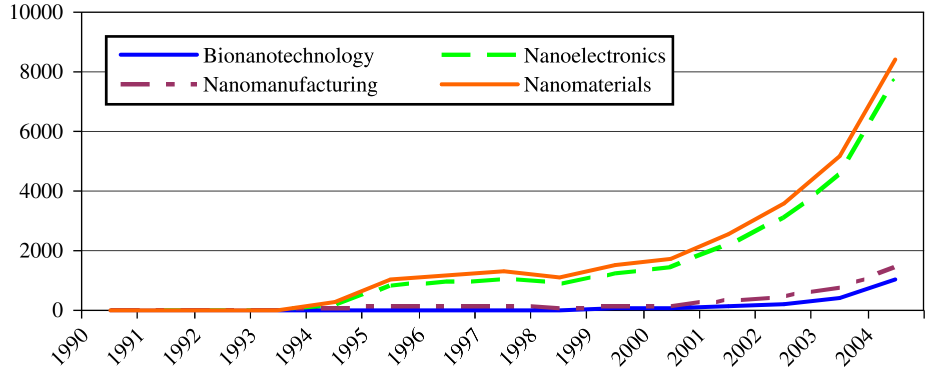


Fig. 2. Nanotechnology domains' research output.

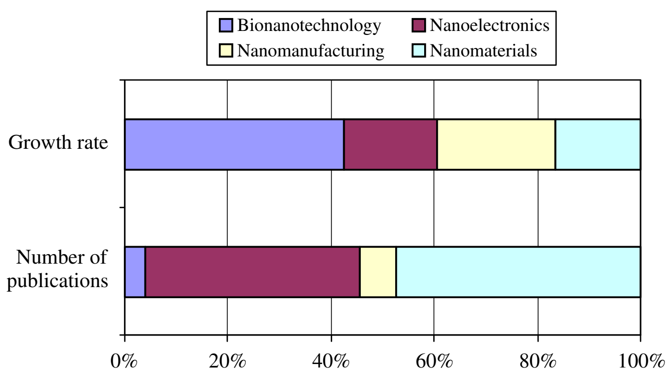


Fig. 3. Comparison of nanotechnology domains' growth rate.

comparing the regional strengths and weaknesses, US leads exceptionally in biotechnology sector focusing on biological aspects of nanotechnology relative to the other regions. The result interprets in a way that the strength in bionanotechnology may either represent a potential support by public and private funding or by the presence of high critical mass of expertise. The EU countries show their strong activity in researching nanomaterials domain. The reason may be the involvement of recently established interdisciplinary research centres (IRC), within and outside the universities across Europe, explore the new properties and functions of nanomaterials. The Asian player, for example, Japan, China, South Korea and India show their strong research performances in nanoelectronics and nanomaterials domains considered by some to be areas that may quickly become a commodity, while the performances in bionanotechnology and nanomanufacturing have lagged behind.

Fig. 6 illustrates a comparison with respect to specific types of organizations, such as universities, public research institutes and private companies. The finding indicates that universities are the main actors for generating nanotechnology knowledge and public research institutes complement them. Private companies account for little contributions to nanotechnology knowledge generation, i.e. nanotechnology research engagement with industry still face challenges. The part of reason is that industry itself either does not understand the opportunities of nanotechnology or not willing to take a risk due to the market uncertainties. As illustrated in the figure, it clearly indicates that nanomaterials and nanoelectronics have reached to mature research areas with respect to the high volume of publications compared to other domains such as bionanotechnology and nanomanufacturing and tools that seem to be the emerging sectors for nanotechnology.

The research then looked at to see whether any overlapping between the domains exists, and how much is the overlapping interest. Table 3 represents an auto-correlations chart between the domains, calculated by *tech mining* software VantagePoint. Very low correlations value from the finding suggests that there are no direct overlaps between the singled out domains, even though many articles are classified as belonging to other domains. Overlapping of the research interests may exist with respect to high value of correlation. Very small values of correlation from the finding, as illustrated in Table 3, suggests the divergence of nanotechnology research interest without or little overlapping.

Nanotechnology research has already been considered as a field of more inter-disciplinary than other areas of sciences. Table 4 shows the inter-disciplinary character of nanotechnology research, as the fractional percentage volume data illuminates bridging between the domains, instead of showing their majority in one discrete domain (data were calculated by *tech mining* software VantagePoint). The finding is so instructive that nanotechnology research has mastered a diversity of areas that originated from different scientific and technological fields.

6. RTA profile analysis of regions in nanotechnology research domains

The data were then converted to calculate regional advantages in nanotechnology as it seems better to compare on a relative rather than on an absolute basis. The transformation widely adopted in recent work on comparative technological development at both country and sector level is the Revealed Technological Advantage (Cantwell, 1993). To view a comparative dynamics on nanotechnology knowledge domains, we compare the findings between the West and the East regions. The dynamic changes in the comparative positions of different regions are identified by a tool introduced by Patel and Pavitt (1997) for categorizing the technological competencies of firms in the Science and Technology poles. The *X*-axis represents the share of publication activities and the *Y*-axis indicates the Revealed Technology Advantage (RTA) of countries to measure the comparative advantage of scientific and technological strength. The RTA-index has been used as an approximation of the advantages in certain technology fields, consists of the ratio of the number of patents of a country in a particular technological sub-domain, divided by the total number of patents in this sub-domain, and the number of patents of the country under study in the whole field, divided by the total number of patents in the field $RTA=(P_{ij}/\sum_i P_{ij})/(\sum_j P_{ij}/\sum_{ij} P_{ij})$; The firm's RTA in each technological field is similar to the revealed scientific advantage (RSA) measure which can be used to assess the scientific performance of the regions.

A value above 1 indicates relative strength and a value less than 1 indicates relative weakness. The regions of high share and

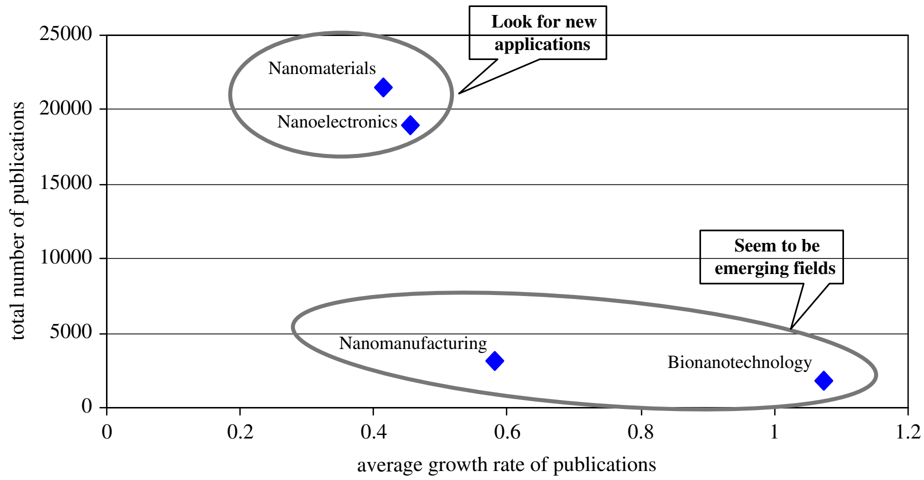
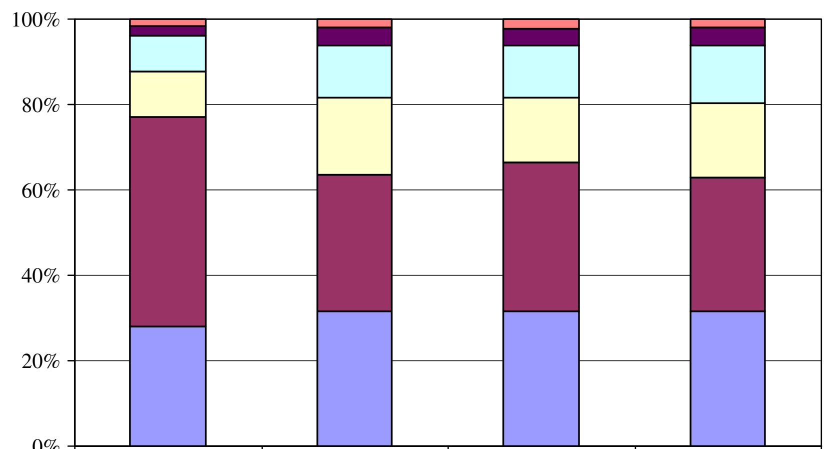


Fig. 4. Forecasting of nanotechnology domains.

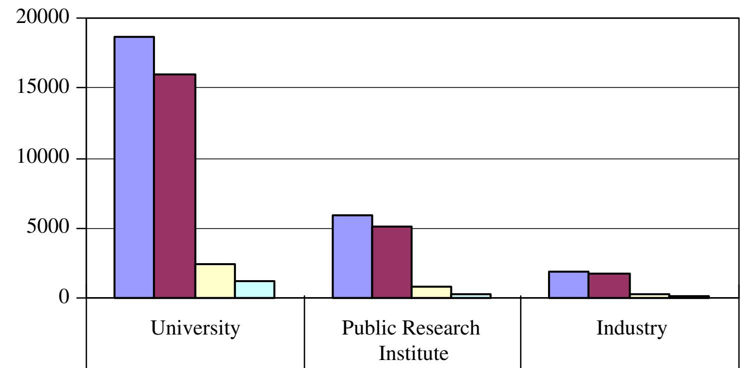


	Bionanotechnology	Nanoelectronics	Nanomanufacturing	Nanomaterials
India	23	354	69	452
South Korea	29	855	115	957
China	121	236	365	3002
Japan	147	3496	447	3935
United States	685	6194	1029	6992
European Union	391	6139	935	7098

Fig. 5. Regional publication share in the domains.

high RTA can be interpreted as countries having relatively strong share in the Science pole (i.e. relative importance to competencies in nanotechnology) and having distinctive advantage nationally. The region of low share and low RTA reveals countries allocating relatively less resources to technology or science and having less distinctive advantage nationally. It is to be noted that the value of the benchmark share in the *X*-axis is difficult to identify and varies depending on various dimensions such as the countries or region considered, innovation process analyzed, national requirements, etc. In this case, a break-even share is chosen in order to accommodate all countries in such a way that a proper comparison of their innovation or science performance be made. Fig. 7 illustrates the relative comparison of strength of the US and the EU. The result indicates that the position of the EU in bionanotechnology domain lies in the low share and low RTA zone revealing their weak competitiveness in the relevant research field, while the US is exceptionally positioned in the high share and high RTA zone. Alternatively, the EU has gained much strength in nanomaterials domain. The finding is an indicative that the US nanotechnology research has focused and directed towards biotechnology sector, i.e. nano-knowledge may apply in the fields of medicine (e.g. drug discovery, drug development, drug targeting, and drug delivery) and emphasis will be given to techniques used in pharmaceutical applications.

Fig. 8 illustrates the relative comparison of strength between the Asian countries. The result shows that Japan and South Korea are gaining their research strength in nanoelectronics sector, while China is showing its strength in nanomaterials, and India is concentrating more in nanomanufacturing domain although their publication shares lie in very low share zone. As evident in the finding, Japan and South Korea are researching more on electronics sector to explore nanotechnologies top-down application (e.g. production of IT chips, computer peripherals, and consumer electronic devices). On the other hand, China is concentrating



	University	Public Research Institute	Industry
Nanomaterials	18707	5908	1867
Nanoelectronics	15977	5036	1799
Nanomanufacturing	2407	749	335
Bionanotechnology	1195	266	130

Fig. 6. Organizational output share by domains.

Table 3
How different or similar are nanotechnology research domains?

Types of nanotech domains	Nanomaterials	Nanoelectronics	Nanomanufacturing and tools	Bionanotechnology
Nanomaterials	**1.00**	0.01	-0.02	0.04
Nanoelectronics	0.01	**1.00**	-0.07	0.01
Nanomanufacturing and tools	-0.02	-0.07	**1.00**	-0.03
Bionanotechnology	0.04	0.01	-0.03	**1.00**

Table 4
Inter-disciplinary character of nanotechnology research.

Types of nanotech domains	Nanomaterials	Nanoelectronics	Nanomanufacturing and tools	Bionanotechnology
Nanomaterials	44.43	13.66	32.99	8.92
Nanoelectronics	8.33	48.65	34.61	8.40
Nanomanufacturing and tools	10.09	17.35	62.48	10.08
Bionanotechnology	8.87	13.7	32.79	44.64

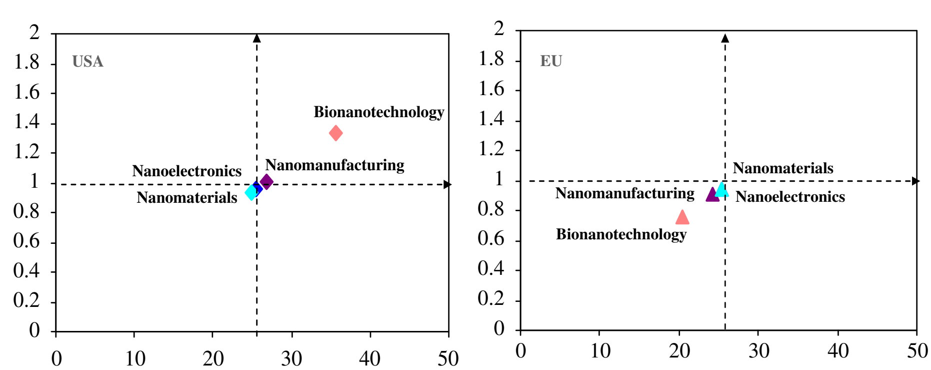


Fig. 7. RTA profile of European and American regions in nanotechnology domains.

solely on nanomaterials, since China continues to aggressively support public-funded science parks and to small start-ups as evidenced by its commitment to $2 billion Yuan ($240 million US) during 2003–07 to this sector including another $2–3 billion Yuan committed from local governments (Nemets, 2004). It seems China to be the most likely contender for catching-up with advanced countries. India is also a contender for catch up in the Third World in the nanotechnology arena. Including public infrastructures several grassroots organizations are sprouting up to take advantage of nanomanufacturing domain. It is very

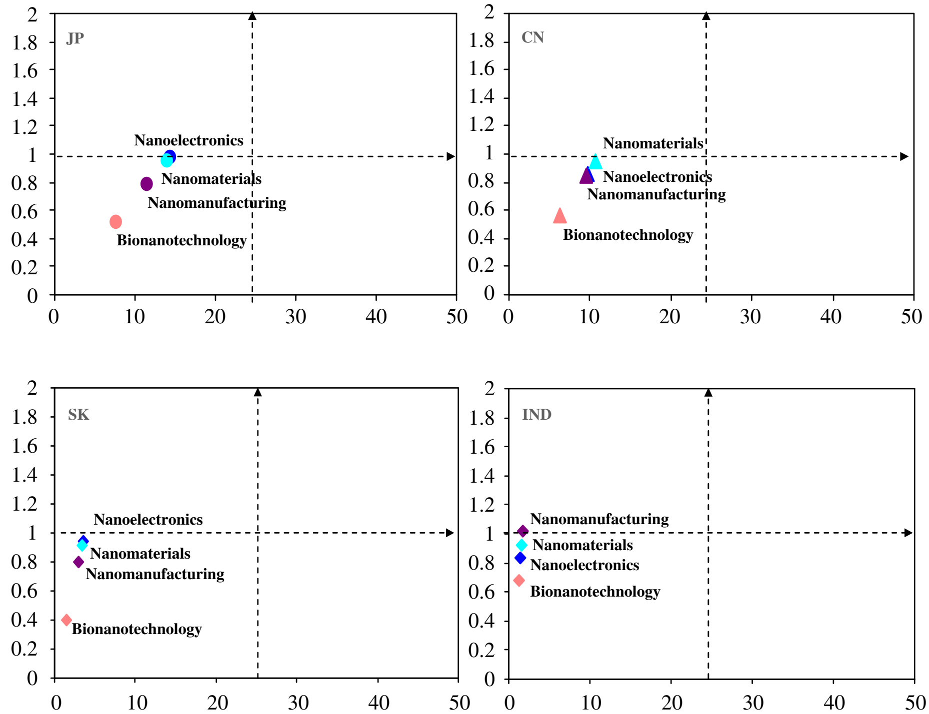


Fig. 8. RTA profile of Asian regions in nanotechnology domains.

interesting to see that the direction of the Asian players are high exponential in nature in their nanoscience pole.

7. Conclusions

The motivation to conduct this research is the increasing pace of nanotechnology research and technology development worldwide. In this paper, the main output is a refine classification of nanotechnology domains including the horizontal comparisons and the regional strengths and weaknesses. The findings show the maturity of electronics and materials sectors in terms of publication and forecast the emerging sectors for nanotechnology. Although the overall publications share is much less in bionanotechnology, the average growth rate of publications in bionanotechnology is significantly higher than the other domains, which is instructive as the emerging sector for nanotechnology. Further, this research has proved the divergence and interdisciplinary character of nanotechnology by focusing the inter-domains comparisons.

The present study has characterized and analyzed the importance of specific nanotechnology domains for the East and the West regions. Relative to other domains, bionanotechnology research sector has been gaining much strength in the US and lagging behind in other regions. When comparing regional strengths and weaknesses, US leads exceptionally in bionanotechnology, which seems either a potential support in the relevant research domain by public and private finance or the potential interest of critical mass of expertise to explore the biological applications. The EU countries show their strong activity in researching nanomaterials domain. European organizations are much interested on the exploration of new functionalities and properties of nanomaterials (e.g. CNTs and Fullerene) for the efficient application in a range of sectors, for example, coatings, fabrics, paints, thin films, healthcare products and fuel additives. On the other hand, the Asian players (e.g. Japan, China, South Korea and India) have shown their strong research performances in nanoelectronics and nanomaterials domains, while they have lagged greatly behind in bionanotechnology.

Within technological systems of innovation, the studies in the dynamics of nano-knowledge generation and the horizontal comparison of nanotechnology research domains have proved a worthy contribution to enrich the literature. Therefore, it would be useful to adopt strategies that could facilitate in building a network platform for sharing or exchanging nano-expertise and nano-information across domains. The limitations and gaps of existing studies in the emerging nanotechnology field led to the initial idea of a more comprehensive analysis on nanotechnology domains that have so far been accomplished in this paper. This research calls for further research to understand the differing technologies within a domain and their interface with other technologies. It is expected that more knowledge about understanding nanotechnological systems can be obtained through further research in order to increase its robustness.

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