Evolutionary trends in nanotechnology studies across worldwide economic players

Mario Coccia*[1], Ugo Finardi**, Diego Margon*

*National Research Council of Italy
CERIS-CNR, via Real Collegio, n. 30, 10024
Moncalieri (Torino) - Italy
Tel.: +39 011 68 24 925; fax : +39 011 68 24 966
m.coccia@ceris.cnr.it

**Università di Torino - Dipartimento di Chimica
via P. Giuria, 7 - 10125 Torino (Italy)
Tel. +39/011.670 83 85 -Fax +39/011.670 78 55
ugo.finardi@unito.it

1. Corresponding author

ABSTRACT: The purpose of this paper is to analyze the current temporal and spatial research trajectories in nanoscience and nanotechnology studies in order to display the dynamic patterns of research fields across main economic players. The results show the current nanotechnology studies have been growing in chemistry and medicine because of applications of nanomaterials mainly in Chemical Engineering, Biochemistry, Genetics and Molecular Biology. In addition, the concentration ratio of the production of nanotechnology research across different macro subject areas has been reducing over time and space, because knowledge dynamics of nanotechnology research has been spreading among new research fields and different industries. Results also show a relative higher scientific performance in nanotechnology research production by South Korea in comparison with Japan and other geo-economic areas. This research can provide vital findings to support research and innovation policies aimed at improving the development of this technological system for modern patterns of economic growth.

KEYWORDS: Nanoscience, Nanotechnology, Technological Trajectories, Research Trends, Data Mining, Comparative Innovation Systems, Technological System

JEL-CODES: L6; O3; Q57

The authors thank Prof. S. Coluccia and Dott. L. Bertinetti (University of Torino, Italy) for helpful comments and suggestions. Silvana Zelli has provided excellent research assistance and Maria Zittino a meticulous editing. The usual disclaimer applies.

1. INTRODUCTION

Modern patterns of economic growth are also driven by nanotechnologies and nanoscience which represent a new "technological system" (Freeman and Soete, 1987, p. 56)[1]. As a matter of fact, nanoscience studies are flourishing in several countries and scientists tend, more and more, to publish on some critical research topics such as recently applications of invented nanomaterials, new nano-techniques that are suitable to study and characterize them, preparation techniques and substances used to produce nanomaterials and nanostructured objects, properties and technological uses of nanostructured materials and so on (*cf.* Islam and Miyazaki, 2010; Bainbridge and Roco, 2006). In particular, the importance of nanotechnologies and nanoscience has begun to go beyond the bare entourage of laboratories and research centres and is nowadays well present everywhere industrial innovation takes place (Goddard III *et al*., 2007). In fact, nanotechnological innovations are critical in several industries such as microelectronics, bio-chemistry, pharmaceutics, ICT, etc. (*see* Bainbridge and Roco, 2006; Pilkington *et al*., 2009; Tegart, 2009; Glenn, 2006; van Merkerk and van Lente, 2005).

The spreading of nanotechnology in technological applications has also caused the insurgence of great interest towards their study by economics of science and innovation (*cf.* Bozeman *et al.,* 2007). In fact, there is a vital interest to analyze the dynamic technological trajectories of nanotechnology and the specificity of countries in nanoscience production and its application in order to forecast evolutionary research trends and future effects onto industrial dynamics across sectors and industries (*cf.* Salerno *et al.,* 2008; Bainbridge and Roco, 2006; de Miranda Santo *et al.,* 2006).

The purpose of this paper is to analyze the current technological trajectories in nanosciences and nanotechnologies across worldwide economic players. In particular, the main research questions addressed are:

- Which are the evolution of current driving nanotechnology research fields that will underpin future technological trajectories?
- Which is the behaviour of leading geo-economic areas in the production of nanoscience and nanotechnology knowledge?
- Which is the intensity of scientific collaborations in nanotechnology across leading geo-economic players?

This research, based on Scopus (2010), will analyze the codified production in this vital "technological system" to show how different geo-economic regions (such as the North America and Europe) have acted and reacted towards nanotechnology studies, and how they have been behaving over time in the scientific knowledge production and international collaboration in Nanoscience and Nanotechnologies (NSTs). This research can provide main findings in order to understand the current worldwide research trends in NSTs. This topic is important to support current innovation policies aimed at improving the development of such "converging technologies" (Bainbridge and Roco, 2006)[2] able to support modern patterns of economic growth.

---

[1] Freeman and Soete (1987, p. 56) defines new technological systems as: "innovations, which were technically and economically inter-related . . . . They include numerous radical and incremental innovations in both products and processes".

[2] It is important to note that Roco and Bainbridge by National Science Foundation coined the term of converging technologies in NBIC Report in June 2002.

This paper presents in section 2 a theoretical framework about nanotechnologies and nanosciences; section 3 describes the methodology of research, whereas section 4 analyzes the results and section 5 discusses lessons learned and some concluding remarks.

2. THEORETICAL BACKGROUND ON NANOTECHNOLOGY STUDIES

"Nanoscience is the result of interdisciplinary cooperation between physics, chemistry, biotechnology, material sciences and engineering towards studying assemblies of atoms and molecules" (Renn and Roco, 2006, p. 154)[3].

The "birth certificate" of Nanotechnologies (NSTs), at least from the conceptual point of view, is considered the renowned speech given at an American Physical Society meeting at California Institute of Technology by Richard P. Feynman (1960), where the 1965 Nobel Prize Laureate uttered the famous sentence "There is plenty of room at the bottom" talking about the opportunities for science and technology given by the vast expansion of scientific and technological research towards the nanometric dimensional range and describing molecular machines built with atomic precision. The first use of the word "nano-technology" instead has to be assigned to Taniguchi (1974) of Tokyo Science University, who used it in an article on ion-sputtering machining.

Since then, the spreading and growth of NSTs has been marked by inventions and findings in terms of new nanostructured materials, investigation and characterization techniques, and new nano-objects. By the operational point of view, one of the most common opinion is that NSTs did originate in 1981 with the creation of Scanning Tunnelling Microscope (STM) in the IBM laboratories in Zurich, by 1986 Nobel Prizes Laureates for Physics Gerd K. Binnig and Heinrich Rohrer (Bonaccorsi and Thoma 2007). From the point of view of nanostructured materials 1985 marks the discovery of Buckyball (Buckminsterfullerene) by Kroto and Smalley (the discovery will gain them the Nobel Prize in Chemistry in 1996, see Kroto *et al.*, 1985); 1990 the discovery of Silica mesoporous materials by Yanagisawa and co-workers at Waseda University in Tokio (Yanagisawa *et al.*, 1990); 1991 the discovery of Carbon nanotubes by Iijima (1991) at NEC Corp. By the point of view of new nanostructured objects, it is remarkable the work performed by Eigler and Schweizer (1990) who did spell the IBM logo in individual atoms on a nickel surface. Several scientific journals having the stem "nano" on their title are published nowadays.

NSTs represent mostly an approach to science, technology and innovation rather than a specific sector by itself. For instance, the website of the American National Nanotechnology Initiative[4] states[5]:

> Nanoscience involves research to discover new behaviours and properties of materials with dimensions at the nanoscale which ranges roughly from 1 to 100 nanometres (nm). Nanotechnology is the way discoveries made at the nanoscale is put to work. Nanotechnology is more than throwing together a batch of nanoscale materials — it requires the ability to manipulate and control those materials in a useful way.
>
> Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modelling, and manipulating matter at this length scale [...] Unusual physical, chemical, and biological

[3] *Cf.* also Roco, 2007, pp. 3.1-3.26.

[4] See: http://www.nano.gov/Nanotechnology_BigThingsfromaTinyWorldspread.pdf, accessed May 2010; http://www.nano.gov/html/facts/whatIsNano.html; accessed June 2010.

[5] *Cf.* also Siegel *et al.*, 1999.

> properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules.

By one side the definition discriminates between science and technology, which is sometimes hard to tell. But on the other side, it describes precisely and briefly the fundamental characters of NSTs: they act in a well defined dimensional field and this is substantial and cannot be disregarded; purpose is discovering new behaviours and properties distinctive of materials when nanostructured. From this point onwards, technologies have the purpose of transforming the new knowledge in innovation.

As we can define NSTs as an approach towards matter, when we discuss the transfer of nanoscience into technological innovation, as far as the "transversal" character of NSTs has been defined, it is clear that we cannot talk about "application sectors" of NSTs. This, not because nanotechnologies cannot be applied to industrial innovation and to the production of goods, but, on the contrary, because the list of sectors is virtually endless.

The technological application of NSTs has been first of all in niche industries, mostly knowledge-intensive and with high-added-value products, such as the production of catalysts for industrial production (*cf.* Zecchina *et al.*, 2007; Evangelisti *et al.*, 2007) or biomaterials produced for bone substitution inside the human body (*cf.* Bertinetti *et al.*, 2006; Celotti *et al.*, 2006). In these cases, the distance existing between basic/purpose-free research and technological innovation is almost not existing, or very narrow, and the high added value of goods justifies the economic engagement of the scientific research.

Other edge industries where the use of nanotechnologies is established are those of biotechnologies and electronics. In this last case the downscaling of circuitry – until the present limit of 45 nm (nanometers) – has mostly benefited of the extreme frontier of manipulation technologies in order to reach a higher miniaturization.

NSTs are not only transversal to possible industrial applications, but also to scientific sectors: *e.g.* material sciences, chemical and physical sciences, and material engineering. Different traditional scientific fields have in general a different approach towards NSTs, as well described by Balzani (2005) who gives his own definition of sciences and technologies, and underlines the different approaches adopted towards NSTs by different categories of scientists. The typical approach of physicists and engineers is the so-called *top-down* approach, where the matter is manipulated instrumentally – *e.g.* with the techniques of photolithography – in order to obtain the desired results: in this way the dimensional barrier of 100 nanometers has been a hard one to overcome.

The typical approach of chemists is exactly reverse to the previous one: a *bottom-up* approach where objects lying in the molecular dimensional domain – thus around and slightly below the nanometer – can be used as "bricks" to build nanostructured objects with bigger dimensions, such as the molecular computers with high scientific and technological content in the quest for an innovating application.

Nanotechnologies are nowadays fully inserted in the paths of "creative destructions" generated by technical knowledge in industries (Bozeman *et al.*, 2007). NSTs are at the convergence of several scientific and technological fields and affect the organizational behaviour of both entrant firms and incumbents in several sectors (Bainbridge and Roco, 2006). Moreover, university spinouts in NSTs are gaining importance and are playing a critical role for regional development (Libaers *et al.*, 2006). NSTs are also in a cutting-edge position in order to enhance new systems for environmental control and remediation, though some envisage dangers from their use (Rickerby and Morrison, 2007).

Scientometrics studies are effective approaches to analyze the emergence and development of research fields in nanotechnology (Braun *et al.*, 1997). Leydesdorff and Zhou (2007), basing their work on Journal Citation Report data; "nano" journals have more complex content than other journals – from the point of view of citations – and their position is at the interface between physics and chemistry. In fact, Leydesdorff (2008) shows the growing interdisciplinary effects of NSTs.

Kostoff *et al.* (2006; 2007; 2007a) describe an overview on the NSTs literature. These works show the continuous evolution and growth in NSTs, also driven by Asian countries.

It is then obvious from this theoretical background that a deep scientific analysis of research trends in the scientific production of NSTs across leading worldwide players is an important topic to be developed in order to understand the evolution of current technological trajectories that may support future spatial patterns of economic growth.

3. METHODOLOGY OF RESEARCH

Salerno *et al.* (2008) argue that: "Bibliometric analysis of publications … can help have a synthetic picture of the best players at a worldwide level, their lines of inquiries and their relationships, that is, they could help to cope with the extremely fragmented knowledge, actors and applications involved in the evolution of the field" (p. 1220). This paper uses Scopus database (2010). "Scopus is the largest abstract and citation database of peer-reviewed literature and quality web sources with smart tools to track, analyze and visualize research. It's designed to find the information scientists need […] Scopus provides superior support of the literature research process" (Scopus, 2010)[6].

Scopus has been preferred to other analogous web-databases because:

- It encompasses a wider set of data: "With over 18,000 titles from more than 5,000 publishers, Scopus offers researchers a quick, easy and comprehensive resource to support their research needs in the scientific, technical, medical and social science fields and, more recently, also in the arts and humanities"[7].
- It has the broadest available coverage, with more than half of the content originating from Europe, Latin America and the Asia Pacific region[8].
- It has a wide set of data retrieval instruments, useful in performing Data Mining.
- It exploits a system of classification of titles under categories: "Titles in Scopus are classified under four broad subject clusters (Life Sciences, Physical Sciences, Health Sciences and Social Sciences & Humanities) which are further divided into 27 major subject areas and 300 minor subject areas. Titles may belong to more than one subject area"[9].

Data mining from Scopus (2010) was performed using the following methodology:

a) the search of "nano*"[10] on "Article Title, Abstract, Keyword" is made;

b) on the selected records a further refinement is performed using the "Refine results" frame, selecting only those records containing one or more of the following keywords: "Nanostructured materials", "Nanotechnology" or "Nanostructures".

---

[6] http://info.scopus.com/about/ (accessed 11 June 2010);
See also http://info.scopus.com/why-scopus/academia/ (accessed June 18th, 2010).

[7] http://info.scopus.com/scopus-in-detail/content-coverage-guide/ (accessed June 18th, 2010).

[8] http://info.scopus.com/scopus-in-detail/facts/ (accessed July 1st, 2010).

[9] http://info.scopus.com/scopus-in-detail/content-coverage-guide/journalclassification/ (accessed June 18th, 2010).

[10] "*" is the usual dummy meaning "any series of character after the ones written"

In particular, Data Mining is performed on:

- Time Horizon from 1996 to 2008 in order to analyze the temporal research trends. Within the range 1996-2008 we have the opportunity to retrieve all information analyzed, whereas this is not possible for year before 1996 (when Scopus starts gathering full data) and after the 2008 (as Data Mining was performed in January 2010).
- Key geo-economic areas: selected areas have been USA and Canada, South Korea, Japan, China and Europe[11]. These geo-economic and politic areas are the main worldwide players in the production of nanotechnology and nanoscience studies.
- Main documents retrieved are: Articles, Conference Papers, Reviews, Letters, Editorials, Short Surveys, Conference Reviews, Notes and Books.
- Scientific outputs carried out by Academic laboratories, Government founded labs and Company labs operating in the vast research field of basic research on nanotechnology as well as on its industrial applications.
- Content-related analysis of nanotechnology researches is based on subject areas provided by Scopus.

After that quantitative data have been retrieved, we have main information about several characteristics of scientific products. In particular we exploited the *affiliations* of authors (*i.e.* main research institutions and/or labs where the research is carried out by scholars) and the *subject areas*[12] of nanoscience and nanotechnology studies published on leading scientific journals. Our samples are based on the 149 324 scientific products (*e.g.* Articles, proceedings, etc.) on nanotechnology studies with their affiliations (about 96% of main research centres operating in NSTs) retrieved as above described per countries and years. As papers concerning the nanotechnology studies are published on journals that are classified per 28 subject areas[10], the 149,324 scientific products have almost 400,000 occurrences of subject areas. In general, the number of occurrences of subject areas by journals is greater than the total number of scientific products (*i.e.* papers)[13]. The occurrences of articles represent a view of subject areas in nanotechnology studies and how much attention they have received in the scientific literature.

The vast sample of papers classified by Scopus in main subject areas has been aggregated in five “Macro Subject Areas”: Material Science, Chemistry and Medicine, Physics and Earth Sciences, Engineering; all marginal areas of nanotechnology studies (less than 5% of the sample) have been included under the category “Others” (Information and Mathematics Sciences, Social and Economic Sciences, Energy, Environmental Science). Table 1A and 2A in Appendix show the content of subject areas per each Macro Subject Areas (in short, macro areas). This aggregation has been important to show the temporal and spatial pattern of nanotechnology research trends across countries. The more detailed analysis per keywords has not been considered first of all because of the high number of generic keywords like

[11] In “Europe” the selected countries are: Albania, Austria, Belarus, Belgium, Bosnia, Bulgaria, Croatia, Czech Republic, Estonia, Finland, France, Germany, Greece, Holland, Hungary, Ireland, Italy, Latvia, Lithuania, Macedonia, Moldova, The Netherlands, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, and United Kingdom.

[12] Scopus classifies journals in major subject areas, such as “Energy”, “Chemistry”, “Engineering”, etc. Journals can be allocated to multiple subject areas as appropriate to their scope. We use all subject areas containing papers on nanotechnology studies. Interestingly, the average number of subject areas that journals in the “Energy” papers belong to (2.09) is higher than the average value of all science (1.37), indicating that they exhibit a strong degree of interdisciplinarity.

[13] For instance a paper about the nanotechnology published on the journal *Scientometrics*, is one paper with 3 subject areas, since *Scientometrics* is classified with three subject areas (computer science applications, social sciences and library and information sciences).

"Synthesis", "Chemistry", "Priority journal", "Crystallization", "Methodology" etc. Moreover single keywords do not refer necessarily to a single research area, making such an analysis less meaningful. Also the categorization of research domains in "nanomaterials" and "nanoelectronics" has not been considered because of their inner overlaps: nanomaterials are heavily applied in nanoelectronics; therefore considering this categorization is not fruitful for investigating the real nanotechnology research trajectories and could bring to ambiguous results and misleading research trends. *Vice versa*, the aggregate sets applied in this research provide more accurate and robust results about the temporal and spatial evolution of research trends.

Another main analysis performed is the scientific cooperation in nanotechnology production across geo-economic areas. We have considered in each geographical area, for its scientific output, the foreign affiliations in nanotechnology studies in order to see the mutual cooperation for nano scientific research fields. The information analysis of our sample is carried out by simple statistical and graphs analysis considering some critical research fields and geo-economic areas in order to show driving research trends in nanotechnology studies

In addition, economic literature shows the interesting research by Shapira and Youtie (2008, pp.191 ff.) that measure regional economic concentration using the Herfindahl index. Following concentration measure explores and compares research trends in nanotechnology researches across countries providing main information on key aspects of evolutionary research trajectories.

- *Concentration at country level over time*. R Gini's ratio of concentration measures the degree of concentration (inequality) of nanotechnology research per country over time.

  x_{ji} = total number of occurrences of nanotechnology research publications of the *j-th* country in a macro subject area *i-th*; A_i = cumulative values of x_{ji};
  p_i is i/N (N is total number of macro subject areas), while q_i is A_i / A_N

$$R_{j\,t} = Ratio\ \ of\ \ concentration = \frac{\sum_{i=1}^{N-1}(p_i - q_i)}{\sum_{i=1}^{N-1} p_i} \qquad [1]$$

$j = country$ (e.g. USA); $t = time(e.g.2000)$

per all macro subject areas

$i \in$ [Basic and Earth, Chemistry and Medicine, Engineering, Material Sciences]

Gini's ratio of concentration R is calculated per country for t= 1996, …, 2008. It ranges between 0, when there is no concentration (perfect equality), and 1 when there is total concentration (perfect inequality).

The main limit imposed by Scopus search engine is the maximum of 160 items (the most represented ones) for each data mining. Other limits could be the fact that NSTs are not present as an autonomous subject area in Scopus (limit overcome with our Data Mining) and not all papers /proceedings in nanotechnology studies are captured and included in Scopus dataset. Nevertheless this is also a weakness point for other web-based data collections.

4. EMPIRICAL ANALYSIS: EVOLUTIONARY TRENDS OF NANOTECHNOLOGY STUDIES

This paper analyzes five main geo-economic areas in the production of nanotechnology, based on research centres and their scientific outputs present into Scopus (2010). Structure of domestic research centres shows the highest number of research labs in nanotechnology in Europe and North America (*i.e.* USA and Canada) that have a steady trend over 1996-2008 period (Fig. 1). Europe and North America have in 2008 about 150 research centres operating in nanotechnology fields. Japan has a number of research centres lower than previous leading geo-economic areas, with roughly 100 units, with a stable cumulative temporal number in the range 107-117. China and South Korea are the two geo-economic areas where the number of nanotechnology research centres has been increasing, reducing in 2008 the high gap presents in 1996 in comparison with Europe and North America[14]: in particular, China has more than 130 nanotechnology research centres operating in 2008 (Table 3A in Appendix shows the cumulative number of these research centres over 1996-2008 across geo-economic areas, and their scientific outputs in the last 15 years). Nanotechnology researches have been carried out mainly universities across all geo-economic players, but public labs have a higher percentage of production in Japan (25.71%) and South Korea (about 20%), whereas USA &Canada have a mere 10.8%. Japan has also the higher percentage of company labs operating in nanotechnology (roughly 6.5%), Europe the lowest (0.93%).

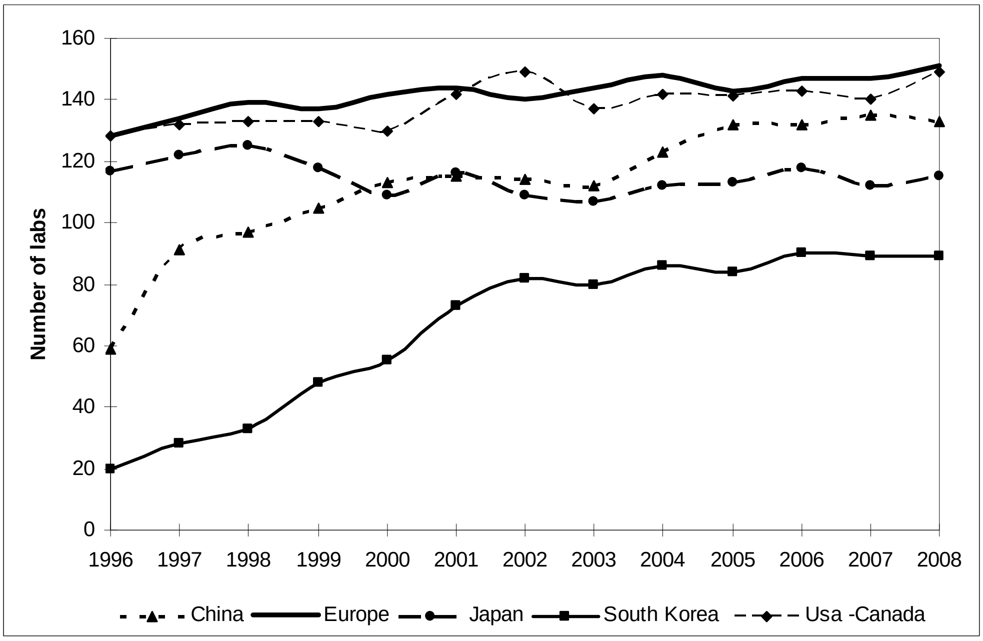

FIGURE 1. RESEARCH CENTRES OPERATING IN NANOTECHNOLOGY ACROSS COUNTRIES, 1996-2008 PERIOD

14 *Cf*. de Miranda Santo *et al.* (2006) pp. 1022ff.

As nanotechnology researches are growing over time, this paper assumes the following epistemological position:

> Concentration ratio of nanotechnology researches across research fields has been reducing over time: *i.e.* there is an increase of the heterogeneity by widely spread of the research production among different research domains and new technological trajectories.

Figure 2, based on index [1], shows a moderate concentration ratio of nanotechnology researches across geo-economic areas (in general the concentration ratio R on y-axis is less than 0.5): in China and South Korea, R is higher than Europe and North America. In particular, figure 2 shows a declining trend of concentration ratio across geo-economic regions as function of time: this means a diversification of nanotechnology research among different macro subject areas by a widely develop in new scientific fields. The underlying causes of this declining concentration ratio over time can be due to: China in 1996 had a high concentration of the production of nanotechnology researches in material science (52.41% of total), as well as a similar behaviour there was in South Korea (50.79% of total), USA and Canada (45.23%), Europe 41.54% and Japan 38.93%. In 2008, the production of nanotechnology researches in material science across countries is considerably decreased and the current distribution of nanotechnology researches has more uniformity among different macro subject areas, generating lower concentration ratios. These patterns across countries confirm the development of nanotechnology research in different scientific fields that represent possible future technological trajectories in the techno-economic paradigm of the "converging technology".

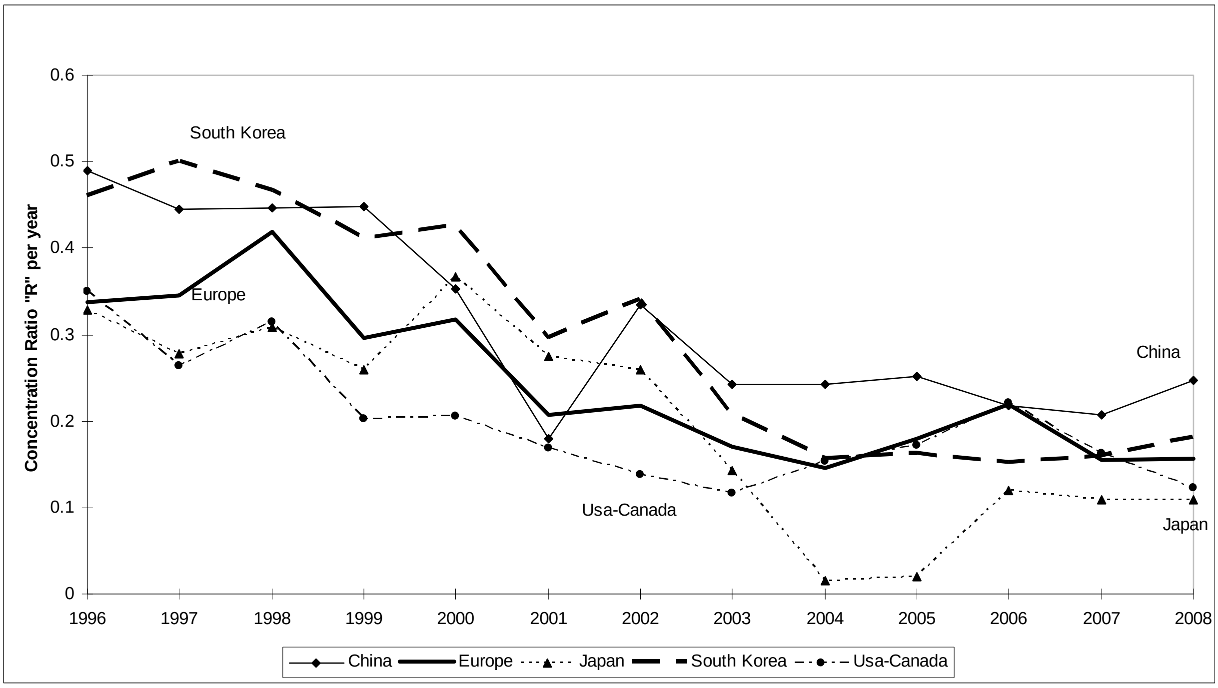

FIGURE 2:CONCENTRATION RATIO "R" BASED ON PRODUCTION OF NANOTECHNOLOGY RESEARCHES ACROSS GEO-ECONOMIC AREAS AS FUNCTION OF TIME

Figures 3-8 show the main research fields of nanoscience studies from 1996 to 2008 across geo-economic areas. As the absolute numbers of scientific products across geo-economic areas are not suitable values for reliable spatial and temporal comparisons (as research trends are similar), we apply percent values to analyze the mutual temporal knowledge dynamics within research fields in NSTs. These trends show some common patterns: although the nanotechnology studies in material science have an higher scientific production in comparison with other macro subject areas (see table 1A and 2A), the internal dynamics among macro subject areas shows mainly a relative reduction over time and space of studies in nanomaterial sciences (decreasing returns to production), whereas the studies of nanoscience applied in Chemistry and Medicine have been increasing over time[15]. In addition, the highest relative increase of nanoscience studies in Chemistry and Medicine, measured by coefficients of regression lines, is in China (β=2.2) and South Korea (β=1.95), whereas the lowest magnitude is in Japan (β=1.4). These results indicate that some nanotechnology research domains which have generated main inventions of several nanomaterials are mature research fields, whereas nowadays studies of nanotechnology in Chemistry and Medicine have been growing because modern research centres focus on their scientific research on critical innovation in more applied sectors of NSTs. This means that some nanotechnology trajectories have been passing from invention to innovation phase.

Nano-sciences studies in "Physics and Earth Sciences" have roughly a relative steady declining trend across geo-economic areas. Studies of nanotechnology in Engineering sciences have also a steady trend across the areas, except for Japan that shows an unstable increasing temporal trend. The results are confirmed by Figure 8, for all geo-economic areas.

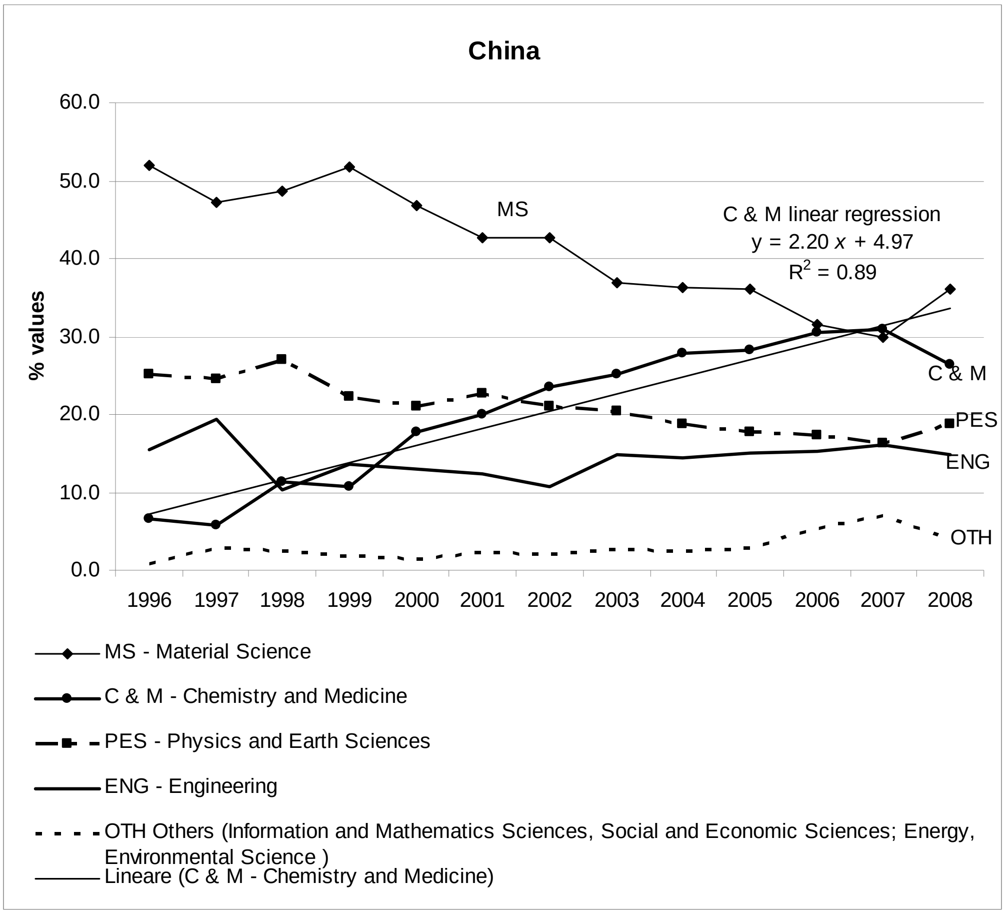

FIGURE 3. RESEARCH TREND MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES (% VALUES) CLASSIFIED PER MACRO SUBJECT AREAS – CHINA

[15] Figure 1A in Appendix A shows the subject areas included in this and other macro subject areas.

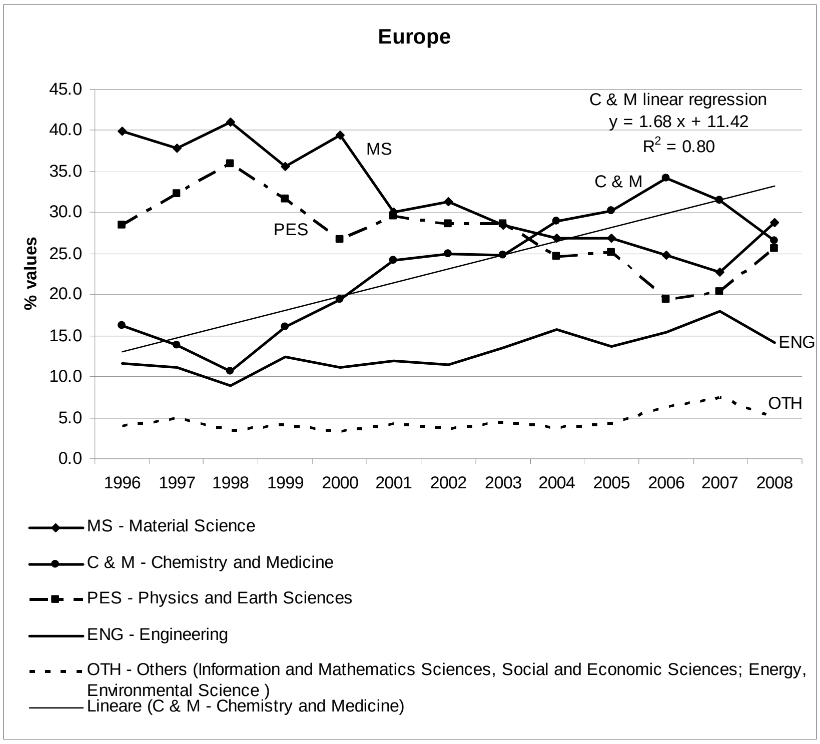

FIGURE 4. RESEARCH TREND MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES (% VALUES) CLASSIFIED PER MACRO SUBJECT AREAS - EUROPE

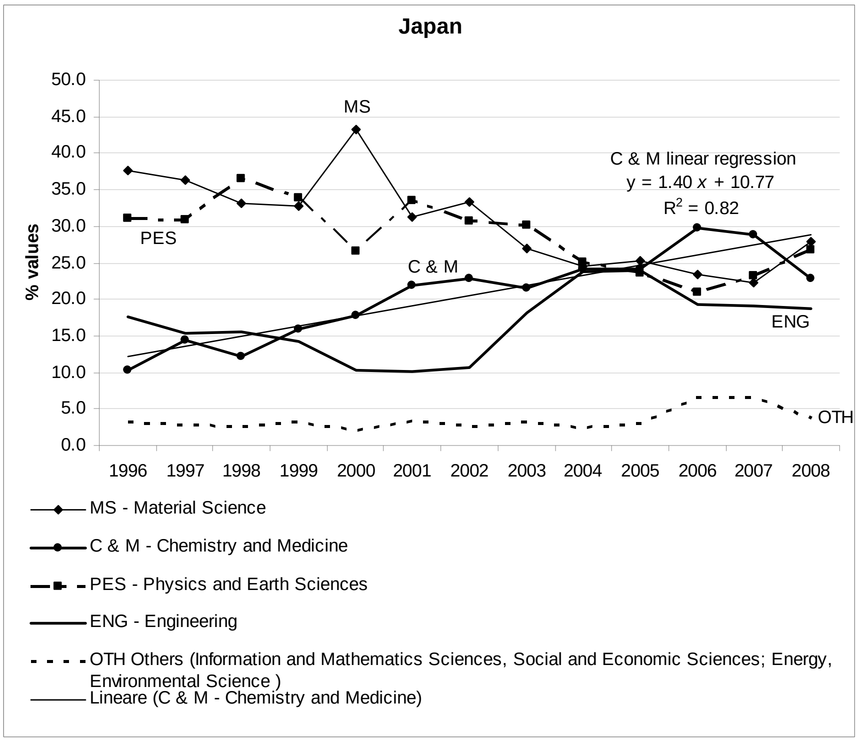

FIGURE 5. RESEARCH TREND MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES (% VALUES) CLASSIFIED PER MACRO SUBJECT AREAS - JAPAN

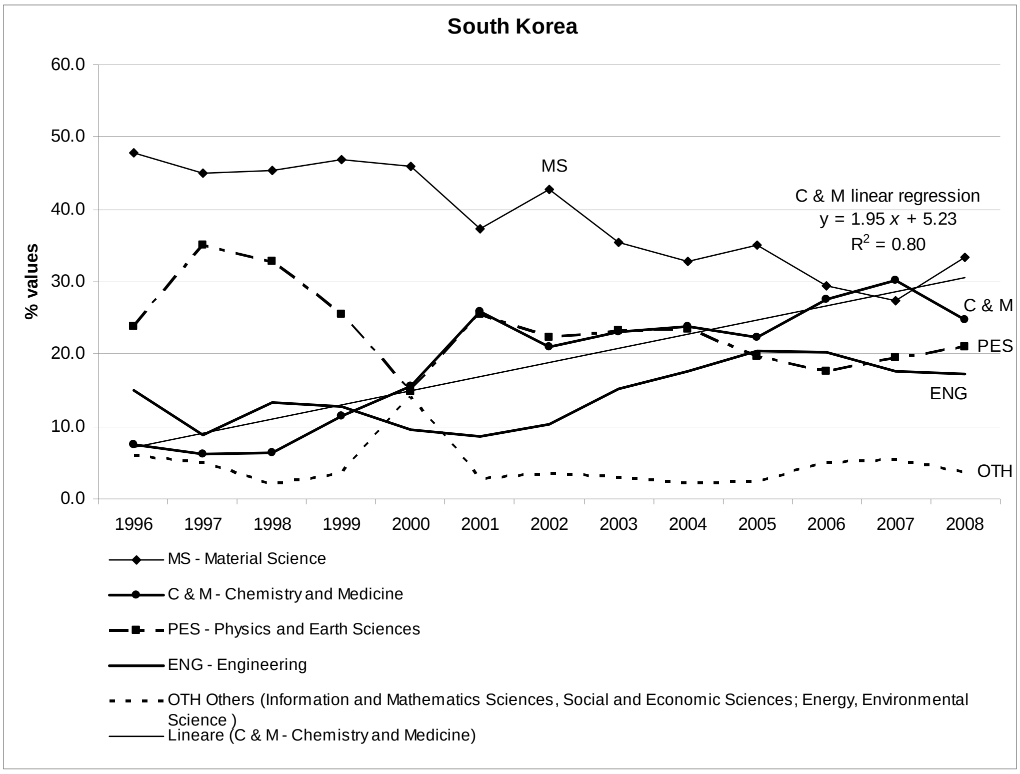

FIGURE 6. RESEARCH TREND MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES (% VALUES) CLASSIFIED PER MACRO SUBJECT AREAS - SOUTH KOREA

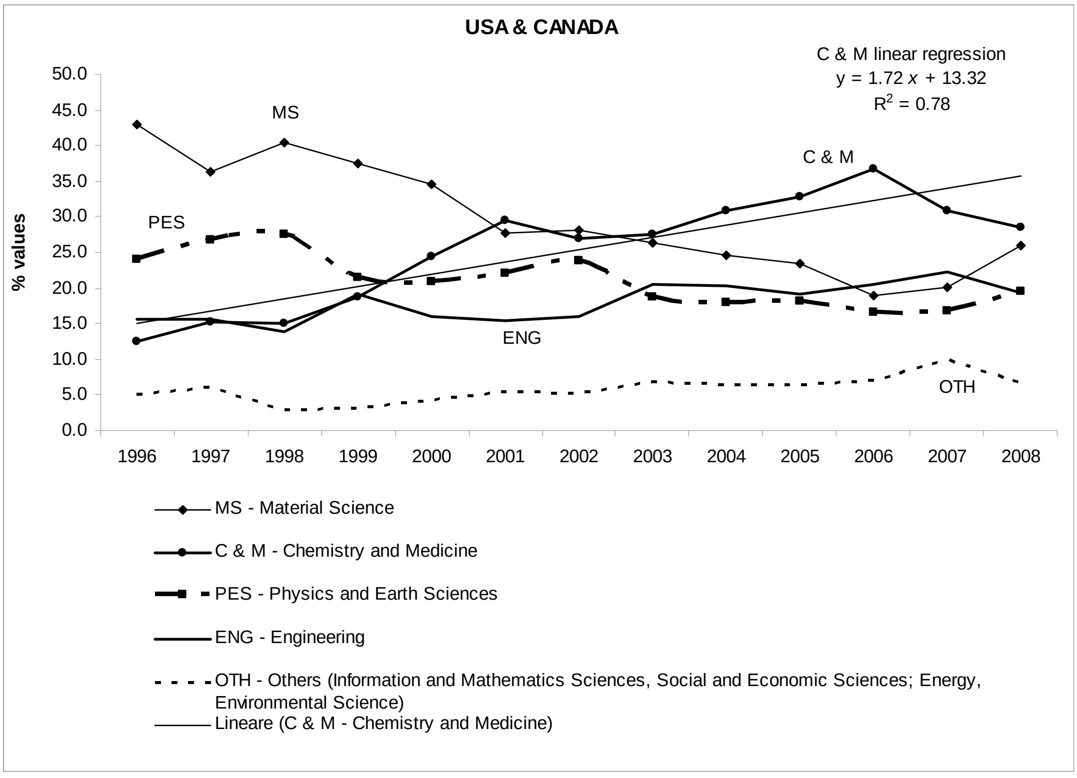

FIGURE 7. RESEARCH TREND MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES (% VALUES) CLASSIFIED PER MACRO SUBJECT AREAS - USA & CANADA

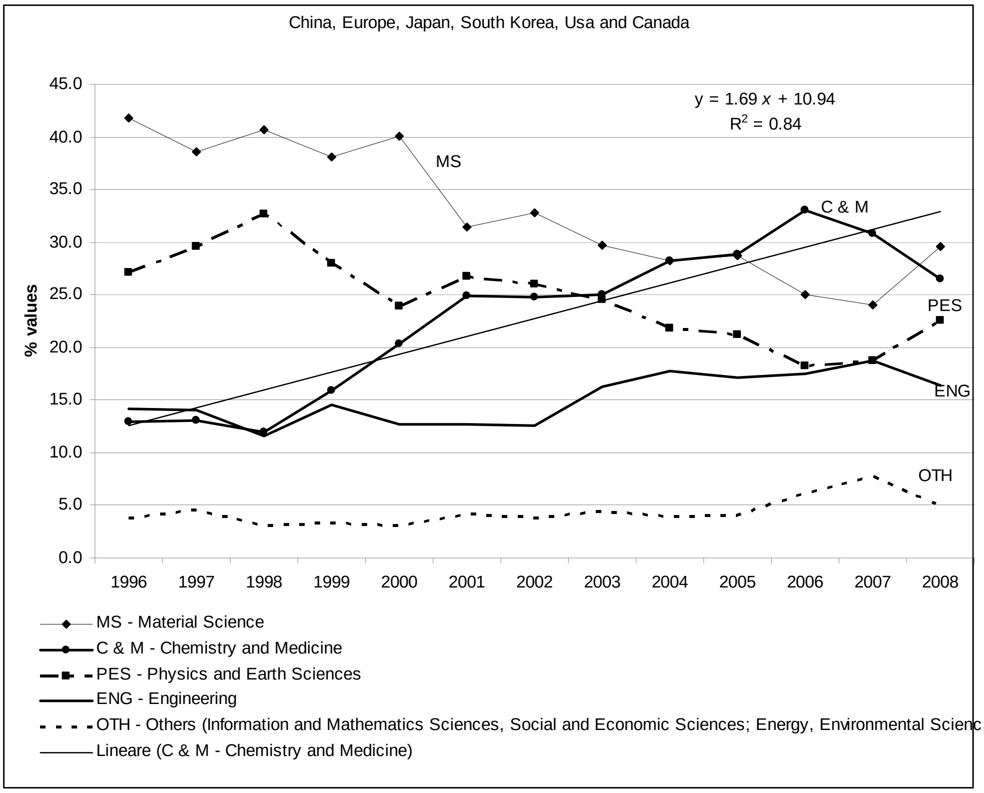

FIGURE 8. RESEARCH TREND MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES (% VALUES) CLASSIFIED PER MACRO SUBJECT AREAS – ALL GEO-ECONOMIC AREAS

As the driving nanotechnology studies in "Chemistry and Medicine" have been increasing in the last 15 years with a relative high rate of growth, due to the high number of applications (innovations) in several research fields, the inner dynamics have been divided in two periods (1996-2002 and 2002-2008) in order to capture the temporal paths across countries. Figure 9 shows a relative critical role, over 1996-2002 period, by Europe and USA-Canada, followed by Japan (Third position). If this analysis is repeated over 2002-2008 period (see Figure 10), nanotechnology studies in Chemistry and Medicine carried out in China have been increasing, predominating over the trend of Japan[16].

Figure 11 shows the Subject Areas of nanotechnology studies included in the macro subject area "Chemistry and Medicine"; these subjects areas confirm the innovation phase of the knowledge dynamics of some nanotechnology trajectories.

As far as the nanotechnology studies in "Material sciences" are concerned, the leading countries are mainly Europe and China over 1996-2008 period, although the relative role of China has been increasing over 2002-2008 (Figg. 12 and 13). Other macro areas, *i.e.* "Physics and Earth Sciences" and "Engineering", show the leadership of Europe and USA-Canada. For the sake of briefness some figures are not reported.

[16] de Miranda Santo *et al.* (2006) confirm the great contribution of China to scientific research in nanoscience and nanotechnology in the group of competitor countries (p. 1024).

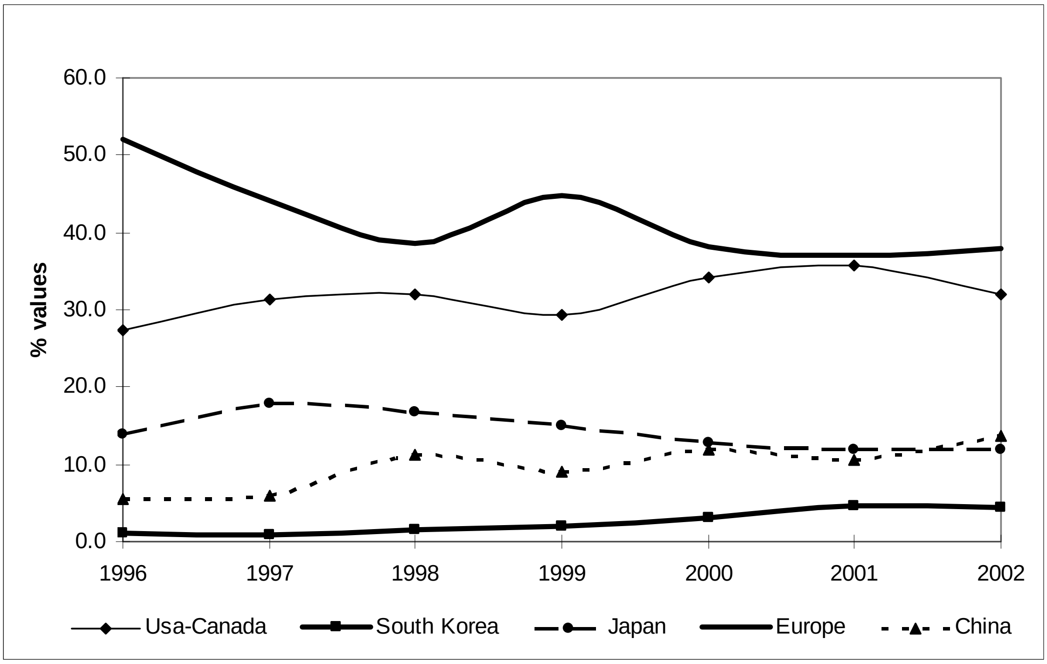

FIGURE 9. RESEARCH TREND PER GEO-ECONOMIC AREAS MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES CLASSIFIED IN CHEMISTRY AND MEDICINE OVER 1996-2002 (% VALUES)

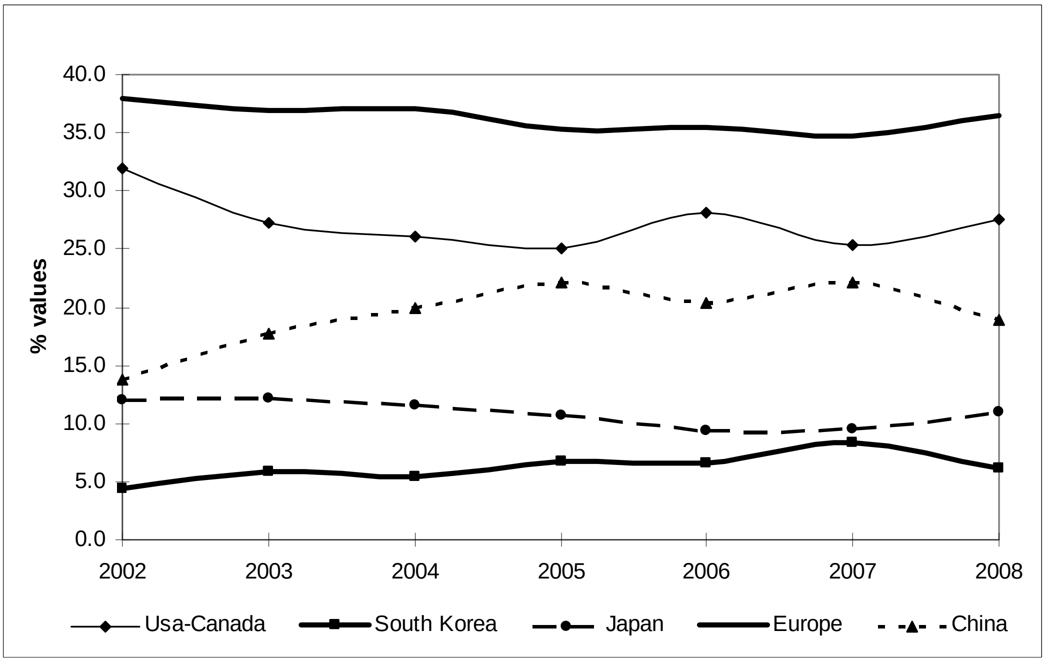

FIGURE 10. RESEARCH TREND PER GEO-ECONOMIC AREAS MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES CLASSIFIED IN CHEMISTRY AND MEDICINE OVER 2002-2008 (% VALUES)

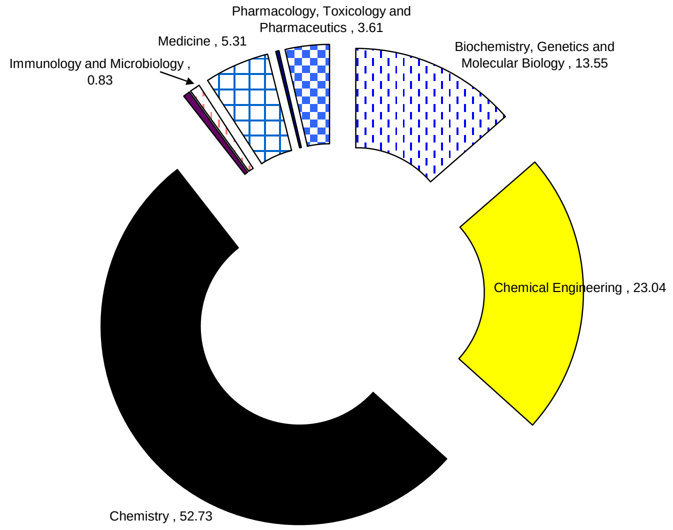

FIGURE 11. PERCENT VALUE OF MAIN RESEARCH FIELDS OF NANOTECHNOLOGY STUDIES APPLIED IN CHEMISTRY AND MEDICINE

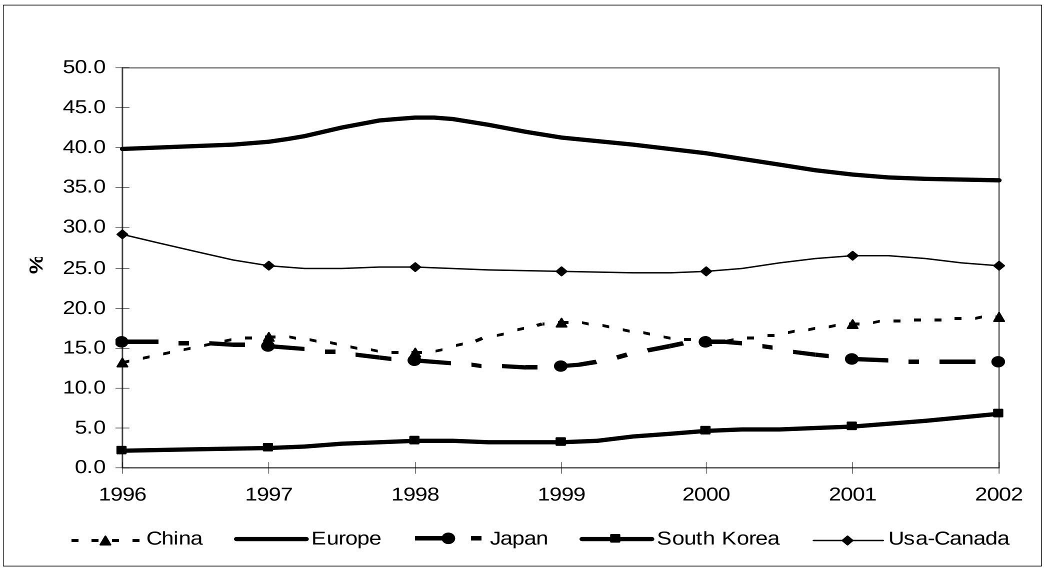

FIGURE 12. RESEARCH TREND PER GEO-ECONOMIC AREAS MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES CLASSIFIED IN MATERIAL SCIENCE OVER 1996-2002 (% VALUES)

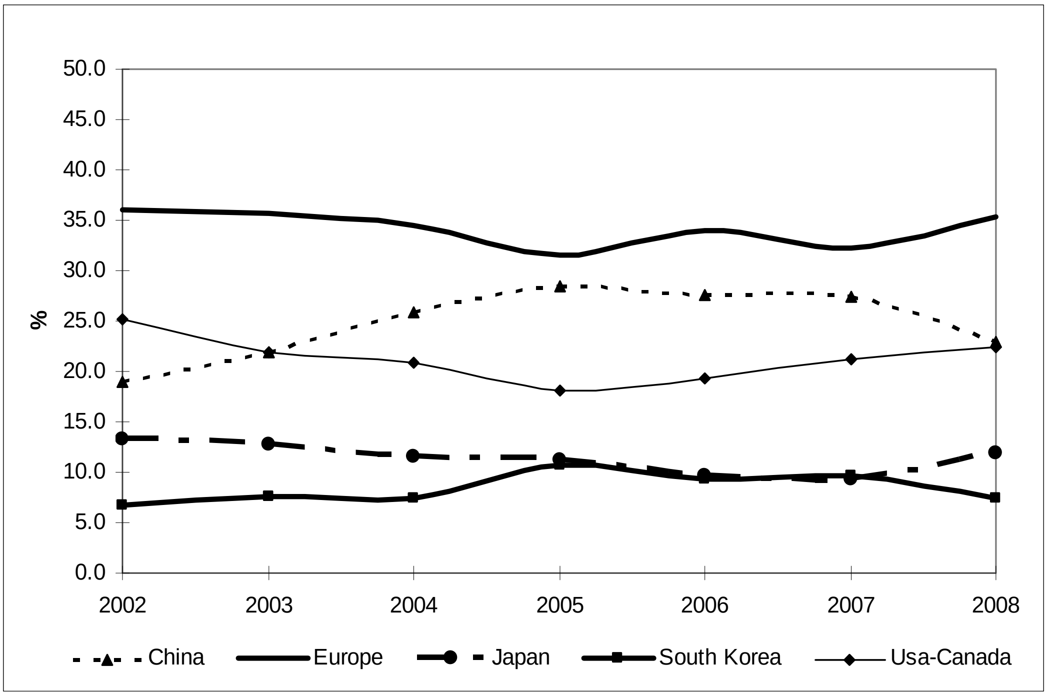

FIGURE 13. RESEARCH TREND PER GEO-ECONOMIC AREAS MEASURED BY NUMBER OF PAPERS IN NANOTECHNOLOGY STUDIES CLASSIFIED IN MATERIAL SCIENCE OVER 2002-2008 (% VALUES)

Another main result is shown in figure 14 about the mutual cooperation across geo-economic areas in nanotechnology studies. Although each geo-economic area has a vast production of scientific outputs within domestic nanotechnology research centres (about 90%), the residual is carried out in collaboration with foreign scholars and research centres. The results are: Europe and USA-Canada have a high capacity of attraction of foreign scholars in the scientific research on nanotechnology and nanoscience, measured by joint affiliations in papers (see the simple bars above the *x*-axis in figure 14), whereas South Korea and China are the two geographic areas having the highest number of scientific collaborations with other scientific players in nanotechnology studies.

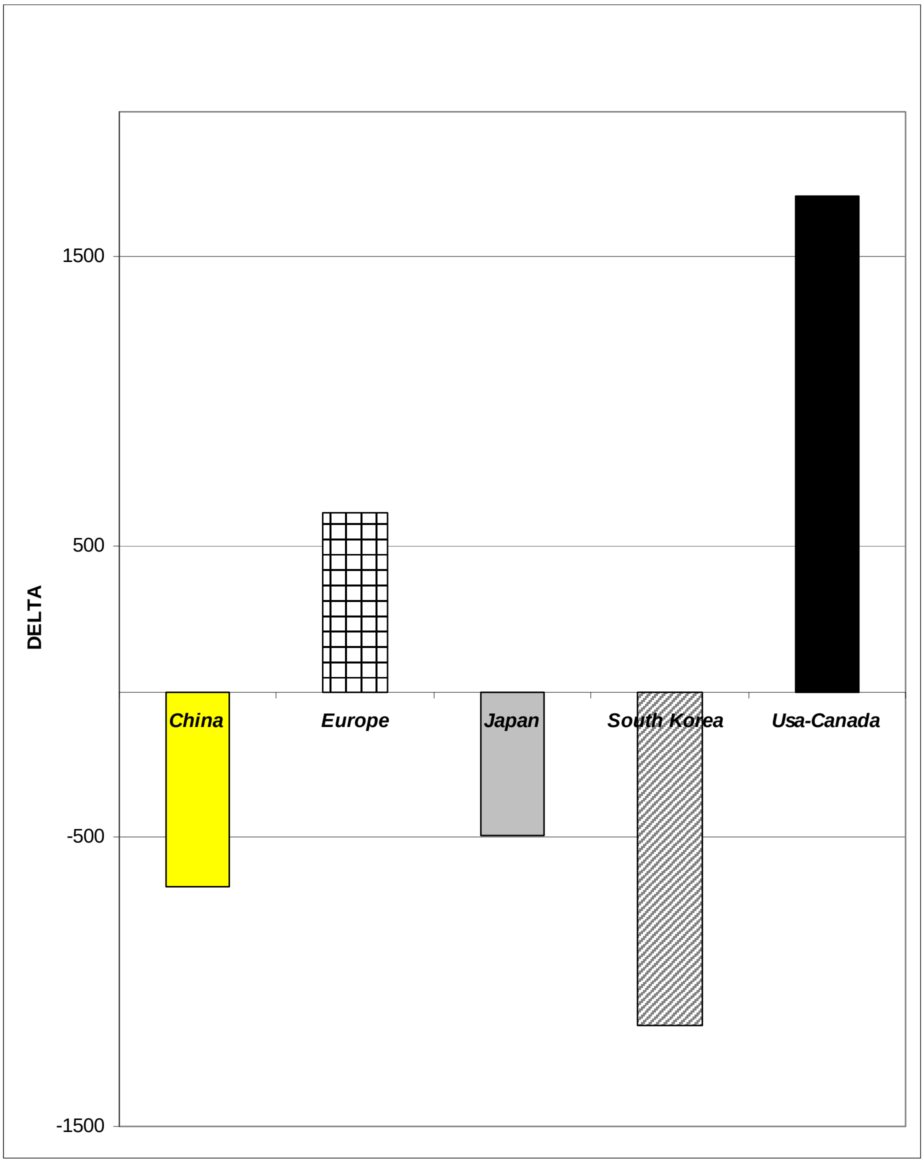

FIGURE 14. RESEARCH ATTRACTION CAPACITY OF FOREIGN SCHOLARS IN NANOTECHNOLOGY RESEARCH PER GEO-ECONOMIC AREAS 1996-2008 PERIOD

Note: **DELTA** is the difference between (scientific products in nanotechnology study produced in domestic research centres of the country **A** with foreign institutions) and (scientific products produced by other geo-economic areas in collaboration with research centres of the country **A**); positive delta means high attraction capacity in nanotechnology research by the specific country, *vice versa* negative delta means country with intensive collaborations in nanotechnology research with foreign labs.

5. LESSONS LEARNED AND DISCUSSION

The main results of this research are:

- ☐ Europe and USA-Canada have the highest number of nanotechnology research labs, although the key role of China has been increasing over time[17]: in 2008 the most prolific institutions in nanotechnology are 35% in China and 30% in Japan.

- ☐ Concentration ratio of nanotechnology researches across research fields has been reducing over time, confirming the widely spread of nanotechnology research across different research areas by the emerging of new trajectories of development of nanotechnologies in new scientific domains (*epistemological position)*;

- ☐ Nanotechnology studies in Material Science over 1996-2008 period have a higher scientific production in comparison with other macro subject areas, however there is a relative production increase in the research fields of "Chemistry and Medicine" and a relative production decrease in "Material Sciences".

- ☐ The driving geo-economic areas of nanotechnology studies in "Chemistry and Medicine" are Europe and North America, whereas the relative highest rate of growth is in China and South Korea[18].

- ☐ Main nanotechnology research fields applied in "Chemistry and Medicine" are: Chemistry (~53%), Chemical Engineering (~23%), Biochemistry, Genetics and Molecular Biology (~14%).

- ☐ Europe and North America have a high attraction capacity of collaborations in nanotechnology research of scholars from other geo-economic areas, whereas the country with the highest number of collaborations in nanotechnology studies with leading countries is South Korea (over 1996-2008).

Why Europe and USA-Canada have higher production in nanotechnology studies?

The determinant can be due to the higher rate of investments in Public R&D in NSTs, that according to Roco (2005) in 2004 were about $1,100M in the USA (3.7 $/Capita)[19], ~$1,050M in EU-25 (2.3 $/Capita), ~$950M in Japan (7.4 $/Capita), ~$250M in China (0.2 $/Capita) and ~$300M in Korea (6.2 $/Capita). According to Huang *et al.* (2004) the United States have over

[17] *Cf.* Shapira P., Wang J. (2009) for strategies and issues in the commercialization of nanotechnology in China.

[18] However, these results based on a linear trends are only an approximation such that should be further examined if they have to be used for forecasting purpose.

[19] "The 2011 Budget provides $1.8 billion for the National Nanotechnology Initiative (NNI), reflecting steady growth in the NNI investment. The cumulative NNI investment since 2001, including the 2011 request, now totals almost $14 billion. Cumulative investments in Environmental, Health and Safety (EHS) research since 2005 now total over $480 million. Cumulative investments in education and in research on ethical, legal, and other societal dimensions of nanotechnology since 2005 total over $260 million" (US National Nanotechnology Initiative: http://www.nano.gov/html/ about/funding.html, accessed 8 december 2010).

60 percent of world nanotechnology patents. This result is confirmed by Shapira and Youtie (2008, p. 188 ff).

Why relative nanotechnology research trend in "Chemistry and Medicine" has been increasing, while "Material Sciences" studies has been decreasing?

Results on the temporal relative decrease of NSTs studies in "Material science" and increase in "Chemistry and Medicine" can be due to the evolution of technology trajectories that have been passing from the invention phase of new nanomaterials to the innovation phase focused on innovative applications in biochemistry, medicine, genetics, etc. In other words, NSTs is a dynamic "new technological system" (Freeman and Soete, 1987, p. 56): some inventions might have become radical and incremental innovations applied in several fields such as chemical engineering and medicine. Islam and Miyazaki (2010) argue that "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" (p. 229). In addition, this new "technological system" has different inner nanotechnology trajectories that by cross-fertilization have been generating new "converging technologies" (Bainbridge and Roco, 2006) that are in the first phase of the *S-shaped* curve of growth (cf. Roco, 2007), *i.e.* before the point of inflection: this phase is characterized by high level of exponential growth that will generate new radical and incremental innovations in not-too-distant future. Roco (2007) also conjectures that the dynamics of nanotechnology outcomes will pass the point of inflection after the year 2020 or thereabouts.

Figure 15 confirms that the development curves of nanotechnology production is not linear, but *S-shaped* over 1996-2008 period, characterized by a disequilibrium pattern of growth. In particular, figure 15 shows the relative higher number of scientific outputs per million people in South Korea and Japan. A critical point is 2002 where the increasing trend of South Korea has been prevailing on Japan and other geo-economic players. In addition, table 1 shows that R&D investment in nanotechnology as $/capita is 6.2 in South Korea, lower than Japan (7.4). However, NSTs outcome in South Korea is of 27.92 scientific products per million people, a higher value than Japan (22.30). This gap is higher if the scientific performances of 2008 are considered: 41.98 scientific products (in nanotechnology) per million people in South Korea *vs.* 19.93 in Japan. Therefore these results show that the specificity of national sub-set of nanotechnology in South Korea has more efficiency in comparison with Japan and other geo-economic areas.

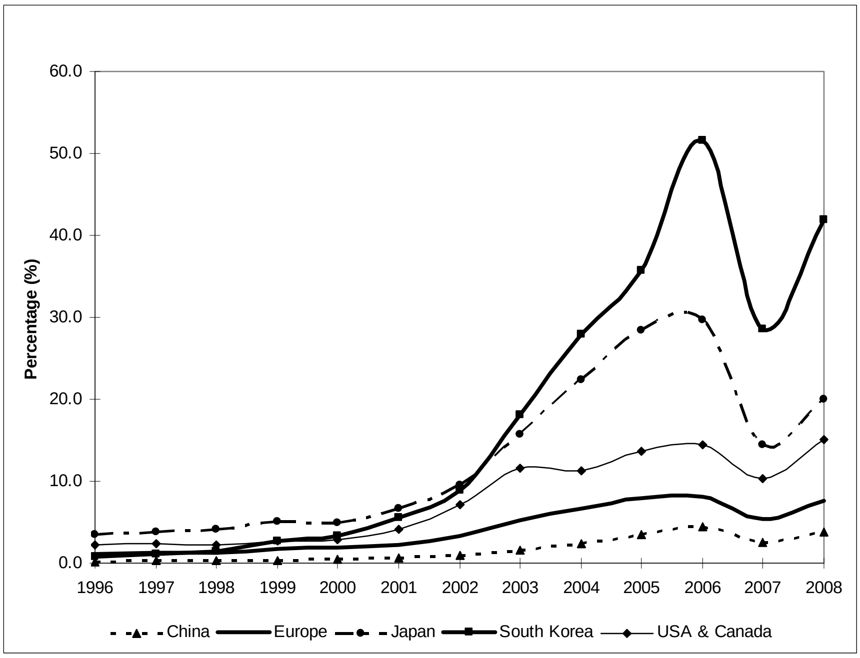

FIGURE 15. SCIENTIFIC PRODUCTS IN NSTs PER MILLION PEOPLE ACROSS GEO-ECONOMIC AREAS OVER 1996-2008

TABLE 1. RESEARCH INVESTMENTS AND SCIENTIFIC PERFORMANCE IN NANOTECHNOLOGY STUDIES ACROSS COUNTRIES

Countries	*Specific. Nanotech R & D 2004 ($ / Capita)**	*Nanotechnology scientific products per million people 2004*	*Nanotechnology scientific products per million people 2008*	*Δ %*
USA	3.7	11.28	15.07	33.60
Europe	2.3	6.62	7.65	15.56
Japan	7.4	22.30	19.93	-10.63
China	0.2	2.40	3.80	58.33
South-Korea	6.2	27.92	41.98	50.36

* S*ource*: Roco (2007), pp. 3.1-3.26

This research shows main dynamic of research trends in NSTs studies, though the results could have some limits. The main one is that Scopus retrieves the first 160 results for each item (Source, Affiliation, Keyword, etc.) set by Scopus to Data mining; in addition, Scopus is a relatively new instrument for scientific literature classification and not all nanotechnology research might be included (though this limit is common with other web-based datasets).

Although "nanotechnology is still in an early phase of development" (Renn and Roco, 2006, p. 153), these results show the current growing applications of nanotechnology in some key sectors, such as Chemistry and Medicine[20], which may imply some ethical and social issues that Governments might need to face in the next future in order to support a sustainable development of pattern of technological innovation and economic growth as well.

[20] According to de Miranda Santo *et al.* (2006) "many areas will suffer impacts caused by Nanoscience and Nanotechnology … as health, chemistry and petrochemicals, computing, Energy, agribusiness, metallurgy, textiles, environmental protection, among other" (p. 1020).

Renn and Roco (2006, p. 154) argue:

> As with other new technology, nanotechnology evokes enthusiasm and high expectations: for new progress in science and technology, new productive applications and economic potential on one hand; and for concerns about risks and unforeseen side effects on the other.

Renn and Roco (2006) also claim the general risks associated with nanotechnology applications, showing that the nanotechnology innovation proceeds ahead of the policy and regulatory contexts: "Governance gap is … especially significant for the several 'active' nanoscale structures and nanosystems that … have the potential to affect not only the human health and the environment but also aspects of social lifestyle human identity and cultural values" (p. 153, original emphasis). Robinson (2009) describes the notion of "*Responsible Research and Innovation* of nanotechnology as an opportunity to develop support tools for exploring potential co-evolutions of nanotechnology and governance arrangements" (p. 1222, original emphasis).

No doubt that information analysis and foresight studies for the evolutionary research trends in nanotechnologies are a hard work since this technological system is characterized by "interdisciplinarity" and "pervasiveness" (Salerno *et al.*, 2008, p. 1206, 1208, and 1220, *passim*) in the current disequilibrium phase of growth. In presence of these scientific and analytical issues, further research about these research trends is *needed* to strengthen this important topic in for "Evolutionary Theory of Economic Change" (Nelson and Winter, 1982)[21] in order to design provident innovation policy and governance practices aimed at driving sustainable paths of growth for modern economies that are more and more based on these "new converging innovations" (*cf.* Bainbridge and Roco, 2006) within the technological system of nanotechnology.

REFERENCES

Bainbridge W.S., Roco M.C. (Eds.) (2006), *Managing nano-bio-info-cogno innovations, converging technologies in society*, Springer, Berlin.

Balzani V. (2005), "Nanoscience and Nanotechnology: A personal View of a Chemist", *Small*, vol. 1, n. 3, pp. 278-283.

Bertinetti L., Tampieri A., Landi E., Ducati C., Midgley P.A., Coluccia S., Martra G. (2006), "Surface structure, hydration, and cationic sites of nanohydroxyapatite: UHR-TEM, IR, and microgravimetric studies", *Journal of Physical Chemistry C*, vol. 111, n. 10, pp. 4027-4035.

Bonaccorsi A., Thoma G. (2007), "Institutional complementarity and inventive performance in nano science and technology", *Research Policy*, vol. 36, n. 6, pp. 813-831.

Bozeman B., Laredo P., Mangematin V. (2007), "Understanding the emergence and deployment of "nano" S&T", *Research Policy*, vol. 36, n. 6, pp. 807-812.

Braun T., Schubert A., Zsindely, s. (1997), "Nanoscience and nanotechnology on balance", *Scientometrics*, vol. 38, n. 2, pp 321-325.

Celotti G., Tampieri A., Sprio S., Landi E., Bertinetti L., Martra G., Ducati C. (2006), "Crystallinity in apatites: how can a truly disordered fraction be distinguished from nanosize crystalline domains?", *Journal of Materials Science-Materials in Medicine*, vol. 17, n. 11, pp. 1079-1087.

de Miranda Santo M., Massari Coelho G., Maria dos Santos D., Fellows Filho L. (2006), "Text mining as a valuable tool in foresight exercises: A study on nanotechnology", *Technological Forecasting and Social Change*, vol. 73, n. 8, October, pp. 1013-1027.

[21] Cf. Dosi *et al.* (1988)

Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. edits (1988), *Technical Change and Economic Theory*, Pinter, London

Eigler D.M., Schweizer E.K. (1990), "Positioning single atoms with a scanning tunnelling microscope", *Nature*, n. 344, pp. 524-526.

Evangelisti C., Vitulli G., Schiavi S., Vitulli M., Bertozzi S., Salvadori P., Bertinetti L., Martra G. (2007), "Nanoscale Cu supported catalysts in the partial oxidation of cyclohexane with molecular oxygen", *Catalysis Letters*, vol. 116, n. 1-2, pp. 57-62.

Feynman R.P. (1960), "There's plenty of room at the bottom", *Engineering and Science*, vol. 23, Feb., pp. 22-36.

Freeman C., Soete L. (1987), *Technical Change and Full Employment,* Basil Blackwell, Oxford (UK).

Glenn J.C. (2006), "Nanotechnology: Future military environmental health considerations", *Technological Forecasting and Social Change*, vol. 73, n. 2, February, pp. 128-137.

Goddard III W., Brenner D., Lyshevski S., Iafrate G. (Eds.) (2007), *Handbook of Nanoscience, Engineering and Technology*, Second Edition, Taylor and Francis Group.

Huang Z., Chen H., Roco M.C. (2004), "Longitudinal patent analysis for nanoscale science and engineering in 2003: country, institution and technology field analysis based on USPTO patent database", *Journal of nanoparticle research*, vol. 6, n. 4, pp. 325-354.

Iijima S. (1991), "Helical microtubules of graphitic carbon", *Nature*, n. 354, pp. 56-58.

Islam N., Miyazaki K. (2010), "An empirical analysis of nanotechnology research domains", *Technovation*, vol. 30, n. 4, pp. 229-237.

Kostoff R N., Stump J.A., Johnson D., Murday J.S., Lau C.G.Y., Tolles W.M. (2006), "The structure and infrastructure of the global nanotechnology literature", *Journal of Nanoparticle Research*, vol. 8, n. 3-4, pp. 301-321.

Kostoff R.N., Koytcheff R.G., Lau C.G.Y. (2007), "Global nanotechnology research metrics", *Scientometrics*, vol. 70, n. 3, pp. 565-601.

Kostoff R.N., Koytcheff R.G., Lau C.G.Y. (2007a), "Global nanotechnology research literature overview", *Technological Forecasting & Social Change*, vol. 74, n. 9, pp. 1733-1747.

Kroto H.W., Heath J.R., O'Brien S.C., Curl R.F., Smalley R.E. (1985), "C60: Buckminsterfullerene", *Nature*, n. 318, pp. 162-163.

Leydesdorff L. (2008), "The delineation of nanoscience and nanotechnology in terms of journals and patents: A most recent update", *Scientometrics*, vol. 76, n. 1, pp. 159-167.

Leydesdorff L., Zhou P. (2007), "Nanotechnology as a field of science: its delineation in terms of journals and patents", *Scientometrics*, vol. 70, n. 3, pp. 693-713.

Libaers D., Meyer M., Geuna A. (2006), "The Role of University Spinout Companies in an Emerging Technology: The Case of Nanotechnology", *The Journal of Technology Transfer*, vol. 31, n. 4, pp. 443-450.

Nelson, R. R. and Winter, S. G. (1982), *An Evolutionary Theory of Economic Change*, Belknap, Harvard.

Pilkington A., Lee L.L., Chan C.K., Ramakrishna S. (2009), "Defining key inventors: A comparison of fuel cell and nanotechnology industries", *Technological Forecasting and Social Change*, vol. 76, n. 1, January, pp. 118-127.

Renn O., Roco M.C. (2006), "Nanotechnology and the need for risk governance", *Journal of Nanoparticle Research*, vol. 8, n. 2, pp. 153-191.

Rickerby D.G., Morrison M. (2007), "Nanotechnology and the environment: A European perspective", *Science and Technology of Advanced Materials*, vol. 8, n. 1-2, pp. 19-24.

Robinson D.K.R. (2009), "Co-evolutionary scenarios: An application to prospecting futures of the responsible development of nanotechnology", *Technological Forecasting and Social Change*, vol. 76, n. 9, pp. 1222-1239.

Roco M.C. (2005), “International perspective on government nanotechology funding in 2005”, *Journal of Nanoparticle Research*, vol. 7, n. 6, pp. 707-712.

Roco M.C. (2007), “National Nanotechnology Initiative. Past, Present, Future”, in W. Goddard III, D. Brenner, S. Lyshevski & G. Iafrate (Eds), *Handbook of Nanoscience, Engineering and Technology*, *Second Edition*, Taylor and Francis Group, Chp. 3, pp. 1-26.

Salerno M., Landoni P., Verganti R. (2008), “Designing foresight studies for Nanoscience and Nanotechnology (NST) future developments”, *Technological Forecasting and Social Change*, vol. 75, n. 8, October, pp. 1202-1223.

Scopus (2010), http://www.scopus.com, accessed April 2010.

Shapira P., Youtie J. (2008) “Emergence of Nanodistricts in the United States Path Dependency or New Opportunities?” *Economic Development Quarterly*, vol. 22 , n. 3, pp. 187-199.

Siegel R.W., Hu E., Roco M.C. (1999), *Nanostructure Science and Technology*, Springer, Dordrecht, The Netherland.

Taniguchi N. (1974), “On the Basic Concept of Nano-Technology”, *Proceedings International Conference Production Engineering*, Part II, Japan Society of Precision Engineering, Tokyo.

Tegart G. (2009), “Energy and nanotechnologies: Priority areas for Australia's future”, *Technological Forecasting and Social Change*, vol. 76, n. 9, November, pp. 1240-1246.

US National Nanotechnology Initiative (2010), http://www.nano.gov/, accessed June 2010.

van Merkerk R.O., van Lente H. (2005), “Tracing emerging irreversibilities in emerging technologies: The case of nanotubes”, *Technological Forecasting and Social Change*, vol. 72, n. 9, November, pp. 1094-1111.

Yanagisawa T., Shimizu T., Kuroda K., Kato C. (1990), “The preparation of Alkyltrimethylammonium-Kanemite Complexes and Their Conversion to Microporous Materials”, *Bulletin of the Chemical Society of Japan*, vol. 63, n. 4, pp. 988-992.

Zecchina A., Groppo E., Bordiga S. (2007), “Selective Catalysis and Nanoscience: An Inseparable Pair”, *Chemistry- A European Journal*, vol. 13, n. 9, pp. 2440–2460.

APPENDIX A

TABLE 1A: AGGREGATION OF SUBJECT AREAS IN MACRO SUBJECT AREAS IN NSTs STUDIES

Macro Subject Area	*Subject Area (S.A.) of Scopus per journals*	*Total papers in S.A.*	*Total papers in Macro S.A.*	*%*
Material Science	Materials Science	117,808		29.46
			117,808	
Chemistry and Medicine	Biochemistry, Genetics and Molecular Biology	14,471		3.62
	Chemical Engineering	24,617		6.16
	Chemistry	56,329		14.09
	Dentistry	212		0.05
	Health Professions	376		0.09
	Immunology and Microbiology	889		0.22
	Medicine	5,677		1.42
	Veterinary	42		0.01
	Neuroscience	336		0.08
	Nursing	30		0.01
	Pharmacology, Toxicology and Pharmaceutics	3,855		0.96
			106,834	
Physics and Earth Sciences	Earth and Planetary Sciences	1,555		0.39
	Physics and Astronomy	88,418		22.11
			89,973	
Engineering	Engineering	65,421		16.36
			65,421	
Information and Mathematics Sciences	Mathematics	2,061		0.52
	Computer Science	5,794		1.45
	Decision Sciences	86		0.02
			7,941	
Social and Economic Sciences	Arts and Humanities	266		0.07
	Business, Management and Accounting	562		0.14
	Economics, Econometrics and Finance	82		0.02
	Multidisciplinary	2,412		0.60
	Psychology	75		0.02
	Social Sciences	680		0.17
			4,077	
Energy	Energy	3,921		0.98
			3,921	
Environmental Science	Agricultural and Biological Sciences	770		0.19
	Environmental Science	3,086		0.77
			3,856	
TOTAL		**399,831**	**399,831**	**100.00**

Note: Scopus classifies journals in major subject areas, *e.g.* “Energy”. Journals can be allocated to multiple subject areas as appropriate to their scope. The subject areas contain scientific products concerning nanotechnology studies.

TABLE 2A: NUMBERS OF SCIENTIFIC PRODUCTS IN NANOTECHNOLOGY STUDIES PER SUBJECT AND MACRO SUBJECT AREAS OVER 1996-2008 ACROSS ALL GEO-ECONOMIC AREAS

Number	*Macro Subject Area (8)*	*Papers*	*Macro Subject Area (5)*	*Papers*
1	Material Science	117,808	Material Science	117,808
2	Chemistry and Medicine	106,834	Chemistry and Medicine	106,834
3	Physics and Earth Sciences	89,973	Physics and Earth Sciences	89,973
4	Engineering	65,421	Engineering	65,421
5	Information and Mathematics Sciences	7,941		
6	Social and Economic Sciences	4,077		
7	Energy	3,921		
8	Environmental Science	3,856	Others	19,795

TABLE 3A: CUMULATIVE NSTs RESEARCH CENTRES AND THEIR SCIENTIFIC PRODUCTS IN NANOTECHNOLOGY STUDIES OVER 1996-2008 ACROSS GEO-ECONOMIC AREAS

Year	*China*		*Europe*		*Japan*		*South Korea*		*USA-Canada*	
	Labs	*Scientific products**	*Labs*	*Scientific products**	*Labs*	*Scientific products**	*Labs*	*Scientific products**	*Labs*	*Scientific products**
1996	59	210	128	675	117	430	20	37	128	673
1997	91	312	134	856	122	483	28	51	132	700
1998	97	414	139	874	125	519	33	68	133	670
1999	105	467	137	1,135	118	645	48	124	133	841
2000	113	612	142	1,234	109	621	55	159	130	878
2001	115	780	144	1,414	116	848	73	260	142	1,294
2002	114	1,185	140	2,122	109	1,214	82	425	149	2,264
2003	112	2,001	144	3,404	107	1,993	80	864	137	3,696
2004	123	3,070	148	4,313	112	2,836	86	1,330	142	3,607
2005	132	4,476	143	5,167	113	3,607	84	1,705	141	4,375
2006	132	5,760	147	5,280	118	3,780	90	2,460	143	4,601
2007	135	3,324	147	3,556	112	1,834	89	1,363	140	3,301
2008	133	4,864	151	4,980	115	2,534	89	2,000	149	4,819
Total 1996-2008	**1,461**	**27,475**	**1,844**	**35,010**	**1,493**	**21,344**	**857**	**10,846**	**1,799**	**31,719**

* Scientific products are papers, proceedings, etc.