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TEMPORAL AND SPATIAL RELATIONS BETWEEN PATENTS AND SCIENTIFIC JOURNAL ARTICLES. THE CASE OF NANOTECHNOLOGIES

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Temporal and spatial relations between patents and scientific journal articles: the case of nanotechnologies

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ABSTRACT: Patent citations have been widely used in order to study inter-technology and science-technology relations. The present work aims at:
i) exploring time relations and distance between technical/innovative activities and scientific knowledge, using journal articles citations in patents as a proxy;
ii) exploring the origin of the knowledge cited in patents.

The study is performed on a field particularly relevant both on the scientific and technological side, that of nanosciences and nanotechnologies. In parallel a field less on the edge of research (polymers) is studied in order to compare results and shed better light on what is happening in nanotech. Studied items show a common behaviour and a higher rate of citations and a shorter time lag between citing patents and cited articles for nanotechnologies rather than for polymers. Knowledge cited in patents shows in many cases a common origin with that of citing documents. Conclusions on these behaviours are drawn.

KEYWORDS: Patent-research relations, Patent, Journal Article, Nanoscience, Nanotechnologies, Polymers, Technological trajectories, Data mining, Innovation, Knowledge diffusion

JEL-CODES: L6, O31, O33

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CONTENTS

1. INTRODUCTION

The relation between target free research, applied research and innovation has been studied widely in the last years due to its growing importance in the development of economies (Dasgupta and David, 1994). This is particularly true for new, emerging scientific and technological sectors such as the nanosciences and the nanotechnologies (NST), which have undeniably reached an outstanding role in scientific and technological research during the last two decades. Scientific publications on the topic and on its different articulations have been growing steadily since the beginning of the 1990s in all areas of the world (Coccia *et al.*, 2010). NST have been developing more and more as a field of research, gaining autonomy despite their original nature of interdisciplinarity and trans-disciplinarity. NST in fact developed out of several different scientific/technological fields (chemistry, physics, sciences of materials, engineering of materials) and have affirmed themselves as a specific vision and way to perform research and to obtain new materials and objects. In fact, acting on the matter at nanometric scale enables to work on properties otherwise unattainable by conventional methodologies.

This is also why applications of NST are gaining more and more importance in industrial innovations, and their importance for economic development is steadily growing. Peculiarities of the nanotech approach, in fact, enable to obtain products that otherwise could not be achieved, and to exploit production processes that are otherwise unattainable.

In the last years also social scientists and economists are paying more attention to the world of the NST. In particular the exploration of the relations between nanosciences and nanotechnologies by one side and their exploitation in innovation by the other side has received attention. This work deals with the relations between science and industry, with the exploitation of the results of scientific research in public research organizations, and on the influence scientific discoveries have on the world of production.

These facts suggest that NST are an ideal subject for the aim of the present work. In fact this article aims at contributing to the debate on the relations between scientific/technological research, technological applications and innovation in knowledge intensive sectors, trying to elucidate the mechanisms enabling knowledge to flow into innovation. In particular it tries to describe in a quantitative manner and in terms of time the flow of knowledge from its production to its exploitation. In order to do so it explores the relation in time and origin (in terms of institutional affiliation) between patents and the scientific literature cited into them. As NST have the characters of novelty in the vast panorama of sciences and technologies, of being highly valuable on both the scientific and industrial sides, and of having a vast production in literature and patenting, they are an ideal subject for such a kind of investigation.

The research questions at the basis of the present work have been the following: is it possible to measure the time lag needed for knowledge produced and made public through the usual channels of publication to its incorporation into a technical application provided of novelty, originality and applicability in an invention described in a patent? Is this time lag typical of a defined scientific area or not? Are there differences in this time lag between different scientific areas? Is it possible to describe the nature of this knowledge in terms of its origin?

In order to answer to the above questions an experimental activity was carried out. The number of journal articles citations in patents was measured concentrating on some items related to NST and on the scientifically and industrially older technology of polymers. This was performed in order to answer to the questions on the nature of the above cited time lag. A further investigation was performed with the scope of understanding how knowledge flows in terms of its origin (affiliations/research institutions).

The article is organized in the following way. First an overview on the nature and history of NST, and on the history of polymers, is performed. Then a theoretical background on the relations between science and innovation and between patents and scientific articles is described. In the following section methodology of the experimental work and its results are described. The last section contains the discussion of results and the conclusions.

2. AN OVERVIEW ON NANOTECHNOLOGIES

The speech (Feynman, 1960) given by Richard P. Feynman at an American Physical Society meeting at California Institute of Technology on December 29th, 1959, where the scientist uttered the famous sentence "There is plenty of room at the bottom" describing the possibilities for science and technology given by their expansion towards the scale of nanometers is considered the beginning of the nanotechonologies. From the operational point of view their start can be set with the invention of Scanning Tunnelling Microscopy (STM) (Bonaccorsi and Thoma, 2007) at IBM laboratories in Zurich, which gained Gerd K. Binnig and Heinrich Rohrer the Nobel Prize for Physics in 1986 (Binnig and Rohrer, 1986). In 1985 Harold Kroto, Robert Curl and Richard Smalley discovered Buckminsterfullerene (Kroto *et al.*, 1985) (this discovery gained them 1996 Nobel Prize for Chemistry), and Japanese scientist Sumio Iijima at NEC Corporation discovered Cabon nanotubes in 1991 (Ijiima, 1991).

Since then the spreading and growth of nanosciences and nanotechnologies has been marked by inventions and findings of new nanostructured materials, new production, investigation and characterization techniques, new nano-objects produced.

A working definitions of nanotechnologies is that given by American National Nanotechnology Initiative[i], stating "*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 are 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". This definition discriminates between science and technology, and accounts for the fact that "nanotech" is first of all an approach towards the matter. Time will tell if this approach will evolve towards an independent scientific/technological sector or not. As Balzani describes (Balzani, 2005) different sectors have different approaches (the so-called top-down for physicists and engineers, the bottom-up approach for chemists) and this difference has to harmonize itself. Also, nanotechnologies can be roughly divided into three main areas – nanomaterials, nanoelectronics, bio-nanotech – that share the common approach and the common dimensional belonging.

NST applications in innovation can still be considered as highly knowledge intensive, as all the sectors where they take place – for instance production of catalysts for industrial production (Zecchina *et al.*, 2007; Evangelisti *et al.*, 2007) or biomaterials produced for bone substitution inside the human body (Bertinetti *et al.*, 2006; Celotti *et al.*, 2006) – still rely much on the results of research. This fact has attracted the attention towards NST of scientists engaged in studies of organization and management, economics, innovation studies. The revolutionary potential of such a fluid and cross-bordered sector has been affirmed (Bozeman *et al.*, 2007), so as their position at the convergence of several scientific and technological fields (Avenel *et al.*, 2007).

The scientific production on NST has been studied by Leydesdorff and Zhou (2007) who, basing their work on Journal Citation Report data, show that the citation

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[i] http://www.nano.gov/ , accessed july 2010.

environment of the most relevant "nano" journal is shrinking with time, that "nano" journals are more complex – again from the point of view of citations – than "classic" disciplinary journals and that their position is at the interface between physics and chemistry. Yet a conceptually simple analysis of this kind show the most important peculiarities of NST, that is to say their growing delineation as a scientific field and, at the same time, their interdisciplinarity as a fundamental character.

Also Kostoff *et al.* (2006; 2006a) give an overview on NST, retrieving data for years 2002 – 2005 and working on the number of occurrences of items such as author names, affiliations, countries etc.

Waldron *et al*. (2006) describe the state of public understanding of nanotechnology studying a sample of children and adults based in the United States. Their findings show that the general knowledge and state of public understanding on the topic is very low, not only in younger generation but also among adults. A similar work was performed on an European target (Caputo *et al*., 2009) showing again a low level of knowledge on NST regardless of the level of education, but at the same time an high level of confidence towards their applications.

Finally, Coccia *et al.* (2010) have widely explored the topic, studying the growth of nanotechnologies and the interrelation between different areas in the world in performing research on the topic.

3. AN OVERVIEW ON THE HISTORY OF POLYMERS

If NST are one of the last scientific novelties enriching the panorama of hard and applied sciences, polymer sciences have a long and complex history. The first stage in this field has been the exploitation of natural polymers. Caoutchouc (rubber) has been used intensively by the native populations of South America all along their existence, and has been introduced in Europe and America since the beginning of the XIXth century. The process of rubber vulcanization (discovered in 1839 by the American C. Goodyear) has probably been the first industrial process on polymers. In 1811 the French chemist H. Braconnot began his experiments on cellulose compounds. But the first man-made polymer was created in 1907 by Leo Bakeland, who produced Bakelite via a reaction of phenol with formaldehyde, controlling temperature and pressure condition. Two years later, in 1909, Bakelite was produced for the public.

In 1927 W. L. Semon found a method to plasticize PVC (PolyVinylChloride), a polymer that was accidentally discovered in several occasions in the previous century. In 1931 industrial exploitation of Polystirene began: the polymer was accidentally discovered one century before in Berlin, but – though recognized as a polymer – it had never been possible to produce it industrially due to the fact that the way it did form was not known.

At the beginning of World War II, some years after its discovery by W. Carothers at DuPont, Nylon Polyammide, the first condensation polymer and one of the biggest commercial successes in the field, began its commercialization. The production of Polyethylene, the sinthesis of which was accidentally discovered in 1933 at ICI, began in the same years. In 1951 at Phillips petroleum a polymerization catalyst for Polyethylene was discovered, while in 1953 the German chemist K. Ziegler developed a better catalytic system based on Titanium halydes and Organoaluminum composites.

K. Ziegler is also involved in the discovery of isotactic Polypropylene. This polymer was discovered in 1954 by the Italian chemist Giulio Natta, who used a catalyst derived from the Ziegler catalyst in order to produce a stereo regular polymer. Their work on high polymers gained the two scientists 1963 Nobel Prize for chemistry.

In 1965 Kevlar®, the first highly marketed Aramidic polymer, was developed at DuPont, and began its commercialization in the early 1970s.

This short insight in some of the most

important points in the history of polymers' science and industrialization shows the difference between this area of the sciences and technologies of materials and the NST in terms of age, development, industrial importance.

4. THEORETICAL BACKGROUND: THE RELATIONS BETWEEN SCIENCE AND INNOVATION AND BETWEEN PATENTS AND SCIENTIFIC ARTICLES

The influence of scientific discoveries on industrial innovation and the speed and paths of this influence have been widely investigated along years. Colyvas *et al*. (2004) describe the exploitation of university inventions via a series of case studies. Results show that Intellectual Property Rights result in being more important for embryonic inventions rather than for those ones ready for exploitation, while the action of Technology Transfer offices is most important for those technological areas where the links with industries are weaker.

The patent-journal article relations have been widely studied. Albert *et al*. (1991) analyzing a set of industrial patents issued by the same company show that highly cited patents are of significantly greater technological value than those that are less cited or not cited at all. The basic idea behind the work is in fact that a highly cited U.S. patent has been "prior art" for several other ones and thus contains significant advances.

Schmoch (1993) describes the science-technology relation on a quantitative basis. He distinguishes the different types of citations in EPO procedures assessing the different type of linkage to the patent, which is not necessarily strong, and the different causes a non-patent citation is made. His analysis of non-patent citations in patents did not reveal clear results under the point of view of assessing new R&D management tools, but according to his statements "there exists plausible support for the hypothesis that a high number of non-patent citations can be considered as an indicator for a strong science interface".

The analysis performed by Narin (1994) on patent productivity and citations shows the closeness between science and technology in several areas, the tendency to prefer within-country citations and the fact that patents and journal articles show many similarities under the bibliometric aspect.

In a further work (Narin *et al*., 1995) he and his co-authors, again using science references in patents, infer the growing link between science and technology in the U.S., and the role of driving force of public science towards high technology. Analyzing non-patent references in patents again Narin *et al*. (1997) show again a steady increase in science linkage, a marked intra-national effect (also present in article-to-article and patent-to-patent citations) and the fact that U.S. industry has a wide science base and that public science plays an essential role in its supporting.

Meyer (2000) first accurately studies the structure of a patent, the role of citations and their different types following Schmoch (1993), describing then 10 case studies in order to assess science links, the direction of the flow of knowledge and possible national differences. Results show the general science-technology connection but the fact that citations hardly represent a direct link between cited journal article and citing patent (thus criticizing the use of citations made by Narin). Scientific findings represent an important background for patents, but links established by citations have a mediated character. Nevertheless, patent citations of scientific references can indicate the intensity of science – technology interrelation, albeit indirectly, for different fields; one should not make comparisons on the effectiveness of knowledge transfer amongst fields.

Again Meyer (2001) studies paper citations in nanoscience and nanotechnology patents. His database considers pieces of knowledge produced at the very beginning of the "nano revolution" (patents issued from 1976 to 1999, and journal articles written between 1991 and 1996) and thus he relies on a very small database. At that historical point evidences did support the idea that in the studied field science and technology were mostly separate activities, whose relation was very mediated: the vision supported was that of a two-branched tree.

The same topic of nanotechnology has been further investigate by Hulmann and Meyer (2003). The authors perform in particular an analysis of journal article citations in patents, studying different journal article categories (and comparing with the total “nano” scientific production), provenance of patents and journal articles in terms of organization and geographic area, and the science-technology linkage. The used sample is very small due to the stage nanotechnologies were (data were collected in the 1991-2000 period); nevertheless findings show that, at that time, the level of interaction between nanoscience and nanotechnology was limited, and the evolution of the topics was huge.

A reverse study has been performed by Glänzel and Meyer (2003) who did study journal articles indexed in the 1996-2000 annual volumes of the Science Citation Index retrieving citations of patents and retrieving those cited in the USPTO database. The most striking finding is the high share of patent citations in chemistry journals if compared to other scientific sectors.

The study of the interactions between science and technology is performed in Meyer 2006 using data on patents and journal articles from Finland. The author uses both journal article citation in patents and university-produced journal articles as indicators of science-technology links; findings show differences between different fields in the behaviour of indicators. Also a survey on academic inventors shows differences, together with the importance of the personal role in Transfer of Knowledge. The work suggests no single appropriate indicator can track interactions comprehensively.

Li *et al.* (2007) studied several types of patent citations networks with a network analysis methodology on a sample of USPTO nanotech patents retrieved with a “full text” query. The topological analysis of patent citations show that the US citations are the most numerous, that citation networks show a very large core component occupying most part of the nodes, that different national networks have different knowledge transfer efficiencies and tend to form local citation clusters. Again Li *et al*. (2007a) compare USPTO patents with EPO and JPO patents retrieved via keyword analysis. Findings show: a quasi-exponential growth of nanotech patents; a similar behaviour of countries (in terms of number of filed patents) in both USPTO and EPO repositories, while this behaviour differs much in terms of patenting institutions and of importance of patents (measured with the number of citations); many overlapping but also several differences between technology fields. In a longitudinal study on patent citations realized by the same group of authors (Hu *et al*., 2007) and based on the same period of the previous two, patent citations to academic literature were analyzed in order to evaluate their impact on technological innovation. Two main fields – chemical/pharmaceutical and material/semiconductor – have bee identified as more relevant according to citations. Few journals accounted for the majority of citations. Article citations retrieved in patents provide information that can be used in order to assess the impact of academic research on innovation, especially in an emerging area such as nanotechnology.

Criscuolo and Verspagen (2008) try to investigate patent citations as indicators of potential knowledge spillovers. USPTO citations are considered *incomplete measures of knowledge flows* as they only capture flows useful for patenting: the level of noise is thus very high. EPO citations, *per contra*, can be assumed scrutinized by the patent examiner (who also can add citations) in relation to prior art, and can thus be considered closer to the patent in time and content. Thus the study was performed on EPO patents with an econometric approach. Results show the difference between EPO and USPTO patents, and the negative influence of geographic and cognitive distance on spillovers.

Bacchiocchi and Montobbio (2009) select patents from some countries and sectors in the years 1978 to 1998 in order to show the knowledge diffusion (from university and public research patents) in Europe. Results show that knowledge “incorporated” in patents coming from Public Research Organizations is more cited than that present in corporate patents. But this is more true for the US in some sectors (Chemical, Drugs & Medical and Mechanics) and less true for EU countries.

Breschi and Catalini (2010) try to trace the links between science and technology via an empirical analysis of journal articles cited in patents, analyzing the presence of researchers in both networks of scientists and technologists. Authors affirm the two communities are largely intertwined, and that certain single individuals play an important role interconnecting the two communities. They also stress some caveats to their work, in particular for the building of the database and the use of social network analysis applied to bibliometric indicators.

Also the problem of the relation between codified and uncodified knowledge affects our work. We can cite on the topic the work of Cowan *et al.* (2000) and the following debate (Johnson *et al.*, 2002; Balconi *et al.*, 2007), just to show that the problem of codification of produced knowledge is always alive in the scholars’ minds.

Building on the above literature, the aim of this work is to provide a measure of the scientific/technological chronological proximity existing between scientific research and industrial innovation for a specific scientific-technological-innovative sector. The topic still needs to undergo relevant research. In particular the aim of this work is to measure the time lag between the registration of a patent and the age in years of the scientific literature it cites, regardless if the citation has been made by the patent examiner or by the author. We assume here that the faster scientific literature is cited in a patent, the more science-intensive is the patent, and the more scientific research directly influences the work of the inventor(s), and vice versa. Thus the more an innovative industrial sector is advanced from the technological point of view and is young in terms of life cycle, the faster should be the flow of knowledge from research and the closer should be the exploited scientific knowledge and the patented technological solution.

Some assumptions were made. Patents and journal articles are used as proxies to measure science-innovation closeness. Scientific journal articles are connected to knowledge production, patents indicate a preapplicative innovative activity. As it is not possible to investigate if patented inventions were actually exploited, we do not know if a patent becomes actual innovation: this poses some difficulties, as not every patent is exploited, not all the innovations/inventions are patented, and not all the patents come from firms and companies; so we can say that patents can be used as a proxy of the codification of technological knowledge – exploitable for innovation – in a definite field, possibly springing out of scientific knowledge.

We also assume that citations in patents are always relevant and pertaining to the content of the patent. Thus if the reference is to a recent scientific content, feasibly the passage from research activities to invention has been faster than the reverse case. This does not mean in principle the presence of a high knowledge-intensity innovative activity. Also a quantitative measure is possible (average number of citations per patent) which must anyway undergo all the caveats described by literature.

5. METHODOLOGY AND RESULTS

The present work is based on the use of proxies: scientific journal articles measure scientific knowledge and patents measure technological knowledge. Journal articles are considered the classic output of codified knowledge springing out from research, while patents on their side are considered as the main output of technological knowledge applying in practice the findings of basic research; “in practice” means here along all the path going from the first idea of application of a research finding (this could be defined as Schumpeter’s “invention”) to the application in practice in the production line (schumpeterian “innovation”).

A method based on citations of scientific journal articles in patents was used. The instrument used for collecting data has been the SCI Finder, peculiar to Chemical Sciences and Materials Sciences. SCI Finder is a common facility in the libraries of Chemistry and Materials’ Sciences Research Institutions, and is published by the Chemical Abstract Service (CAS) of the American Chemical Society. Since 1907 the CAS publishes every year a huge series of volumes containing the abstract – with full bibliographic reference – of virtually every piece of knowledge related to chemistry and materials – journal articles, patents, contributions to congresses, articles etc. – and a complete series of indexes (by author, chemical substance etc.) allowing the retrieval of all the information scientists need. The CAS registry numbers are unique numerical identifiers for chemical compounds, polymers, biological sequences, mixtures and alloys assigned by the same institution. More recently the database of CAS has been digitalized and made available on line. It is accessible via a software client, the SCI Finder, or the SCI Finder Scholar, the latter being a slightly reduced version for academic use. SCI Finder allows on line search of virtually any item one wishes to know about on chemistry and materials’ sciences.

The central point that suggested the use of SCI Finder in order to collect data is its level of completeness, joined to the fact that it is restricted to the fields of interest of this work. The instrument has some drawbacks generated by the fact that it is mainly projected for the scientist who needs to gather all the information existing on a particular molecule or substance, and has no particular features useful in retrieving huge quantities of data like in our case.

In order to perform our research some items (materials, their nanostructured form, study and analysis techniques peculiar of NST) were taken in account with the use of keywords. A parallel work has been performed for other materials (polymers) older from the scientific – technological – innovative point of view. This was done in order to check if the result for nanotech items were peculiar or generalized. Table 1 reports the list of the keywords used in the queries on SCI Finder.

Queries were performed in the following way. In the SCI Finder’s initial mask the “Explore” option (an option with “Locate” and “Browse”) was chosen, followed by “Research Topic” (an option with “Author Name”, “Company Name/Organization”, “Chemical Structure”, “Molecular Formula” and “Reaction Structure”). No filtering (of language, publication year, document type, author name or company name) was operated with the search tags. The keywords were then inserted in the search field, selecting “Exact word” and not “Concept” as an option. Thus all the documents present in the database and containing the chosen keyword in the Chemical Abstract record were obtained. In this and all the subsequent steps the option “Remove duplicates” was constantly used. Then “Analyze/refine” was chosen and the citations were split into groups per years of publication/issuing. In this way series containing the total number of produced items per year for each keyword were obtained.

The same kind of work was then performed filtering only “Journal” in the main search mask, and then filtering only “Patents”. In this case it was chosen to analyze longer series than done in the further analysis – namely from 1980 to 2006 – in order to have a better view over the time response to science and technology production.

Subsequent work was performed on the obtained lists of patent. Using “Analyze/refine” function all the patents in the initial list where ordered by year of registration. Patents registered between 1998 to 2006 were considered, as SCI Finder records contain no data on citations in documents published before 1998. The series stop in 2006 because the data collection for this work began at the end of 2007, when data for this year were not complete.

After having obtained the list for patents on subject “X” published in year “Y” the “Find related” option was used, with the sub-option “Cited references”. Here the database generated a list of references containing the global index of citations in the patents in exam. This list was further analyzed. The “Cited references” were split in groups depending on the kind of cited document, as for instance Conference, General Review, Journal, Letter, News Announcement, Patent… Here a first index, the journal articles/patent ratio for each year, was calculated from the numbers of patents and journal articles cited by the patents issued every year.

The final step of the data analysis was done on the list of cited journal articles. This list was again split with the “Analyze/refine” option choosing to order per year of publication. These lists of data are the final set of data, the one on which the analysis was performed. Figure 1 shows the flow chart of the whole process.

With the obtained data average citations of journal articles in patents per year per item were calculated. Then obtained numbers (averages) were summed up considering the time lag in years back from the year of patent application. That is to say the year of application was considered “year 0” for each year from 1998 to 2006 taken in account, and obtained averages were summed up according to the time lag (all “year 0” averages summed together, all “year -1” figures summed together, et cetera).

Thus: given a = 1980 to 2006 then TOT_a = total number of objects issued/published in year a; PAT_a = number of patents issued in year a; JOU_a = number of journal articles published in year a. At this point it was possible to plot TOT_a, PAT_a and JOU_a versus a.

Then, given b = 1998 to 2006, PAT_b = number of patents issued in year b (obviously for b = 1998 to 2006 $PAT_b = PAT_a$). Again for b = 1998 to 2006 $CITJOU_b$ = number of journal articles cited in PAT_b, and $CITPAT_b$ = number of patents cited in PAT_b. From these data we can calculate:

$$RAT_b = \frac{CITJOU_b}{CITPAT_b}$$

and hence we can plot RAT_b vs b.

Then for c = 0 to 20 $CITJOU_{b-c}$ = number of journal articles cited in PAT_b and published in year b-c.

From here we calculate:

$$AVG_{b-c} = \frac{CITJOU_{b-c}}{PAT_b}$$

Finally we calculate:

$$SUM_{-c} = \sum_b AVG_{b-c}$$

and then we can plot SUM_{-c} versus –c which is our final result.

It is expected that the plots show a maximum for year –c = X; for each specific item X is the most significant time lag between citing patents and cited journal articles; we can expect that the shorter is X the closer temporally are the “facts” happening in research laboratories and the “facts” bringing to codification of knowledge for practical exploitation, and, conversely, that the flow of (codified) knowledge coming out from research activities towards its exploitation is faster and (probably) easier, accounting for a kind of research activity or for a research subject closer to application. We can’t therefore infer on the level of basicness of research and on the kind (greater or smaller radicality) of the inventions and possible innovations coming out from it.

Obtained data were plotted in order to have a graphic representation of the results and are shown in figures.

Figure 2 shows the trend of the data of total documents per year for the different nanotech items.

Figure 3 shows the trends of RAT_b plotted against years of registration of citing patents for the different NST items. For what about polymers journal articles/patent ratio for ABS is always 0 but for 2005 (0.66); for PVC is always 0 but for 2004 (0.11); for PTFE is always 0 but for 1999 (0.02) and 2004 (0.14); it is always 0 for Twaron as no journal citations were found.

Figure 4 and 5 shows most meaningful obtained results, SUM_{-c} versus –c for nanotech items (figure 4) and for polymers (figure 5). Note that no journal article citations were found for “Twaron” patents.

In order to perform a further analysis aggregated data on authors, affiliation, journal for year 2006 for all NST keywords were collected. Due to strong constraints of the SCI Finder database search-and-retrieve system it was not possible to collect full records of patents and journal articles. For each NST keyword an analysis based on affiliations was performed in order to measure the origin of the cited knowledge. Affiliations were preferred to authors in order to bypass possible problems due to the presence of homonyms. For each affiliation present in the list of those producing patents, cited journal articles and cited patents were searched and retrieved. Then percentages of patents/institutions present in both "Patents" list and in "Cited Patents" and/or "Cited Articles" list(s) – in terms of number of affiliations and of number of articles/patents – were calculated. In the case where citations are added by authors we can assume that institutions/authors producing patents tend to cite their own scientific/technological knowledge. In this case calculated percentages give us a measure of the origin of the cited knowledge: the highest the percentage, the highest the quantity of endogenous knowledge cited (and thus feasibly used) in the NST subfield.

In the other case (citations added by attorneys) the relation is less direct. Nevertheless we can assume that the knowledge present in the cited document(s) is strictly connected with the knowledge present in the citing journal article. The relation in terms of origin is in this case less strict, as it is more difficult to assume that patent attorneys tend to cite knowledge having the same origin of the patent. Results are reported in table 2 and in figures 7 and 8.

6. DISCUSSION AND CONCLUSIONS

The present research work tries to calculate the time lag – and thus the operational distance – between research and invention/innovation. It was chosen to work on NST because of the high level of novelty of these subject, of their role of growing importance in industrial innovation and of their scientific relevance.

A preliminary target was building a methodology able to measure the rate of closeness and/or distance between basic research and invention. A second target was to control and calculate the difference in behaviour – if any – between different scientific and technological areas (in this case, different kind of materials). It was chosen to use a class of materials older in terms of scientific research in the laboratory and of exploitation in production.

Analyzing the data on documents number we see a quite common behaviour of the different NST items. Scientific production on different NST items grew continuously from the 1980 onwards, with a slight stabilization of STM and, particularly, Fullerene. The peculiar behaviour of fullerene will be analyzed further. The number of patents is always one magnitude smaller than that of journal articles. For polymers the plot of total citation for ABS, taken as a comparison, shows a continuous and linear growth from 4195 items (1980) to 13744 (2006), a number of the same magnitude of some nanotech items such as nanotubes and AFM. Patent citations in the case of ABS do not make much sense, as the number of patent rises to a maximum of 30 in 2006.

Journal articles/patent ratio in citations RAT_b shows again similar behaviour for all the NST items. Apart from a couple of peaks, ratio is almost always around 0.5-0.6, thus showing also for hi-technology subjects the preference of patent citations in patents, rather than journal articles citations. Nevertheless, when we come to confront data with those of the four polymers taken in account, we easily see that, in this case, the ratio is always almost 0, due to the fact that journal article citations are very low or inexistent.

In order to analyze data on patent- journal article temporal distance it was chosen to keep in account the first and second maxima (the highest and the second value in ordinate) for each one of the studied items. This was done because values in abscissa are discrete values (time span of citation lag in years) and not a continuum, while averages (ordinate) are. This seemed the most meaningful way of proceeding.

A comprehensive analysis of the first and second maxima of the graphs of the citation number SUM_{-c} versus c shows easily some common features, shown in figure 6 below. First of all five out of seven first maxima of the nanomaterials' graph have as abscissa -3 or -4 years back from patent. This is true again for five out of seven of the second maxima. For the other values of the abscissa values are -2 in one case, -5 in two cases and only in one case (the first maximum of fullerene) it is -7. It is then possible to say, according to this analysis that the most common time lag between publication in articles of research results and their technological exploitation resides in the time area of 3-4 years. One must notice that this time lag is that between the two publication years, meaning that the time span of knowledge flow could even be shorter.

Figure 6 shows also the peculiar behaviour of "Fullerene" with respect to the other items. This could be due either to a particular character of the science/technology/ innovation path or to a query unable to collect all the data properly.

Also the behaviour of ordinate value must be taken into account. Their values are again shown in figure 6, and range for first maxima from 0.633 to 1.173, and for second maxima from 0.554 to 1.162. The average of the first maxima values is 0.942, and of the second maxima values is 0.815. If we average values not taking in account the case of fullerene, averages rise respectively to 0.993 and 0.859. These data mean that every patent cites in average almost one scientific journal article published in the year of maximum.

For control items (the four polymers) the behaviour is much different than above described. Abscissa are in the range -6 to -9 years time lag, with even a second maximum at -18. About the ordinate value, first maxima range from 0.087 to 0.173 and second maxima from 0.067 to 0.143, with the limit case of "Twaron", whose patents do not cite journal articles at all in the years taken in account.

Data analysis show that average citations of journal articles in nanotech patents are much higher than for polymers. If this can't demonstrate a higher content in "basic" science it shows with enough evidence stronger relations between inventive and research activities.

In conclusion data on time lag of citations show a common behaviour between the different nanotech items, which all show a maximum around three-four years of time lag between citing patent and cited journal article. If we compare the curves for polymers these look more like a background noise rather than a well shaped curve.

The behaviour of nanotech items could mean a speed of transfer of "basic" science into technology common to all the sector of NST.

The analysis of data on the origin of cited/citing knowledge shows some facts of interest. Data are reported on figures 7 and 8 and on table 2. Figure 7 contains histograms of percent of patents/journals, while figure 8 contains histogram relative to affiliations. Fist of all the percentage of citing/cited affiliations is always lower in terms of number of affiliation rather than in terms of number of patents/articles. This means that patenting institutions tend in average to be cited more than once in more than one patent.

The average percent of patents produced by institutions that have also produced cited documents is 35.4%. Five of the NST topics are around average (going from 34.1 to 38.0) one is much lower (STM, 19.7%) and one is much higher (Nanotube, 50.4%). So, in average, around one third of bodies producing patents has also produced a cited document (patent or article). The case of STM could be explained with the fact that, as it has been invented at the very beginning of the "nano era" and it has soon been outperformed by AFM, the technological interest and thus the grade of innovation and of science-related innovation has soon decreased. On the other side nanotubes see the growth of interests for the application in a wide number of fields of any kind, thus provoking the opposite phenomenon.

In five cases the percent of cited patents produced by patenting institutions is higher or much higher than the number of cited articles with the same origin. In one case the percent is equal (Nanoparticle, where the percent of single affiliations is slightly higher for cited articles than for cited patents) and in one case the percent of articles is higher. Again the case of nanotube is outstanding, with 71.2% of cited patents coming from patenting institutions, and 30.0% of cited articles with the same origin. In this case, which as above described is "under the spot" in terms of applications, the effect might be due to firms/research institutions incrementally patenting new applications with a lower rate of innovativeness.

What is more difficult to explain is the behaviour of AFM. Being Atomic Force Microscopy essentially a technological sector, where one could expect patenting institutions/persons citing more technological knowledge rather than more science-originated knowledge. This might be due to the fact that patents on AFM, rather than being related to the instrumental equipment, deal with application of the technique to research topics and/or with strongly science-related discoveries involving the use of Atomic Force Microscopy.

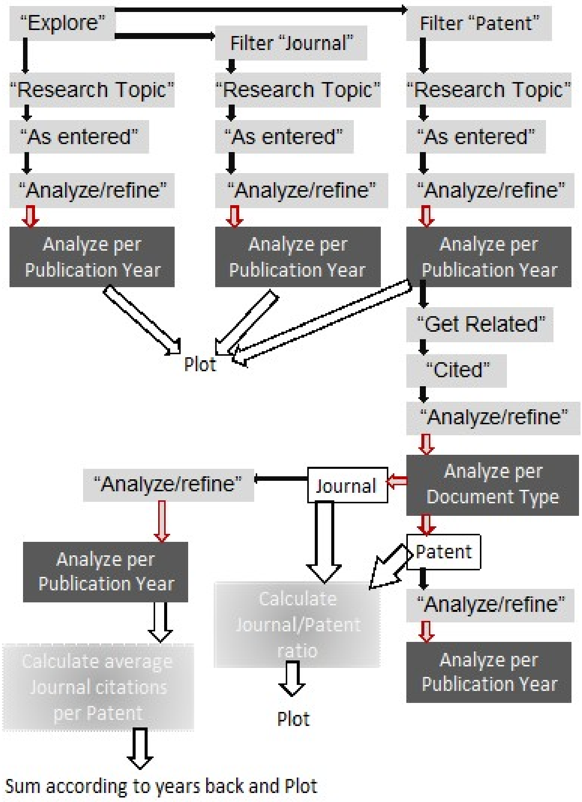

FIGURE 1: FLOW CHART OF THE DATABASE BUILDING ON SCI FINDER

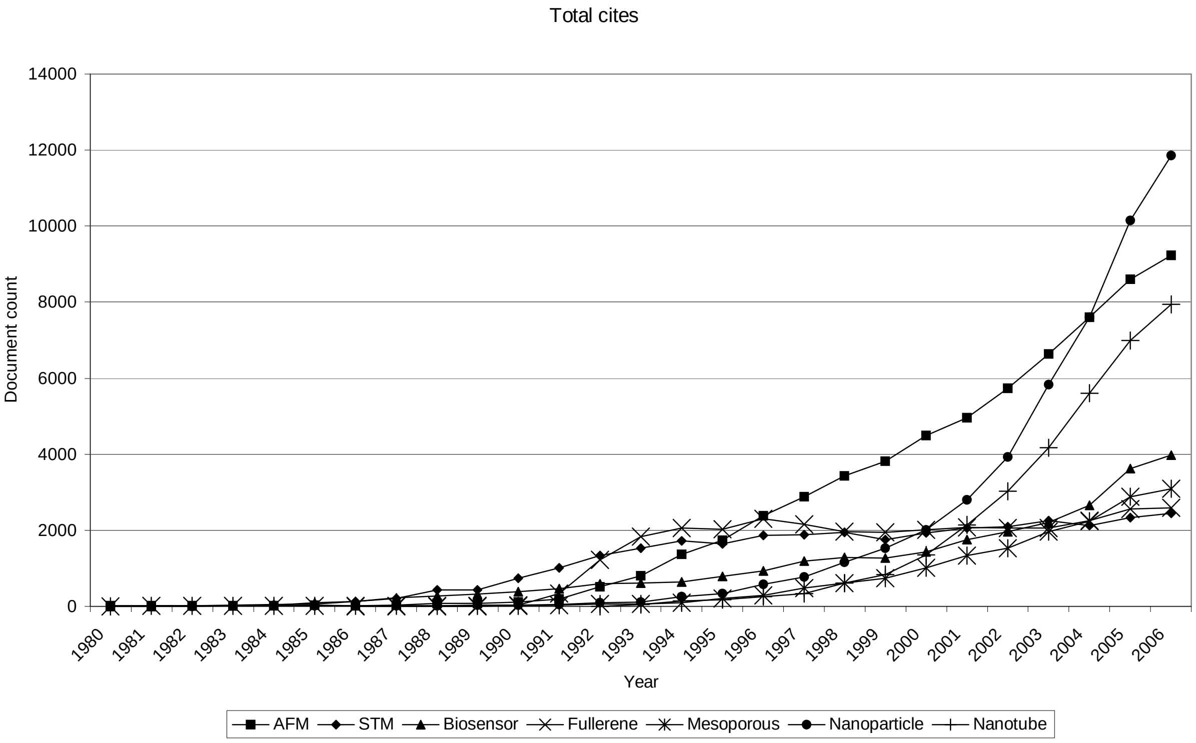

FIGURE 2: TRENDS OF TOTAL DOCUMENTS PER YEAR FOR NST ITEMS

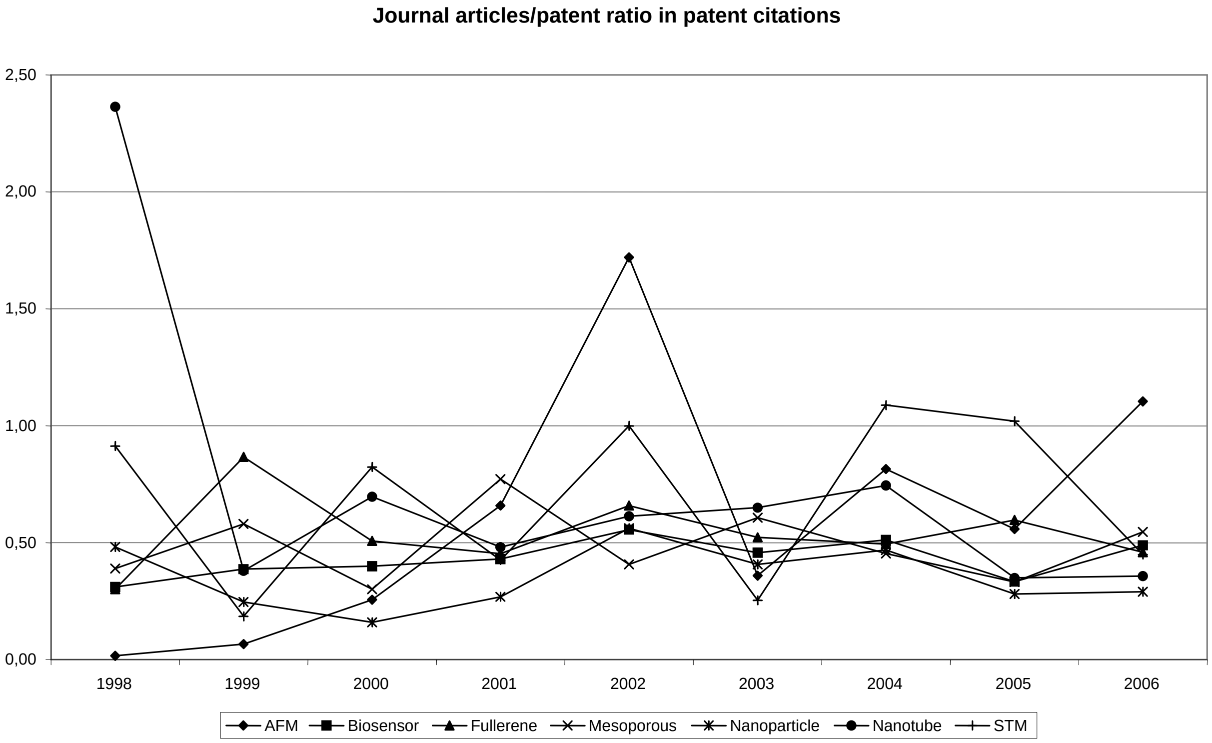

FIGURE 3: JOURNAL ARTICLES/PATENT RATIO IN PATENT CITATIONS FOR NST ITEMS

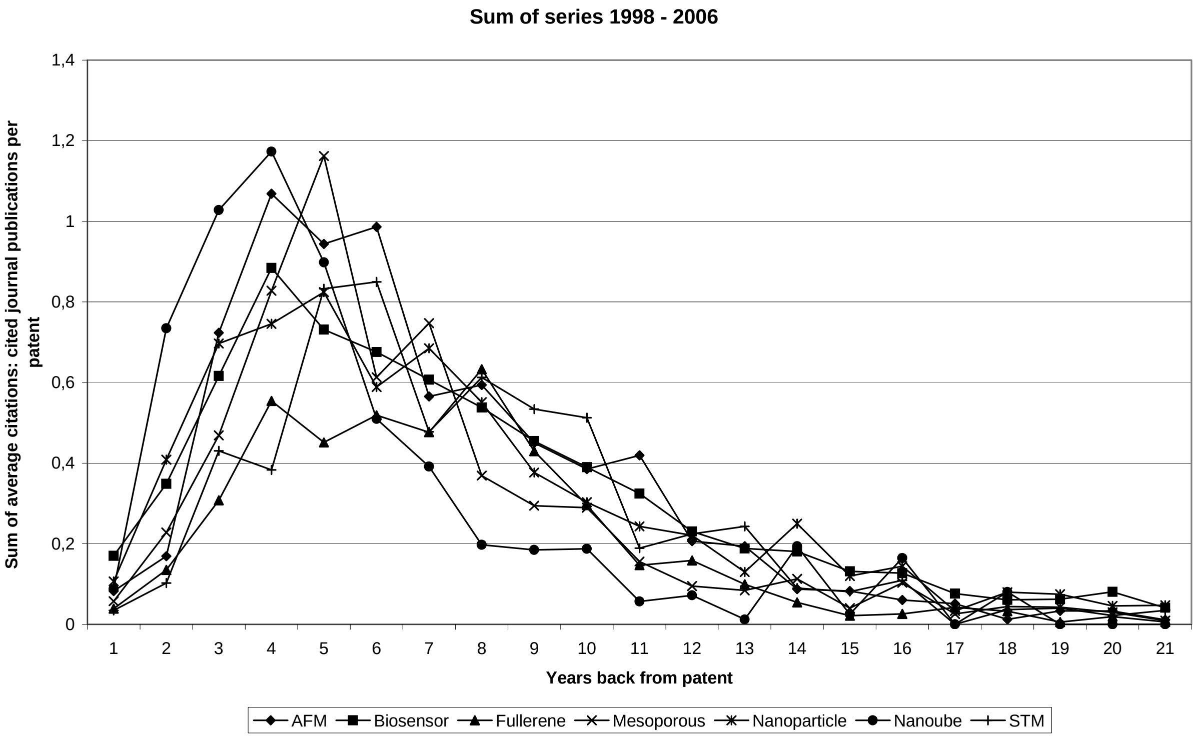

FIGURE 4: SUM$_{-C}$ VERSUS –C FOR NST ITEMS

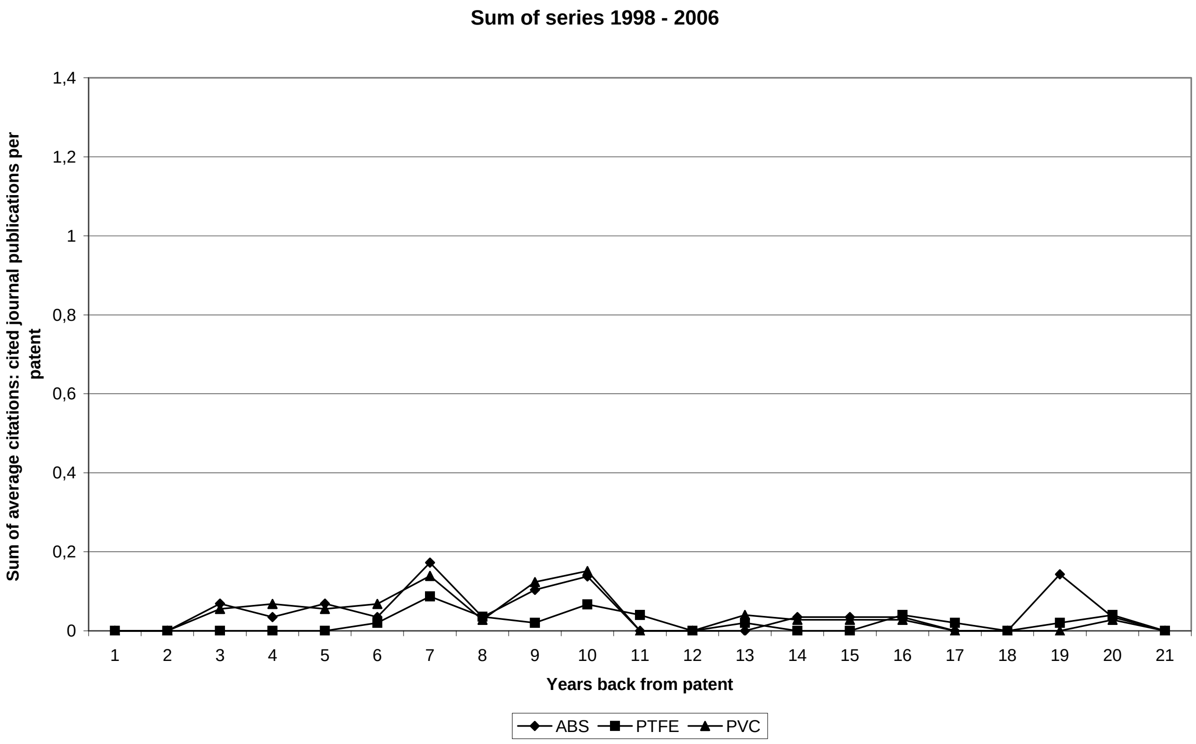

FIGURE 5: SUM$_{-C}$ VERSUS –C FOR POLYMERS

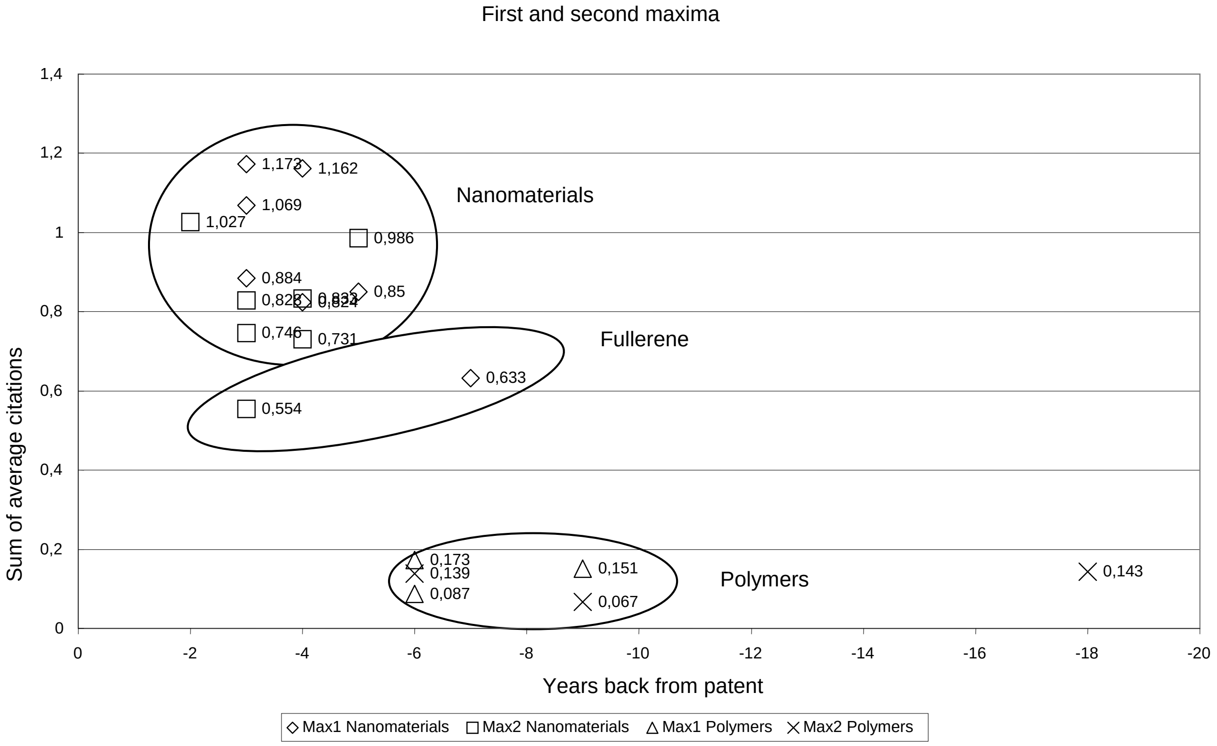

FIGURE 6: FIRST AND SECOND MAXIMA OF THE GRAPHS OF *SUM*$_{-C}$ VERSUS -*C*

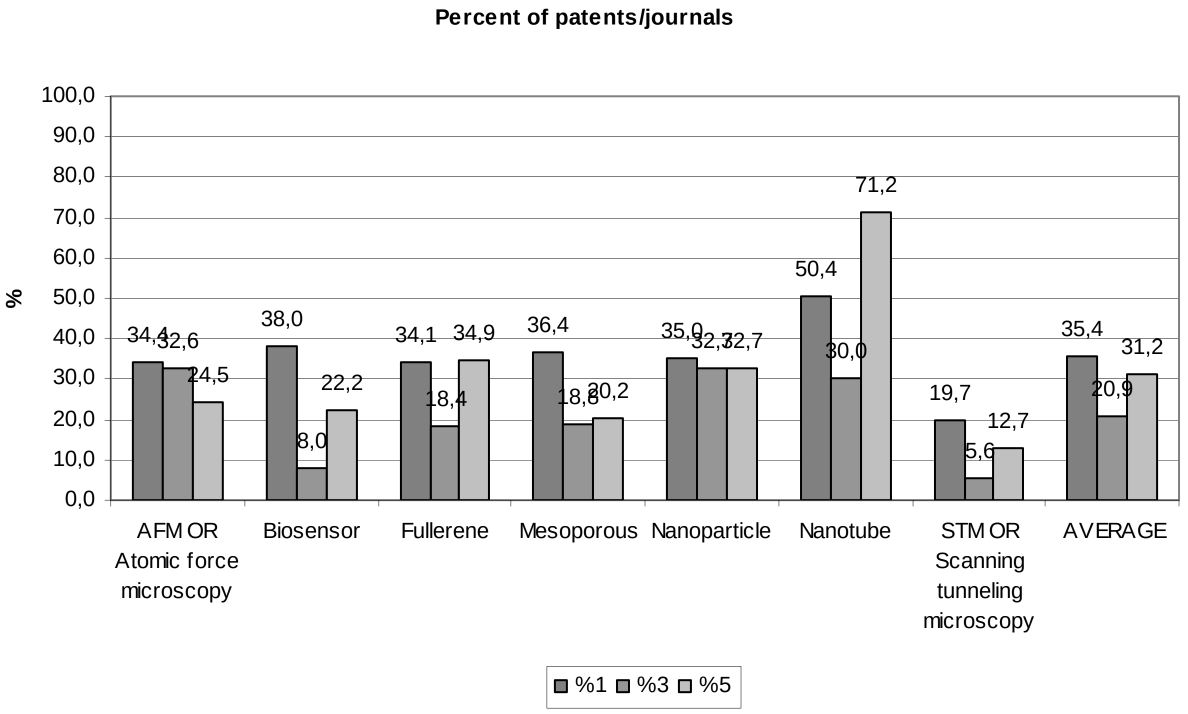

FIGURE 7: PERCENTAGES OF CITED/CITING PAPERS AND PATENTS
(REFER TO TABLE 2 FOR THE MEANING OF DIFFERENT PERCENTAGES)

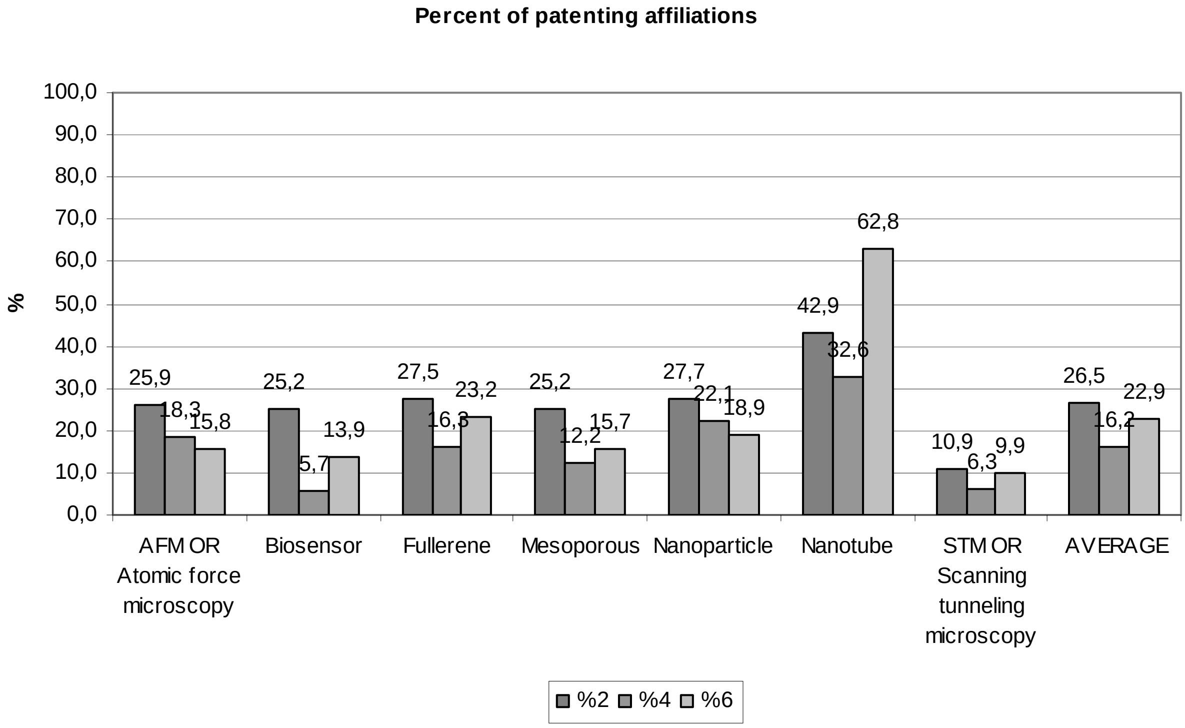

FIGURE 8: PERCENTAGES OF CITED/CITING PATENTING AFFILIATIONS (REFER TO TABLE 2 FOR THE MEANING OF DIFFERENT PERCENTAGES)

TABLE 1: KEYWORDS FOR THE QUERIES ON SCI FINDER

Queries on nanostructured materials or nanotech related items

AFM OR Atomic force microscopy
Biosensor
Fullerene
Mesoporous
Nanoparticle
Nanotube
STM OR Scanning tunneling microscopy

Control queries on elder materials

Acrylonitrile butadiene styrene OR ABS
Polytetrafluoroethylene OR PTFE
Polyvinyl chloride OR PVC
Twaron

TABLE 2: ABSOLUTE VALUES AND PERCENTAGES OF PATENTS AND ARTICLES ISSUED BY PATENTING AFFILIATIONS (EXPLANATION IN NOTE)

Keyword (data for each field in 2006)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**%1**	**%2**	**%3**	**%4**	**%5**	**%6**
AFM OR Atomic force microscopy	195	143	144	93	282	196	67	37	47	17	69	31	34.4	25.9	32.6	18.3	24.5	15.8
Biosensor	479	302	427	317	874	589	182	76	34	18	194	82	38.0	25.2	8.0	5.7	22.2	13.9
Fullerene	384	233	103	86	350	246	131	64	19	14	122	57	34.1	27.5	18.4	16.3	34.9	23.2
Mesoporous	379	218	250	188	405	300	138	55	47	23	82	47	36.4	25.2	18.8	12.2	20.2	15.7
Nanoparticle	2050	1057	1067	571	2668	1316	717	293	349	126	873	249	35.0	27.7	32.7	22.1	32.7	18.9
Nanotube	1545	613	60	46	768	363	778	263	18	15	547	228	50.4	42.9	30.0	32.6	71.2	62.8
STM OR Scanning tunneling microscopy	71	55	18	16	79	71	14	6	1	1	10	7	19.7	10.9	5.6	6.3	12.7	9.9
AVERAGE	729.0	374.4	295.6	188.1	775.1	440.1	289.6	113.4	73.6	30.6	271.0	100.1	35.4	26.5	20.9	16.2	31.2	22.9

***Note*: explanation of Table 2:**

A: Total patents

B: Total patenting affiliations

C: Total cited articles

D: Total affiliations producing cited articles

E: Total cited patents

F: Total affiliations producing cited patents

G: Total patents produced by patenting affiliations that have also produced cited documents

H: Total patenting affiliation that have also produced cited documents

I: Total cited articles produced by patenting affiliations

J: Total patenting affiliations producing cited articles

K: Total cited patents produced by patenting affiliations

L: Total patenting affiliations producing cited patents

%1: G/A%

%2: H/B%

%3: I/C%

%4: J/D%

%5: K/E%

%6: L/F%

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