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Abstract

We deal with nanotechnology research activities in Turkey. Based on publication data retrieved from ISI Web of SSCI database, the main actors and the main characteristics of nanotechnology research in Turkey are identified. Following a brief introduction to nanoscience and nanotechnology research, it goes on with a discussion on nanotechnology related science and technology policy efforts in developing countries and particularly in Turkey. Then using bibliometric methods and social network analysis techniques, this paper aims to understand the main actors of the nanoscale research in Turkey and how they collaborate across institutes and disciplines. The research indicates that there has been an exponential growth in the number of research articles published by Turkish nanoscience and nanotechnology (NST) scholars for the last ten years. However, the analysis of the main characteristics of nanotechnology research carried out at Turkish universities indicates some drawbacks and barriers to the future development of nanotechnology research in Turkey. These barriers are (i) a high concentration of nanoscale research at certain universities; (ii) low level of interdisciplinarity; (iii) a large number of universities which are not well connected to other universities in the field, and finally (iv) low level of international collaborations. Finally, science and technology policy implications of this research are discussed in the conclusion.

Keywords: Emerging technologies nanotechnology, nanoscience, scientific publications, SSCI, bibliometric data, social network analysis, collaborations, interdisciplinarity, science and technology policies, emerging economies, Turkey.

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1. An introduction to nanotechnology

The *nano* prefix comes from a Greek word *nanos* which means dwarf. However this prefix is used by scientists to indicate one billionth of a meter. A single human hair is about 80 thousand nanometer (nm) wide, a red blood cell is approximately 7 thousand nm wide, a DNA molecule 2 to 2.5 nm or a water molecule is 0.24 nm. Thus, when we are talking about nanotechnology we are indeed talking about a scale of size or length; in other words, nanoscale is the size scale at which nanotechnology operates (Allhoff et al., 2010). In this emerging technology field, size matters not only for the aim of a simple delineation of the limits of the technology but also because of the changing properties of materials at the nanoscale. For example, at nanoscale, laws of physics change, metals become harder and ceramics become softer, chemical resistance increases, weight reduces, new electrical and novel biological properties occur (Bhat, 2003).

Although size matters for nanotechnology, what nanotechnology makes revolutionary is not merely the size of the substances that nanotechnology deals with. Because, in the manner of size, nanotechnology is not new; humans have been nanotechnologists for millennia. Lycurgus Cup from 4^{th} century in the collection of the British Museum has some unusual optical properties which are caused by a haphazard dispersion of nanometer sized particles of a gold-silver alloy in a glass matrix (Barber and Freestone, 1990, as cited in McCray 2005). The oldest known nanotechnology dates back to the fabrication of the first lustre potteries; some Abbasid lustre ceramics have nano-gratings and in this way objects would change their color depending on the viewing angle (OECD 2009b). Moreover, the long established materials such as Indian ink invented by ancient Egyptians or soap rely on nanotechnology in the broad sense (Jones, 2004). However, what makes us today talking about the revolution of nanotechnology is, fundamentally, the purposeful control and manipulation of the materials and properties at the nanoscale which is enabled by the inventions of scanning tunneling microscopy (STM) and atomic force microscopy (AFM) by IBM researchers.

The official definition of nanotechnology provided by National Nanotechnology Initiative (NNI) in the USA is as follows: “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, modeling, and manipulating matter at this length scale…Unusual physical, chemical, and biological 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[3]".

The history of nanotechnology starts with a seminal talk given by Richard Feynman, the Nobel Prize winner physicist, to the American Physical Society on December 29th, 1959 at Californian Institute of Technology (Caltech). In this talk entitled "There is plenty of room at the bottom" (Feynman, 1960), he anticipated that physicists would eventually be able to manipulate matter at the atomic scale (Bennett and Sarewitz, 2006) and presented the initial vision of the innovative nano-research that scientists could do (McCray, 2005). Although the initial vision regarding to the nanotechnology was presented in the USA, the term "nanotechnology" was first used by a Japanese researcher Norio Taniguchi in 1974 in a paper (Taniguchi, 1974) on precision engineering which refers to engineering at length scales less than a micrometer (OECD 2009a; Bainbridge, 2007; McCray 2005). However, the rise of the nanotechnology and the nanoscale research in the sense of controlling and manipulating atom and molecules needed to wait until the invention of appropriate tools which are namely scanning tunneling microscopy (STM) and atomic force microscopy (AFM) in the 1980s.

STM was invented in 1981 by Gerd Binnig and Heinrich Rohrer employed by IBM's Zurich Laboratory; and they won the 1986 Nobel Prize in physics for their invention (Baird and Shew, 2004). This invention was shortly followed by the invention of AFM by Binnig, Quate and Gerber in 1986 (Jones, 2004). The invention of these microscopes is perhaps the most important development in the crystallization of nanoscale science and technology as an emerging field or discipline; in both STM and AFM techniques, images are obtained not only by gathering reflected or refracted waves from a sample but also a very fine tip is scanned across the surface of the sample and interacting with it (Wood et al., 2003). Since in these microscopes the images are get through probing they are also called as scanning probe microscopies (SPM).

[3] http://www.nano.gov/html/facts/whatIsNano.html last accessed on October 6, 2010.

In 1985, Richard Smalley, Robert Curl, James Heath, Sean O'Brien, and Harold Kroto at Rice University prepared the first fullerene which is a molecule composed entirely of carbon and takes the form of sphere, ellipsoid or tube. Since ball-shaped structures of the carbon atoms assembled were like the geodesic domes designed by architect Buckminister Fuller in 1960s, these assemblies of carbon atoms came to be called “buckyballs” or more formally “buckminster-fullerenes” or shortly as “fullerenes” (Bainbridge, 2007). The first and most famous fullerene is also known as C60 which is a spherical structure of 60 carbon atoms. Cylindrical fullerenes or nanotubes were first discovered by Sumio Iijima employed by NEC in Japan. These carbon nanotubes (CNTs) are usually only a few nanometres wide but they are the strongest and most flexible material yet discovered. Due to its molecular structure, carbon nanotubes have some special features such as electrical and thermal conductivity (UNESCO, 2006).

In terms of science and technology policy, the most prominent breakthrough in the short history of nanotechnology occurred on January 20th, 2000; former US President Bill Clinton again chose Caltech to announce the creation of National Nanotechnology Initiative (NNI) of the USA (Roco 2004b; Kulinowski 2004). The real nanotechnology breakthrough came with the creation of NNI with a huge research funding program launched by the Clinton Administration (Fiedeler, 2008). At the end of his presidency, Bill Clinton proposed the NNI with a 225 million US dollar budget for fiscal year 2001, appoximately 83% increase over expenditures on nanotechnology in the previous year (Baird and Shew, 2004). Approximately three years after Clinton’s support for the NNI, the ‘21st Century Nanotechnology R&D Act’ was signed by the next president Bush on December 3rd, 2003. Through this Act, nanotechnology was recognized by the US Congress as a key challenge for the future of the USA in the 21st century (Roco 2004b).

Economic expectations related to nanotechnology are extremely high. According to Lux Research, nanotechnology impacted 254 billion USD worth of products (in other words, the worth of all products using any form of nanotechnology) in 2009 (Forfas, 2010). Today, nanotechnology is widely used in textile, cosmetics, sunglasses, and sport equipments. However, in the medium term, new products powered by nanotechnology are foreseen, such as much smaller but powerful computers; nanostructured drugs, drug delivery systems targeted to specific organs, sensors for labs-on-chip, bio-compatible replacements, cancer research; bio-sensors; or new types of batteries, quantum well solar cells, safe storage of hydrogen for use as a clean fuel. These foreseen nanoproducts seem to provide solutions to our most current problems related to energy efficiency, environmental and health related issues, improving the quality of life, etc.

The proposition that nanotechnology provides a great opportunity to address global challenges has increased the expectations related to the future of nanotechnology and also R&D investments in terms of public and corporate fundings. Among those expectations the best known is the one made by National Science Foundation (NSF) of the USA in 2001; NSF estimated a world market for nanotechnological products of 1 trillion USD for 2015 (Roco 2001; 2005; Hullman 2007; EC 2006) and a need for two million workers in nanotechnology and about three times as many jobs in supporting activities (Roco 2001, 2005).

Due to some differences regarding to the definition of nanotechnology and its contribution to the added value of the final products, estimations vary between a moderate level of 150 billion USD in 2010 (Mitsubishi Institute, 2002, as cited in Hullman, 2007) and a very optimistic level of 2.6 trillion USD in 2014 (Lux Research, 2004). In 2008, Lux Research has increased the forecast for the global nanotechnology market in 2015 up to 3.1 trillion USD[4] but after the economic downturn in 2009 again decreased to 2.5 trillion USD[5]. An Indian based market research company RNCOS expects that nanotechnology incorporated manufactured goods will worth 1.6 trillion USD in 2013[6]. Cientifica, a consultancy company based in London, predicts a global nanotechnology market in 2015 of 1.5 trillion USD excluding semiconductors and 2.95 trillion USD including semiconductors[7] One interesting point regarding aforementioned forecasts is that all "predict a substantial increase of the market for nanotechnological products with a take off somewhere in the early 2010s" (Hullman, 2007; EC, 2006). The same argument can also be observed in data provided by UK nanotechnology report (Mini-IGT 2010).

[4] "Nanotechnology boom expected by 2015" article published by Industry Week. Available at http://www.industryweek.com/articles/nanotechnology_boom_expected_by_2015_16884.aspx?SectionID=35 and http://www.luxresearchinc.com/press/RELEASE_Nano-SMR_7_22_08.pdf accessed on Oct 14, 2010

[5] "The Recession's Ripple Effect on Nanotech" report by Lux Research available at https://portal.luxresearchinc.com/research/document_excerpt/4995, accessed on Oct 16, 2010

[6] Nanotechnology Market Forecast to 2013 by RNCOS (March 2010). Available at http://www.rncos.com/Market-Analysis-Reports/Nanotechnology-Market-Forecast-to-2013-IM185.htm , accessed Oct 14, 2010

[7] "Debunking the trillion nanotechnology market size hype" article available at http://www.nanowerk.com/spotlight/spotid=1792.php accessed on Oct 15, 2010

These economic expectations are the main rationale behind the rapidly growing public funding for nanotechnology R&D at the global scale. Roco (2005) reports that the worldwide investment in nanotechnology R&D reported by national governmental organizations and European Commission has increased approximately 9 fold –from 432 million USD in 1997 to 4.1 billion USD in 2005. On the other hand, Lux Research estimated a 9.6 billion USD spending made on nanotechnology R&D worldwide in 2005 and 13.5 billion USD in 2007[8]. According to the nanotechnology report prepared by Lux Research (2006), in 2005, 1.7 billion USD of nanotechnology investments was made in North America (mostly in the USA), another 1.7 billion was invested in Asia (dominated by Japan) and 1.1 billion was in Western Europe. The rest of the world invested only 100 million USD on nanotechnology R&D. The global spending on nanotechnology R&D had doubled in three years and reached 18.2 billion USD in 2008 at the global scale. In this amount of spending the amount of government funding ballooned to 8.4 billion USD, corporate spending edged to $8.6 billion, and venture capitals (VCs) provided 1.2 billion USD[9]. The amount of investment in nanotechnology has been still rapidly increasing; i.e. the US government's 2011 budget provides 1.8 billion USD merely for the NNI which is the broadest financial support provided for this initiative since the beginning.

2. Nanotechnology efforts in developing countries

In the previous chapter on nanotechnology, the expected economic impact of this emerging technology was presented and discussed. All these expectations regarding the innovative and transformative capacity nanotechnology have long been considered by policy makers. Therefore, not only advanced industrial countries but also some developing countries such as China, Brazil, India, Argentina or Mexico have started to invest in basic and applied nanotechnology research since the very early days of the 2000s.

Brazil launched a pioneer program for nanotechnology research and development in 2000 which was in the same year as the US initiative (Invernizzi and Foladori, 2005). With this program four institutional, multidisciplinary networks aiming at promoting NST research

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[8] http://www.luxresearchinc.com/press/RELEASE_Nano-SMR_7_22_08.pdf accessed on Oct. 17, 2010.
[9] "Cleantech's Dollar Investments, Penny Returns" Lux Report in the article "Nanotechnology Intermediates Generate Twice the Profit Margins of Nanomaterials and Nano-Enabled Products" available at http://www.nanowerk.com/news/newsid=8975.php, accessed on Oct 16, 2010.

were created. The number of researchers in these networks reached 300, the number of institutes 77 and number of companies 13 in the period 2002-2005 (Kay and Shapira, 2009). In India, the Nanomaterials Science and Technology Initiative (NSTI) has been launched in the beginning of the 2000s and with this initiative the Indian government committed to invest 20 million USD into nanomaterials research and commercial development over the period 2004 - 2009 (Matsuura, 2006). South Korea is also an early mover country in the field of NST. The government of South Korea had planned to spend 2 billion USD over the first decade of the new millennium (Niosi and Reid, 2007). Among late coming countries China has the most aggressive NST research policy; and several nanotechnology programs at national and regional level have been launched between 1995 and 2005 (Matsuura, 2006). Chinese government launched "Climbing Project on Nanometer Science' for the period 1990–1999 (Wonglimpiyarat, 2005) and 240 million USD in four years from 2003 to 2007 were granted to the sector by the central government and approximately 240–360 million USD by local governments to support nanotechnology research (Niosi and Reid, 2007; Wonglimpiyarat, 2005). While Singapore, in 2002, established University of Singapore Nanoscience and Nanotechnology Initiative (NUSNNI) in Taiwan the National S&T Priority Program on Nanotechnology (NPNT) with a budget of 680 million USD was established in the 2000s. Finally, in Russia, a nanotechnology funding programme has been approved, making it the largest one in the world, with 3.95 billion USD earmarked until 2015 (Mini-IGT 2010, OECD 2009a).

3. An overview of nanotechnology efforts in Turkey

Turkey has attempted to integrate nanotechnology into its technology development strategy with the inclusion of this field in Vision 2023 strategy document (TUBITAK, 2004). In this document, Turkey's future strategy for nanotechnology has been stated by the Scientific and Technological Research Council of Turkey (TUBITAK). According to this document, the subjects which are planned to be focused on are (i) nanophotonics, nanoelectronics, nanomagnetism; (ii) nanomaterials; (iii) fuel cells, energy; (iv) nanocharacterization; (v) nanofabrication; (vi) nanosized quantum information processing; and (vii) nanobiotechnology. Nanotechnology is also included in the last Development Program prepared by State Planning Organization (SPO) for the period 2007-2013 as among the technology fields with priority. Albeit its given importance by these documents, until now no special policy initiative, program, allocated budget or funding scheme have been launched to support nanotechnology research in Turkey. However there are many distributed efforts to support NST research in the country. These efforts can be divided into three groups: (i) foundation of NST-related research centers and institutes to which SPO provides funding, (ii) graduate nanotechnology programs and finally (iii) public funds provided to academia and industry for nanotechnology research and development projects.

In NST field there has been a growing effort for the establishment of nanotechnology research and application centers. A search in the achieves of the Turkish Official Journal (T.C. Resmi Gazete) indicates that six research centers or institutes having nano prefix in their names have been established since 2004. Table 1 provides a list of these centers and institutes. Besides these institutes "Advanced Technologies Education, Research and Application Center at Mersin University" which was founded in 2006 has a declared aim to carry out research in nanotechnology field in its rules and regulations document. The Central Laboratory established at Middle East Technical University (METU) provides state of the art instrumentation not only to the researchers at this university but also to partners from other universities and firms working in nanotechnology field. Moreover, many universities in Turkey (i.e. Gazi University and Hacettepe University in Ankara or Institute of Technology in Izmir) have established their own nanotechnology laboratories.

Table 1. List of nanotechnology research and application centers in Turkey

NST Research and Application Centers and Institutes	The announcement (Turkish Official Journal)
Gebze Institute of Technology Nanotechnology Research and Application Center	24 May 2004
Bilkent University Material Science and Nanotechnology Institute (UNAM)	8 May 2007
Marmara University Nanotechnology and Biomaterials Application and Research center	24 June 2008
Çanakkale Onsekiz Mart University Nanoscience and Technology Research and Application Center	19 June 2009
Gazi University Nanomedicine and Advanced Technologies Research and Application Center	16 June 2009
Sabancı University Nanotechnology Application and Research Center	4 June 2010

Source: Turkish Official Journal (T.C. Resmi Gazete)

The efforts for the establishment of the National Nanotechnology Research Center (UNAM) located at Bilkent University started in 2005 with the application of a group of academicians to the SPO for funding of a nanotechnology center. Although it was named as "national" it is a research institute under the administration of Bilkent University. The first phase of the nanotechnology research center project was completed at the end of 2007 and its cost reached to 28 million TL. In May 2007 the research center project was turned into UNAM Material Science and Nanotechnology Institute. The investments for the second phase of the project were expected to reach 60-70 million TL by the end of 2009[10]. With 62 laboratories in 9000 m² closed area UNAM is one of the centers of excellence in nanotechnology in Turkey. The mission of UNAM is defined as "training experts through a multidisciplinary graduate program and develop new and high technologies based on nanoscience to strengthen the competitiveness of Turkish products in international markets and, hence, to contribute to the improvement of living standards in Turkey". SPO also provides funds to different universities and research centers for nanotechnology infrastructure and equipments. Gebze Institute of Technology, Istanbul Technical University and Sabancı University are also funded by SPO for their expenses on nanotechnology infrastructure.

In recent years the number of graduate studies in NST provided by Turkish universities has also increased. Bilkent University, METU, Hacettepe University, Anadolu University[11] and Istanbul Technical University provide master and / or PhD programs in nanoscience and technology. Among master and PhD programs, those provided by Hacettepe University specifically focus on nanomedicine. Hacettepe University has the advantage of combining its high level capabilities in medicine (including pharmacy, and bio-engineering), natural and engineering sciences. Furthermore some graduate programs in physics and chemistry also provide courses on nanotechnology.

As the interest in NST-related research in academia has increased the number of projects funded by public resources has increased in recent years as well. Searching for projects having nano prefix in their titles in TUBITAK web sources[12] reveals that by June 2010 such 337 academic projects are funded by TUBITAK; of these projects 176 have been

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[10] www.nano.org.tr, accessed on 27 June 2010

[11] Nano Bülten Sayı 09 http://www.nanott.hacettepe.edu.tr/nanobulten/09/nanobulten09.pdf , accessed on 13 June 2010

[12] http://mistug.tubitak.gov.tr/proje/index.php, accessed on 28 June 2010

completed. TUBITAK TEYDEB also provides funds for firms doing nanotechnology research and development; however no data is available at publicly open web pages or documents of TUBITAK regarding the number of industry projects funded in nanotechnology field.

Another important indicator of NST-related research and development activities is the number of patents assigned to Turkish institutes and firms. For patent research the methodology proposed by Huang et al. (2003; 2004) which is based on the search of certain keywords in titles and abstract of patent documents is preferred. USPTO (US Patent Office) and Turkish Patent Office (TPO) databases were searched for 18 keywords provided in these two studies (Huang et al., 2003; 2004). In USPTO database, 46 patents to which Turkish inventors participated were identified but none of these patents are assigned to Turkish institutes. In TPO database, by 3 March 2010, 162 patents including the selected keywords in their titles of abstracts were found; however only 39[13] of these patents are assigned to Turkish institutes or people resident in Turkey. Patent data indicates that nearly half of these 39 patents are assigned to either universities or public research institutes or individual researchers affiliated to Turkish universities. These results provide further evidence for the importance of nanotechnology research held in universities and the potential economic value of research outputs produced at universities in nanotechnology. On the other hand, a search for the number of nanotechnology patents by Huang et al. (2003; 2004) reveals that, between 1976 and 2004, 5363 USPTO and, between 1978 and 2004, 2328 EPO patents are assigned worldwide (Li et al., 2007).

In addition to aforementioned problems related to nanotechnology (i.e. no special support programmes or strong institutional initiatives and low level of patents), some other barriers to NST research in Turkey are (i) scarce financial resources for research activities and technological infrastructure; (ii) concentration of research facilities and activities at certain universities and centers in big cities; (iii) low level of collaborations between academic disciplines to achieve transdisciplinary research; and (iv) low level of collaboration between universities and firms (TÜSİAD, 2008).

[13] The number of patents found were actually 41. However 2 were excluded because nano-prefix used in these patent documents indicated a measure, i.e. nanometer which is not about nanotechnology.

The following sections will mainly focus on NST research activities in Turkish universities. This section aims to understand strengths and weaknesses of NST research carried out mainly in universities and, hence, to make some policy recommendations in order to improve NST research productivity, research collaborations and knowledge transfers among different actors of the nanotechnology innovation system in Turkey.

4. Bibliometric analysis of NST articles by Turkish universities

The most important problem in the bibliometric studies focusing on the emerging field of NST is the delineation of the field. This is not only because nanotechnology is an emerging technology field but also it is interdisciplinary. Many efforts have been spent for analyzing academic efforts and also patents in nanotechnology since the mid-1990s.

Braun et al. (1997) was the first study dealing with nanoscale research (Hullman and Meyer, 2003). For this study, authors (Braun et al., 1997) built a database of articles on the frequency of usage of the prefix-nano in the title of science and technology journal papers during the period 1986-1995. Tolles (2001) followed a similar way and searched the SCI database using “nano*” to analyze the international scientific standing of USA in nanotechnology. At first, searching a nano-prefix seemed a very useful approach for the delineation of the field but this method has the risk of inclusion of some terms or phrases such as nanosecond, nanogram, nanoplankton or some elements such as “NaNO2” or “NaNO3” which are not directly related to nanotechnology.

The first attempt using a list of keywords and phrases instead of nano-prefix was held in a project prepared for the EU Commission; Noyons et al. (2003) summarize the report of the project which, using publication and patent data, aims to identify centers of excellence in nanotechnology across Europe. In this project, authors first started with a core set of publications of which some publicly known NST experts agreed on their representativeness. From titles and abstracts of these core publications noun phrases were extracted. However, the final list of the phrases for the delineation of the NST field was decided through the opinions and suggestions of a wider group of experts doing NST-related research. After 2005, the number of studies aiming at the delineation of the field of nanotechnology using text mining and bibliometric methods has increased. Among those Zitt ve Bassecoulard (2006), Porter et al. (2007) and Kostoff et al. (2007a) have come into prominence more than the others. Table 2 provides the number of NST publications from Turkey which are retrieved from ISI Web of Science (WoS) SCI-EXPANDED database on 24 June 2010 by using three different set of keywords proposed by Kostoff et al. (2007a), Porter et al. (2008) and Noyons et al. (2003).

Table 2. Number of NST publications of Turkish scholars retrieved from SCI-EXPANDED by using three different methodologies, 1985-2010

Years	*Number of publications**		
	Kostoff et al. (2007a)	*Porter et al. (2008)*	*Noyons et al. (2003)*
2010**	554	483	343
2009	1064	996	626
2008	896	826	538
2007	741	696	410
2006	608	544	320
2005	484	453	264
2004	474	459	230
2003	328	336	157
2002	257	279	137
2001	188	196	98
2000	144	143	60
1999	151	158	59
1998	111	116	42
1997	98	100	30
1996	104	83	36
1995	65	49	26
1994	27	35	14
1993	28	27	6
1992	35	30	15
1991	22	24	12
1990	5	3	3
1989	4	3	3
1988	4	2	3
1987	1	2	
1986	3	3	
1985	1	2	
Total	*6397*	*6048*	*3432*
Rate of change 2000-2009	*%639*	*%596*	*%943*

** Numbers include book reviews, editorials and brief notes*
***First semester*
Source: Own calculation from ISI- WoS

Among those three studies Kostoff et al. (2007a), which is carried out for the Office of Naval Research in the US and Porter et al. (2008) which is conducted by scholars in

Georgia Institute of Technology is very similar not only in terms of numbers they produce but also the methodology. Porter et al. (2008) also compares its results with those provided by Kostoff et al. (2007a) because Kostoff et al (2006) research formulation served as the basis for Porter's study. Authors' comparison suggests that the overall nano-publication trend shows a very similar trajectory in both of these studies and country trends are quite aligned as well. However authors find that there are some second tier differences when the publications provided by these two methodologies are compared based on selected topical areas, authors and source journals. Finally, in this research, for the analysis of the NST research in Turkish universities, the methodology and keywords provided by Kostoff et al. (2007a) for the delineation of the field was preferred.

This section summarizes how bibliometric data of nano articles published by Turkish scholars was retrieved from the ISI WoS- SCI EXPANDED database.

(1) For a ten year period from 2000 to the end of 2009, the bibliometric data including the full contents of the articles including the keywords provided by Kostoff et al. (2007a) in their title or abstracts, and having at least one author affiliated to Turkish institutes were retrieved from the ISI Web of Science databases on 11 January 2010

(2) Using pull-down menu on the web page the results were further refined to include only the original articles; in other words, book reviews, editorials, and brief notes were discarded from the set of results and we were left with 4408 original articles.

(3) Full bibliometric records of these articles were exported as a text file from ISI WoS.

(4) These records were reformatted into a Microsoft Access 2003 database using a Visual Basic script.

(5) Each of these articles was given a unique number from 1 to 4408 and all variables included in bibliometric content (i.e. authors. institutes. addresses. titles and keywords) were linked to each other through this unique identifier.

(6) Data manipulation and analyses were performed through created tables and queries in this database. Most of these tables and queries were recreated from bibliometric software tool Sitkis (Schildt, 2005) which is also based on Microsoft Access.

(7) These different tables are used for simple counting of articles by year, institute or author; and queries allow matching different tables by the unique identifier in order to count the frequency of simultaneous occurrences of two different elements (i.e. networks of authors, networks of institutes) in the same document.

The tool, Sitkis, also allows the manipulated data to be exported to MS Excel and UCINET (Borgatti et al., 2002) compatible tables. The network measures (i.e. degree centrality) were calculated using the social network analysis software UCINET and networks were drawn with NetDraw package embedded to UCINET.

5. Results from the bibliometric study

5.1. Turkey presence in worldwide NST research

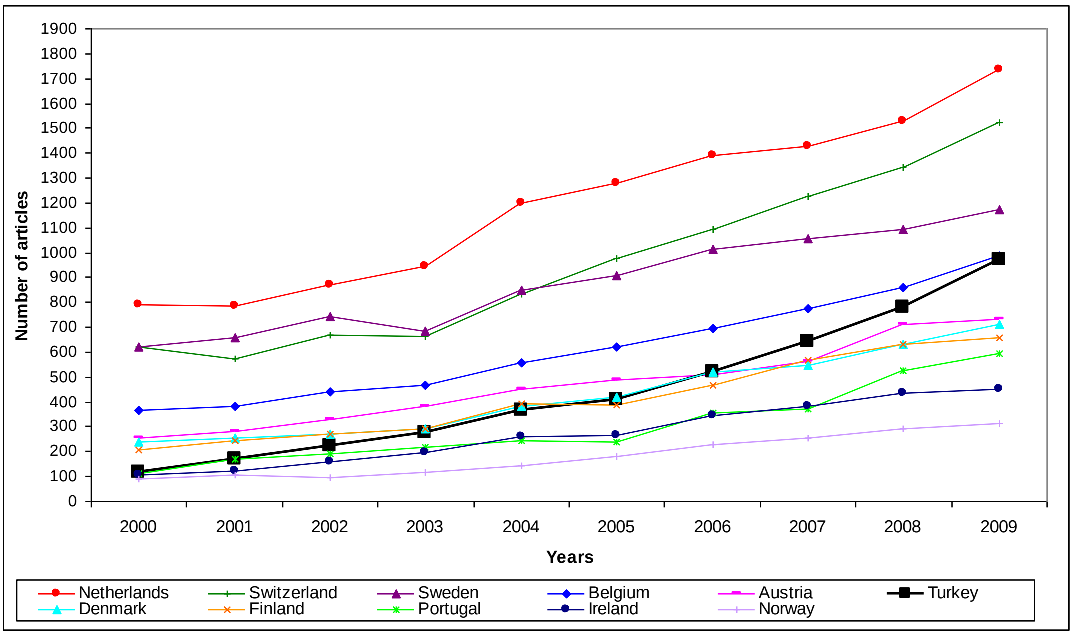
Global NST research literature has grown exponentially in the last two decades. The number of records regarding NST publications in the SCI / SSCI was 11,265 in 1991 however it reached 64,737 records in 2005 with an almost six fold increase (Kostoff et al. 2007b). Our bibliometric research shows that the total number of NST related publications in SCI-EXPANDED has already exceeded a hundred thousands in 2009. Therefore, before concentrating on NST research held in Turkish universities a brief review of the worldwide NST research is going to be provided.

Since the original research article is a good indicator of the new knowledge created in the academia, in the rest of the analysis, the number of research articles instead of all document types (i.e. review, editorial material, proceedings paper, meeting abstract and letter) will be considered. The analysis of the data retrieved from SCI-EXPANDED for this research shows that the number of research articles reached to 91,970 in 2009, a three fold increase as compared to 29,648 in the year 2000. Although the number of research articles has exponentially grown in the last decade the most productive countries in NST field stay more or less the same. These are simply USA, China, Japan, Germany and France. Among those China has made a great effort in the last decade, and increased not only the number of articles but also the quality[14] of its publications which now appears to be comparable to France, Italy, Japan and Australia (Kostoff, 2008; Kostoff et al., 2007b).

[14] The quality of a publication is usually measured by the number of citations.

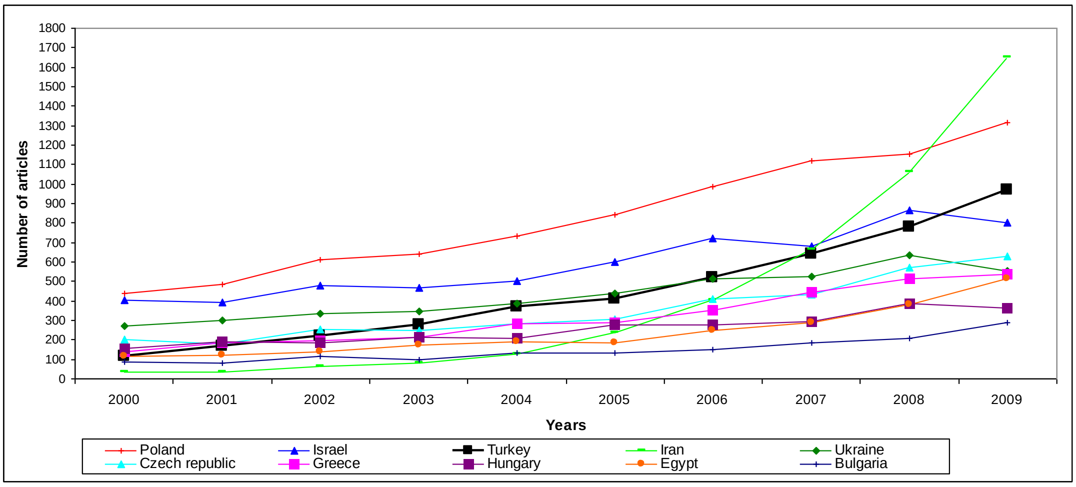
The results of the worldwide NST publications in this study confirm the findings of the previous studies that while shares of the US and Japan in global NST publications have dropped in the period from the early 1990s to 2005; the share of other countries such as China and South Korea grew rapidly over the course of the decade (Kostoff et al., 2007b; Kostoff et al., 2007c).

Bibliometric data collected from ISI WoS indicates that Turkey's presence in the worldwide NST research has improved for the last decade. In the year 2000, Turkey was on the 34th rank among the most prolific countries of NST research; however it went up to 23rd rank in 2009 as a country contributing 1.06 percent of NST research articles in SCI-EXPANDED. Figure 1, Figure 2 and Figure 3 compare the number of research articles linked to Turkey with those linked to some Western European countries, Eastern European and Middle East countries and those in Asia Pacific and Latin America respectively. These figures indicate that Turkey has increased its knowledge stock in the NST field more rapidly than some other countries which are economically and technologically more developed than Turkey such as small countries Austria, Finland, Denmark, Ireland, Portugal or Norway. On the other hand, Turkey lags behind some late-coming, transition or developing countries such as Czech Republic, Poland, Taiwan, Singapore, Iran or Brazil. This also indicates that there is a strong competition among countries in the race for catching up in the field of NST.



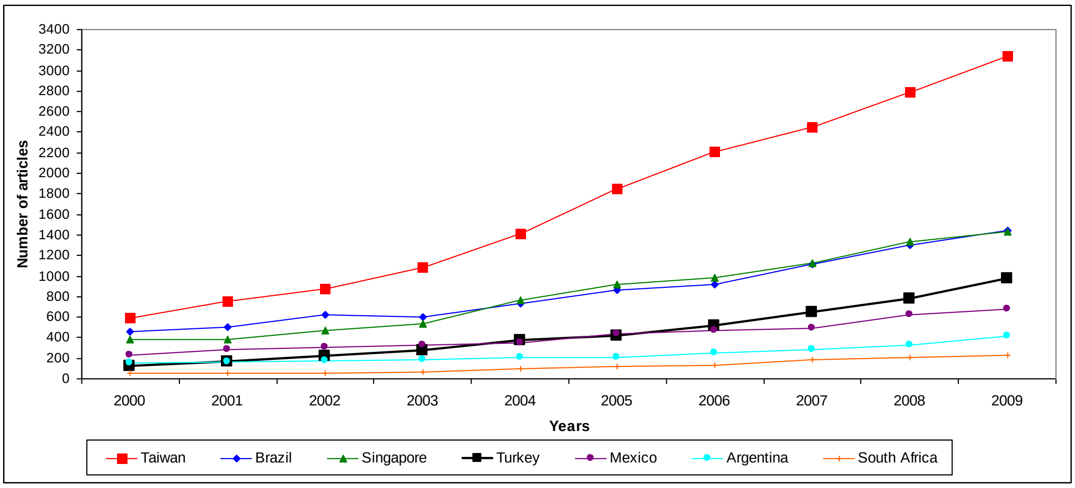
Source: Data retrieved from WoS, SCI-EXPANDED.

Figure 1: Turkey-Western European countries comparison of research articles



Source: Data retrieved from WoS, SCI-EXPANDED.

Figure 2: Turkey-Eastern Europe & Middle East countries comparison of research articles



Source: Data retrieved from WoS, SCI-EXPANDED.

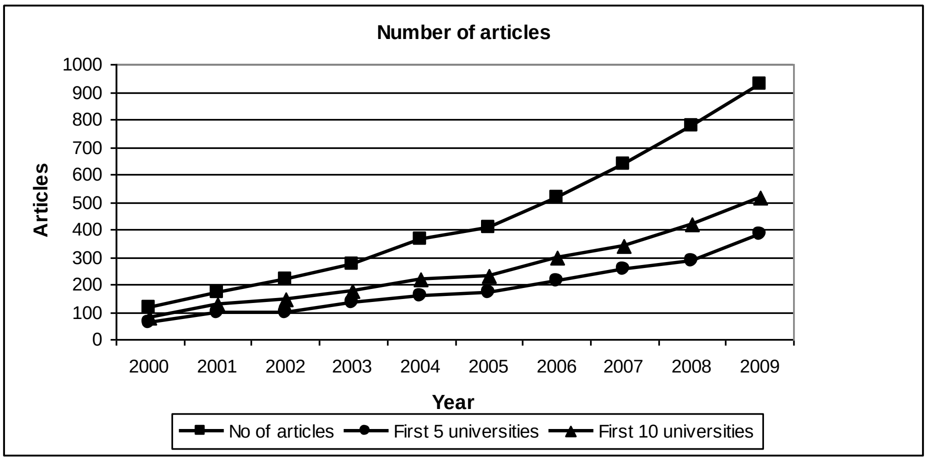
Figure 3: Turkey-Asian & Latin American countries comparison of research articles

The following part of the section will focus on the main characteristics of NST research at Turkish universities and institutes.

5.2. Main characteristics of nanoscale research at Turkish universities

During 1980s and 1990s the number of NST-related publications of Turkish scholars in the SCI-EXPANDED was very low. However after the year 2000 an upward trend in publications became apparent. From 2000 to 2009 an almost eight fold increase (from 115 in the year 2000 to 928 in 2009) has occurred in the number of NST articles written by Turkish researchers. Not only the number of publications but also the number of Turkish institutes contributing to NST literature has increased. While the number of national institutes or organizations contributing to NST-related publications was only 37 in 2000 it increased to 107 in 2009; 90 of these 107 institutes were universities, and only 16 of these universities were private universities. The total number of public universities in Turkey was 94 and the number of private universities was 45 by April 5, 2010[15]. Thus, our data provides that nearly 79 percent of public universities contributed to NST-related research in Turkey.

Figure 4 indicates that the concentration in NST-related research has steadily decreased in the last 10 years. While in 2000 the first ten most prolific universities in Turkey generated 70 percent of NST-related articles this ratio decreased to 56 percent in 2009. Furthermore, the share of the most productive five Turkish universities in total number of NST-related articles decreased from 54 percent in the year 2000 to 41.2 percent in 2009. Thus in the last ten year NST-research in Turkey has become much more dispersed.



Source: Data retrieved from WoS, SCI-EXPANDED

Figure 4 Number of nanotechnology publications (SCI) of Turkish universities by year (2000-2009)

15 www.yok.gov.tr

Analysis of the publication data also shows that the most important contributor to NST research in Turkey is universities. They contributed to 99.2 percent of research articles published in the ten year period from 2000 to 2009. On the other hand, public research institutes and governmental bodies contributed 3.3 percent of articles; among those institutes and organizations TUBITAK was more apparent. However, 2.4 percent of the NST articles in total were produced by different research institutes of TUBITAK; the share of the industry's contribution was only 1.1 percent[16].

Nano-institutions, as defined by Schummer (2007b), are those using the prefix 'nano' in their official names. The measurement of the contribution of nano-instiutions to the NST research in Turkey is important to understand to what extent the institutionalization of nanotechnology research has been achieved and also to assess the success of public incentives and funds provided for the establishment of research infrastructure. Analysis of 4408 articles in our data set shows that nano-institutions first appeared in 2004 in the addresses of Turkish scholars and their share in publications increased to nearly 11 percent in 2009.

Table 3 shows the most prolific universities of NST-related research in Turkey. The list of universities indicates a significant regional agglomeration in nanotechnology research. Five of the top six universities of the field are located in Ankara. Another interesting point that needs to be mentioned is that the number of publications falls significantly after Hacettepe University situated at the third place. The number of articles authored or co-authored by the scholars affiliated to METU is two times higher than the articles of Istanbul Technical University on the fourth rank.

[16] Due to articles co-authored from different types of institutes the sum of ratios does not equal to 100.

Table 3 Top 40 institutions in terms of SCI publications in nanotechnology in Turkey, 2000-2009

Rank	*University*	*Total number of publications*	*Period I 2004-2000*	*Period II 2009-2005*	*Growth rate 2000-2009 (%)*
1	METU	590	201	389	93.53
2	Bilkent Univ	428	117	311	165.81
3	Hacettepe Univ	414	128	286	123.44
4	Istanbul Tech Univ	296	77	219	184.42
5	Gazi Univ	265	66	199	201.52
6	Ankara Univ	248	77	171	122.08
7	Dokuz Eylul Univ	199	60	139	131.67
8	Ege Univ	161	38	123	223.68
9	Istanbul Univ	142	36	106	194.44
10	Gebze Inst Technol	142	28	114	307.14
11	Ataturk Univ	128	41	87	112.20
12	Ondokuz Mayis Un	124	25	99	296
13	Cumhuriyet Univ	122	49	73	48.98
14	Anadolu Univ	109	20	89	345
15	Erciyes Univ	101	27	74	174.07
16	Koc Univ	101	20	81	305
17	Marmara Univ	98	21	77	266. 67
18	Selcuk Univ	98	11	87	690.91
19	Fırat Univ	97	25	72	188
20	Bogazici Univ	94	29	65	124. 14
21	Suleyman Demirel U.	91	9	82	811.11
22	Kirikkale Univ	87	16	71	343.75
23	Balikesir Univ	84	26	58	123.08
24	Karadeniz Tech Univ	84	17	67	294.12
25	Izmir Inst Technol	83	16	67	318.75
26	Inonu Univ	78	18	60	233.33
27	Cukurova Univ	77	9	68	655.56
28	Yildiz Tech Univ	76	14	62	342.86
29	Sakarya Univ	74	18	56	211.11
30	Eskisehir Osmangazi U.	72	8	64	700
31	Sabanci Univ	58	16	42	162.5
32	Gaziosmanpasa Univ	52	10	42	320
33	Mersin Univ	51	14	37	164.29
34	Onsekiz Mart Univ	49	7	42	500
35	Kocaeli Univ	47	8	39	387.5

Source: Data retrieved from WoS, SCI-EXPANDED.

These most prolific universities of NST research in Turkey are also the ones which have achieved a critical mass in terms of researchers. Table 4 shows the number of nano-scientists who are currently affiliated to these universities and have published at least three research papers in the last five years from 2005 to 2009. METU and Hacettepe University have the highest number of NST researchers. Although the number of NST researchers currently affiliated to Bilkent University is a bit lower than the other universities this university has the advantage of hosting a nanotechnology research center.

Table 4 Number of NST researchers affiliated to most prolific universities of Turkey, 2005-2009

University	*Number of NST researchers*
Middle East Technical University	45
Hacettepe University	41
Ankara University	33
Gazi University	31
Ataturk University	27
Bilkent University	26
Istanbul Technical University	26
Gebze Institute of Technology	23
Ege University	21
Dokuz Eylul University	19

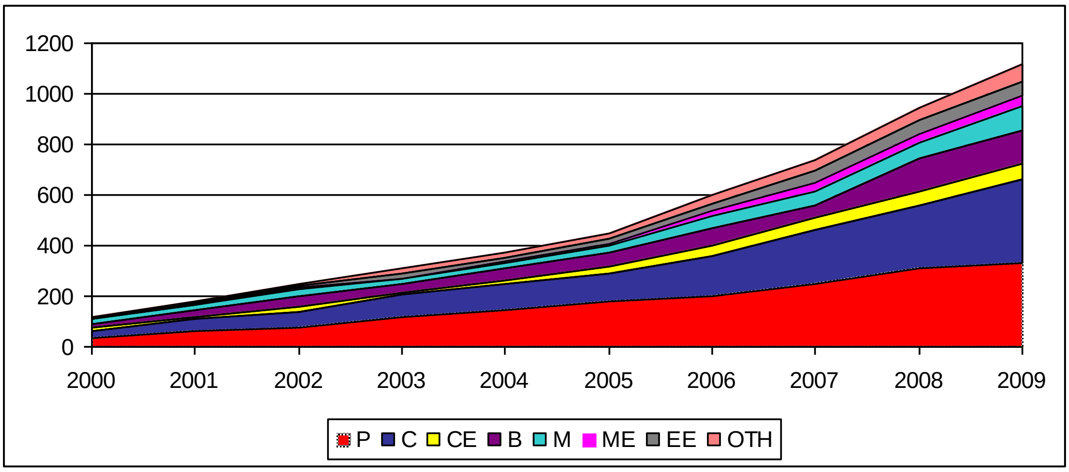
For further analysis of the main characteristics of NST research, disciplinary contributions to 4,408 articles in our dataset are considered. For this aim, the disciplinary classification used by Schummer (2004) is followed (Table 5). In this research, we assume that the disciplinary affiliation of authors corresponds to their disciplinary knowledge contribution and here the 'discipline' is taken as a combined social and cognitive category.

Table 5 Disciplinary categories*

Abbreviation	*Discipline*
P	Physics; engineering physics
C	chemistry
B	biomedical sciences, including biomedical engineering, medicine, dentistry, pharmacology, pharmacy, biochemistry
M	material sciences and engineering, including special materials like ceramics, polymers etc.
ME	mechanical engineering incl. micro manufacturing
EE	electrical engineering incl. electronics, microelectronics, micro systems
CE	chemical engineering, incl. process engineering
IC	information and computer sciences
TG	general technology (unresolved affiliation on the departmental level)
OTH	other sciences mostly earth sciences, geology, mines, minerals, environmental science

*Adopted from Schummer (2004)

The analysis of the disciplinary origins of authors contributing to NST research in Turkey shows that physics and chemistry disciplines contribute nearly to 70 percent of the articles in our dataset. While the researchers in biological sciences contribute to13.6 percent of articles, 16 percent of articles are written by the researchers affiliated to engineering disciplines (Figure 5). While the shares of three disciplines namely chemical engineering and material science and engineering decreased from the year 2000 to 2009 other disciplines increased their shares in NST related research.



Source: Data retrieved from WoS, SCI-EXPANDED.

Figure 5 Disciplinary origins of authors contributing to NST research in Turkey

In science and technology policy discourse nanotechnology is presented as an intrinsically interdisciplinary field (Rafols and Meyer, 2007). Indeed, it is not only about the nanotechnology itself but about the way of making science in this new era. In recent years efforts to promote interdisciplinary scholarship and research have increased. Among those efforts special funds aimed at promoting cross-disciplinary collaboration, interdisciplinary training programs or hiring initiatives targeted at a faculty whose expertise spans traditional academic boundaries are apparent (Jacobs and Frickel, 2009). The underlying assumption of these policies and initiatives is that "cross-disciplinary research generates a higher rate of breakthroughs, is more successful at dealing with societal problems and fosters innovation and competitiveness" (Rafols and Meyer, 2007).

There are many academic efforts aiming to understand and analyze the interdisciplinary characteristics of nanotechnology (Meyer and Persson, 1998; Schummer, 2004; Rafols and Meyer, 2007; 2010; Porter and Rafols, 2009). Among those Schummer (2004) carried out a co-author analysis, which was based on the simple counting of the co-occurrences of disciplinary affiliations. Schummer defined two indices (i) multidisciplinarity and (ii) interdisciplinarity. In the study multidisciplinarity was measured by the number of disciplines involved and multidisciplinarity index ($M^{.05}$) was defined as the number of disciplines involved by authorships in at least 5 percent of the total number of articles.

$M^{.05}$ = count[c_i] if $c_i > 0.05$ and $c_i = n_i / N$

in which c_i was the relative size of discipline i, n_i was the number of papers in which at least one author of discipline i was involved, and N was the total number of papers in NST field.

On the other hand, in the same study, interdisciplinarity was measured by the relative number of papers co-authored by authors from more than one discipline. Two different interdisciplinarity indices were defined.

I^2 = number of papers co-authored by authors from 2 or more disciplines / the total number of papers in NST field.

I^3 = number of papers co-authored by authors from 3 or more disciplines / the total number of papers in NST field.

For the measurement of the extent of interdisciplinarity of nanoscale research in Turkey, the method proposed by Schummer (2004) was used in our thesis. Disciplinary boundaries are traditionally very strict in Turkey; and the low level of collaboration among people from different disciplines is a major barrier to the development of NST research in Turkey (TÜSİAD, 2008). Therefore, any study of interdisciplinarity in the field of NST in Turkey should consider how authors from different disciplines cooperate in a single research, in other words, how traditional disciplinary boundaries have been spanned in NST field. The answers to these questions are also important in order to determine science and technology policy needs aimed at reducing not only cognitive but also social boundaries between academic disciplines because the interdisciplinarity has become the new "mantra of science policy" since the mid-1990s (Rafols and Meyer, 2007; Bruce et al., 2004; Mentzer and Zare, 1999).

Table 6 Percentage distribution of articles in NST field according to the authors' disciplinary affiliations in Turkey, 2000-2009

Years	*P*	*C*	*CE*	*B*	*M*	*ME*	*EE*	*OTH*	$M^{.05}$	I^2	I^3
2000	32.17	23.48	9.57	15.65	13.91	1.74	1.74	6.09	6	0.12	0.02
2001	37.50	27.98	5.95	14.88	10.71	2.38	3.57	3.57	5	0.19	0.02
2002	33.64	29.55	8.64	17.73	13.64	4.09	1.82	3.64	5	0.21	0.02
2003	42.12	32.97	4.03	12.45	6.23	1.47	6.59	6.96	6	0.19	0.01
2004	39.07	27.87	4.10	14.21	4.64	2.73	2.73	5.74	4	0.12	0.02
2005	43.03	28.61	5.13	13.69	6.85	2.93	3.91	4.89	5	0.16	0.02
2006	38.88	30.95	7.93	12.77	8.90	4.84	5.03	7.35	7	0.24	0.03
2007	38.52	34.12	7.55	7.39	8.96	5.66	7.23	6.92	8	0.31	0.03
2008	39.56	32.73	6.70	16.88	8.51	4.12	7.47	6.19	7	0.29	0.04
2009	35.99	35.24	6.79	14.01	10.56	4.09	5.93	7.76	7	0.28	0.04
Total	38.45	31.90	6.60	13.57	8.92	3.90	5.47	6.42	7	0.24	0.03

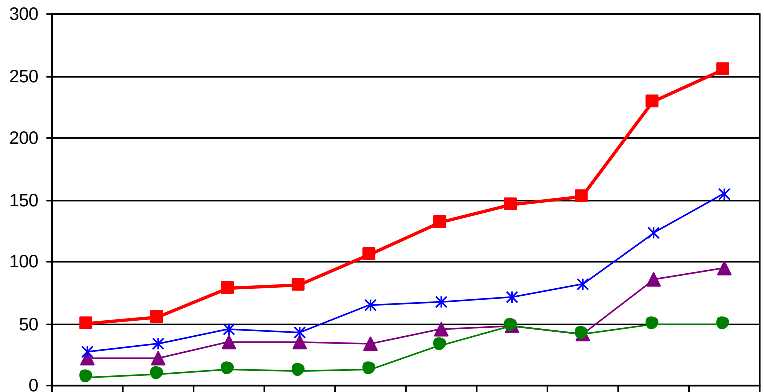
P: Physics; C: Chemistry; CE: Engineering Chemistry; B: Biology; M: Material Science and Engineering; ME: Mechanical Engineering; EE: Electronic Engineering; OTH: Other disciplines, i.e. environmental engineering, geology, mines, etc.
Source: Data retrieved from WoS, SCI-EXPANDED.

The multidisciplinarity index calculated for overall NST research in Turkey is the same with that provided by Schummer (2004) for worldwide NST research (Table 6). This result provides evidence that NST research in Turkey is indeed multidisciplinary as expected. On the other hand, our results provide that Turkish NST research is very weak in terms of interdisciplinarity. Schummer (2004) found I^2 index as 36.5 and I^3 index as 5.7 for worldwide NST articles published in 2002 and 2003 which are higher than those we found for Turkey (0.24 and 0.03 respectively). This low level of interdisciplinarity indicates that the disciplinary boundaries are still a very important barrier to research collaborations in Turkish academia and also emphasizes the importance of promoting collaborations among researchers affiliated to different disciplines.

Not only the collaborations among different disciplines but also collaborations among different institutes, countries and authors are also very important in modern science. There are many studies providing evidence that scientific collaborations not only increase the productivity of researchers which is measured by the number of articles (Lee and Bozeman, 2005) but also the impact of the articles measured by citations (Katz and Hicks, 1997, Van Raan, 1998; Guan and Ma, 2007). Katz and Hicks (1997), for example, use a database containing UK articles in the Science Citation Index (SCI) between 1981 and 1994 and find out that adding an author from the same institution to a paper earns an additional 0.76 citations, an additional author from another domestic institution earns 0.78

and from a foreign institution earns 1.60 additional citations per paper on average. On the other hand, for developing countries the role of international collaboration becomes an important issue and needs to be considered in the evaluation of any increase in productivity and impact of academic studies. Basu and Aggarwal (2001) provide evidence that international collaboration serves to increase both the overall productivity of Indian institutes and the average impact factor of their academic outputs. A similar study on Brazilian research outputs reveals that the average impact of an article written by one Brazilian researcher is just 0.79, the same ratio increases to 1.12 citations for articles written by more than one researcher affiliated to Brazilian institutes and to 3.39 citations when Brazilian authors collaborates with other research in foreign institutes (Leta and Chaimovich, 2002).

Our analysis of international collaborations in NST-related articles produced by scholars at Turkish universities indicates that although the number of international joint publications has increased in the last ten year period, the share of international joint publication among all NST articles decreased from 44 percent in 2000 to 28 percent in 2009. This is probably because of the increase in the number of national institutes which are not connected to international networks. The increase in the number of institutes contributing to NST field is promising in the sense that these institutes have developed their NST capabilities; however this may turn into a disadvantage if these new universities cannot build their own networks, which provide them access to high quality knowledge located abroad. Figure 6 shows that Turkish NST scholars collaborate more with their colleagues affiliated to European institutes than those linked to others located in various regions of the world. Findings of a detailed analysis of collaborations suggest that Turkish scholars are strongly linked to those scholars affiliated to institutes in USA, Germany, UK, France and Italy.



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Number of articles (international collaboration)	50	55	78	81	105	131	145	152	228	255
Number of Artices (North America)	22	22	35	35	34	46	48	41	86	95
Number of articles (Europe)	27	34	45	43	65	67	71	82	123	154
Number of articles (OTHER)	7	9	13	12	13	33	48	42	50	49

Source: Data retrieved from WoS, SCI-EXPANDED.

Figure 6 Distribution of international joint publications of Turkish NST scholars by years and regions, 2000-2009

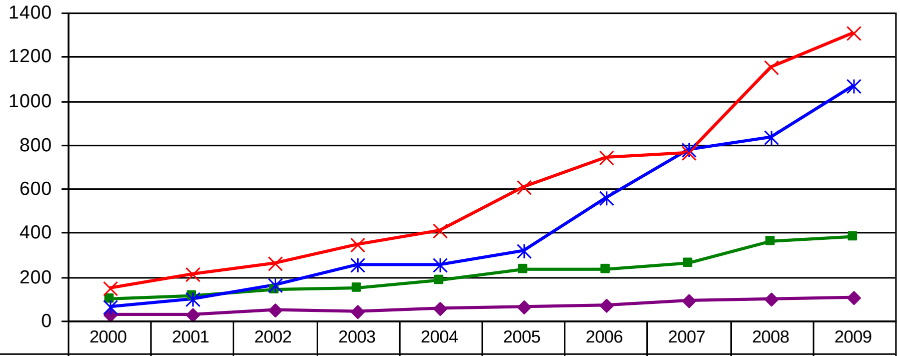
5.3 Collaborations and research networks

The most characteristic tendency of today's scientific production is the intensification of research collaboration (De Solla Price 1963; Hudson, 1996; Katz and Martin, 1997; Glanzel, 2002). In spite of some critics towards the assumption that multi-authorship and collaboration are synonymous terms (Katz and Martin, 1997) scientific collaboration is generally reflected by the co-authorship of publications and analyzed with bibliometric methods (Glanzel, 2002).

The analysis of co-authorship patterns in NST literature generated at Turkish universities indicates that the number of institutes collaborating with each other increased more than three times from the year 2000 to 2009 in line with the increase in the number of institutes. While, in the year 2000, 29 of 37 institutes collaborated, in 2009, 105 of 107 institutes collaborated with another institute. The sharp increase in the number of nodes[17] and links[18]

[17] The number of nodes is measured by the number of institutes / agents in collaboration.
[18] The number of links is measured by using co-authorship patterns: If one researcher from an institute / agent /node co-publishes an article with someone in another institute we can assume that these two researchers and these two institutes have a link.

indicated in Figure 7 also provides evidence for the increasing trend of collaboration in NST research in Turkey.

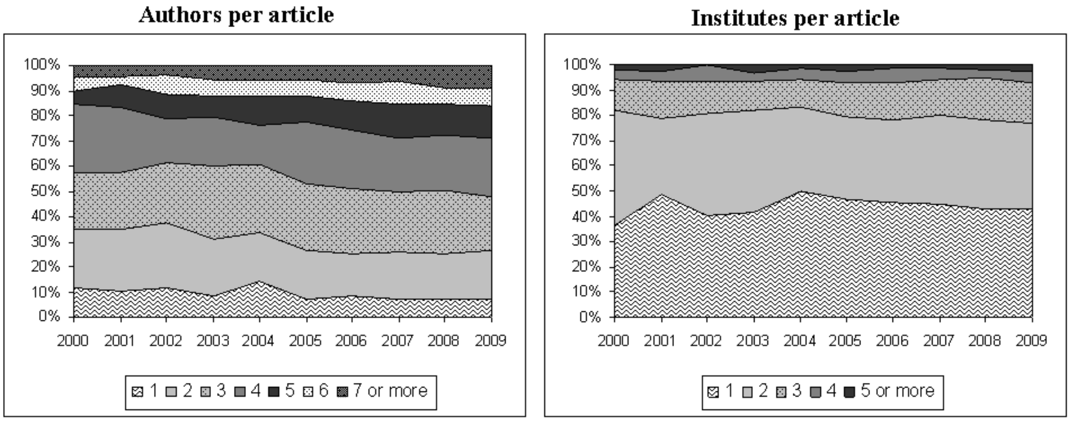


	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Nodes (Natl. Inst)	29	31	48	43	55	64	73	89	100	105
Nodes (All Inst)	98	114	142	147	184	231	235	263	361	385
Links (Natl. Collab)	66	98	166	254	258	318	562	778	834	1068
Links (Collab.)	145	211	259	346	410	610	742	766	1150	1309

Source: Our data collected from Web of Science, SCI-EXPANDED

Figure 7 Turkish NST research networks: Number of nodes and links, 2000-2009

However, the number of institutions and authors per article indicates that Turkish NST research has some weaknesses in terms of collaborations (Figure 8). In 2000, nearly 37 percent of research articles were authored by a single institute this ratio increased to 43 percent in 2009; and the percentage of articles co-authored by two institutes decreased from 45 percent to 34 percent in the same period. While the share of single-authored articles decreased from 11 percent to 7 percent, the share of articles with 5 or more authors increased from 16 percent to 29 percent in the ten year period from 2000 to 2009. This may indicate that authors would prefer to collaborate with other researchers in their own institutes. On the other hand, we found that the average number of authors collaborating per article was 3.38 in the year 2000 and increased to 3.83 in 2009. It is interesting to note that the average number of institutes per article, which was 1.9, did not change in 2009. These findings indicate that while the number of NST-related articles has significantly increased in the last ten years research collaborations and networks (in our case which is measured by co-authorship) have not improved among nano-scientists who are employed in different institutes / universities. In other words, the number of collaborators within universities has increased in this period 2000-2009, probably due to the increased number of nano-scientists, however, the pattern of research networks or collaborations have not changed. Hence, inter-institutional networking is still very low in NST-field.



Source: Data retrieved from WoS, SCI-EXPANDED.

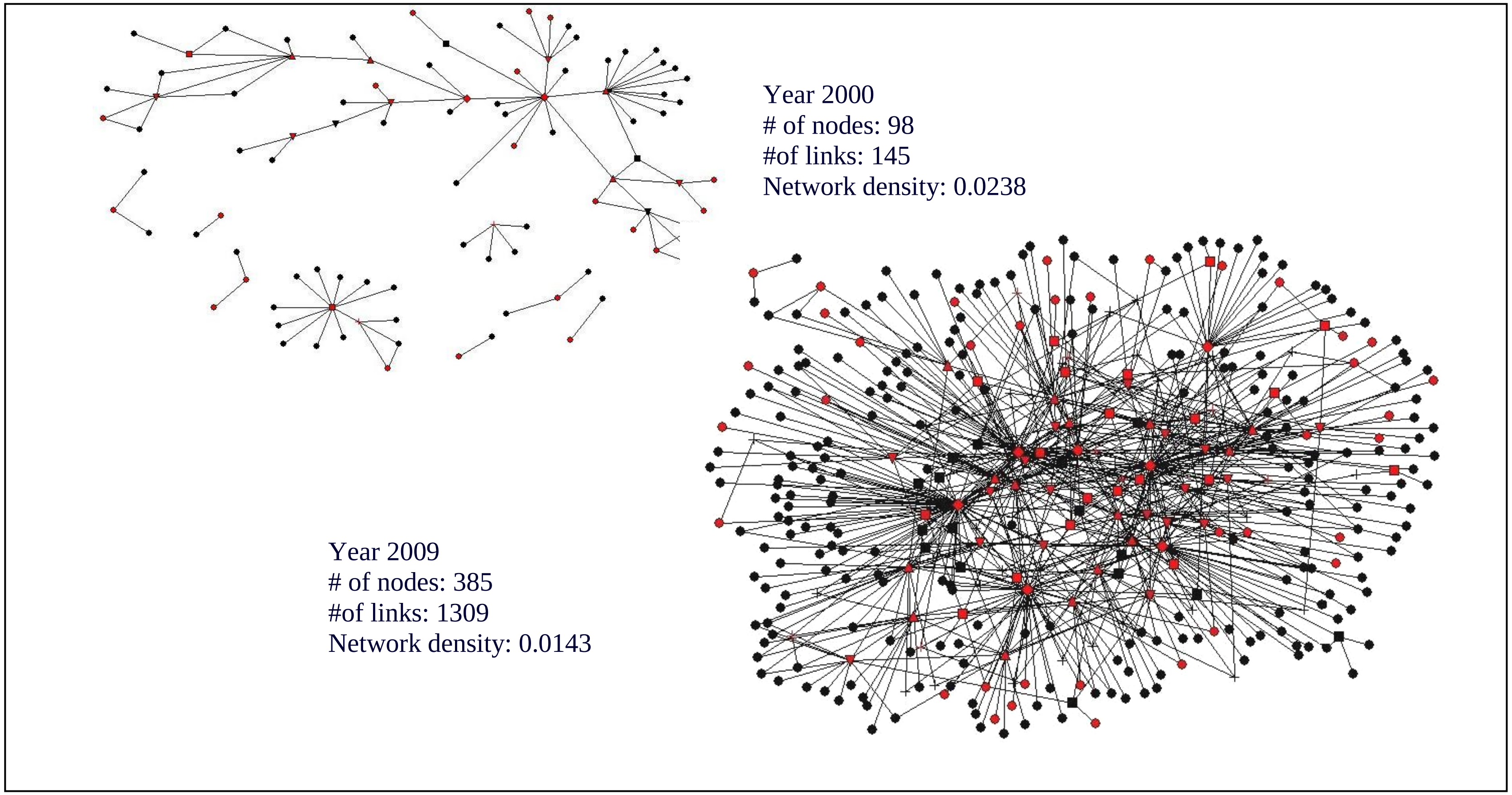
Figure 8 Collaboration per article measures, 2000-2009

For further analysis of Turkish NST research collaborations, social network analysis techniques and indicators (i.e. degree centrality) have been applied. Degree centrality "measures the extent to which a node connects to all other nodes in a social network" (Knoke and Yang, 2008). In network studies, it is proposed that nodes or agents with higher number of ties with other nodes may be advantaged since they occupy a more central position than those having lower number of ties and, hence, have more access to knowledge of other agents in the network. Degree centrality is measured in a non-directed network, in which the relations between nodes are bilateral, by the following formula:

$$C_D = \sum_{j=1}^{g} X_{ij} (i \neq j) \qquad \text{(Eq. 5.1)}$$

where C_D denotes degree centrality for node i and $\sum_{j=1}^{g} X_{ij}$ counts the number of direct ties that node i has to $g-1$ other j nodes. In this formula $i \neq j$ excludes i's relation to itself (Knoke and Yang, 2008).

Figure 9 indicates how NST research network of Turkish universities and institutes expanded in a ten year period from 2000 to 2009. The visual expressions of two networks in 2000 and 2009 show that while the number of links in the networks is increasing the network density figures are decreasing. Network density is simply expressed as the proportion of the number of links to the maximum possible number of links in a network. Hence, it is inversely related to the network size; the larger the social network the lower the network density because the number of possible links increases rapidly with the number of nodes included in the network.



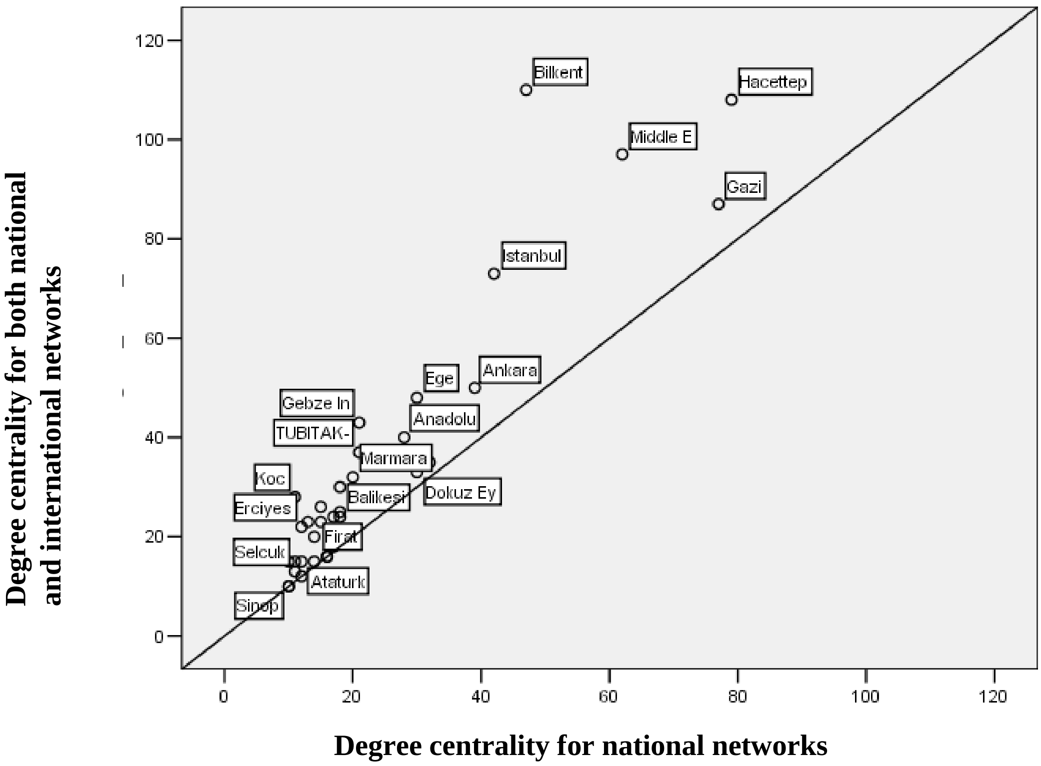
* Black nodes represent national institutes; and red ones for foreign institutes

Source: Data retrieved from WoS, SCI-EXPANDED.

Figure 9 NST research networks: a comparison 2000-2009

The mean degree centrality of NST research networks was 2.306 and the standard deviation was 2.597 in the year 2000. While, in 2009, mean degree centrality increased to 5.486 the standard deviation has increased to 12.622 with an almost five fold increase. This might indicate the presence of two different groups of institutions: (i) a large group of institutes with low degree centrality and (ii) a small group of institutes with higher degree centrality, or in other words, a small group of institutes which are well connected to others and a large group of institutes with low number of links to the other nodes in the network. Even though it is expected that in growing networks degree centrality measures are more heterogeneous; therefore, mean value is not representative (Kay, 2008), such a higher standard deviation indicates that NST research network follow a power law where there is a large number of institutes with a very low number of links. The cause of this heterogeneity in the network might be the fact that especially in recent years many universities entered into NST research network and they have not built their links with the others yet.

Another interesting point of Turkish NST research occurs when domestic network among Turkish institutes are separately considered. Degree centrality measures indicate that domestic NST research network is less heterogeneous than international networks. However, the detailed analysis focusing on certain institutes reveals that some research institutes have different characteristics in national and overall research networks. Figure 10 compares degree centralities of institutes in domestic research networks and whole research networks which include national and foreign institutes for the year 2009. It indicates that universities on the diagonal line have no international links however those slightly over the line have international links but their share in their network is comparatively low. According to this diagram, while Hacettepe, Gazi and Middle East Technical University have very central positions in domestic research networks, Bilkent University occupies the most central position when the whole NST research network is considered due to its higher number of international links. For example, in 2009, according to the degree centrality measure (which is 110) Bilkent University is the most central node in the network; however in the same year, it is at the fourth most central position in domestic research network after Hacettepe, Gazi and Middle East Technical University. Here the positions of Hacettepe and Middle East Technical University are remarkable because these two universities are well connected to national and international networks. Thus, they can play a brokerage role for knowledge flows from foreign institutes to some national institutes which are generally located in the periphery of networks with a small number of linkages to others (see also Gossart and Ozman, 2009).



Source: Data retrieved from WoS, SCI-EXPANDED.

Figure 10 Comparison of degree centrality measures of Turkish institutes, 2009

6. Conclusions and implications of the research

This paper aims to understand the structure of NST-related research in Turkish universities. The analysis of the data retrieved from ISI WoS SCI-EXPANDED to characterize the NST research in Turkish research institutes indicates that Turkey's presence in worldwide NST research has become more apparent in recent years. There has been an exponential growth in the number of research articles published by Turkish NST scholars for the last ten years. Moreover, the NST research network has grown in the same period in terms of institutes, authors, links, national and international collaborations.

The overall NST research in Turkey presents an advantageous position for achieving technological change and, hence, may open up a window of opportunity for economic growth. However, the analysis of the main characteristics of nanoscale research carried out at Turkish universities indicates some drawbacks and barriers to the future development of the NST field in Turkey. The results indicate that, first of all, there is a high concentration of nanoscale research at certain universities. Although the intensity of concentration has been decreasing in the last five years, the most ten prolific universities in Turkey generated more than half of the NST related research articles in 2009.

Second, although NST-related research in Turkey is multidisciplinary, in other words, generated by the contribution of various disciplines, it is not interdisciplinary in the sense that articles are produced by collaborating academicians from the same disciplines. Third, analysis of research networks among universities in the NST field in Turkey also indicates that there is a small number of universities with a large number of links, on the other hand, a larger number of universities are not well networked with other universities in the field. Fourth, in the recent years, with the increase in the number of institutes in the NST research networks, national collaborations have increased. However, the number of universities which have access to international research networks is still limited to some prolific universities of the country. Nonetheless, the international collaborations which allow accessing new knowledge located in other countries are important especially for countries which are new in the NST field with limited research capabilities. Last but not least, the most important contributor to the NST research in Turkey is universities; the share of industry's contribution is limited with the 1.1 percent of the total NST-related articles.

There is a race among countries which are not only the advanced but also developing ones (e.g. China, Brazil, India, Russia, South Korea) to become the leading countries of NST research; and scientific research carried out at universities is one of the most important components of these efforts. Any science policy design for nanotechnology in Turkey, therefore, needs to consider NST-related research activities at universities in order to become part of in this race. Nanotechnology-related science and technology policies, therefore, need to cover some measures to eliminate the aforementioned conclusions about the NST-related research at Turkish universities.

High concentration of nanotechnology research at certain universities or labs is a common phenomenon due to the nature of NST-related research. The role of instrumentation in scientific research in this field is very important; not only because of higher cost of instruments used in nanotechnology research but also the need for specialized research staff to use these instruments, especially SPMs. Therefore, the establishment of nanotechnology centers should consider the needs of specific regions and the agglomeration of industries in regions; and should be designed to support regional innovation systems. One or two universities in certain regions can be selected and supported to increase NST-related academic research, create new centers of excellence. Technological agglomeration in the sense of co-location of scientific and technological capabilities supports the development of nanotechnologies in a region; therefore, new organizational arrangements for sharing of facilities, equipment and skilled technicians across different disciplines, and in a wider range of institutions are required (Robinson et al., 2007). Research infrastructures which are mainly held by universities in Turkey might serve as an effective tool for the establishment of technological platforms on the regional basis.

The number of institutes per article and number of authors per article reveal that research collaborations are still weak in Turkish academia even in the field of NST which supposedly increases collaboration (Rafols and Meyer, 2007; 2010; Porter and Rafols, 2009; Porter and Youtie, 2009). In order to increase collaborations among institutes and authors science policy tools and support mechanisms are needed. For instance, during the application for public research funding universities or TUBITAK might consider whether and to what extent the prospected research project is open to collaboration; and whether the research projects which include academicians from different institutes, different disciplines and even from different regions might be preferred over the others. Supporting collaborative research from different national and international institutes and disciplines is an important policy tool and it is easy to apply without too much additional cost. Thus, in this way, collaborations across various institutes, disciplines or regions would accelerate the diffusion of NST research results; and might decrease the inequal distribution of NST-related knowledge and research skills.

Moreover, collaborations with countries such as USA, UK, Germany, France or Italy needs to be supported because co-authorship networks with the institutes located in these developed countries might affect positively not only the number of publications but also the quality of the research and knowledge flow to Turkish institutes through these research links. Indeed, there are many mechanisms launched by TUBITAK to support international mobility of scientists and their networking activities. However, our research indicates that, at least for the field of nanotechnology, except some researchers at certain universities (i.e. Bilkent, METU, Hacettepe) international research collaboration of Turkish nano-scientists is considerably low. Therefore, why these tools and mechanisms designed to support collaboration do not work should be investigated carefully and redesigned, if needed.

This problem might be due to the fact that research capabilities of some university-scientists do not suit well for the requirements to access international networks. In this sense, new strategies should be needed to improve these research capabilities; such as implementing mechanisms to encourage some universities to play the role of brokerage among Turkish and foreign scholars. As aforementioned Hacettepe and METU are good candidates for knowledge brokerage. However, if, for example, Bilkent University increases its collaboration with Turkish institutes and if Gazi University increases its links with the foreign institutes they may become successful knowledge brokers as well. In other words the development of policies that foster the tying down of international knowledge at national level is essential (Gossard and Ozman, 2009) for Turkey.

On the other hand, the weak contribution of the industry to NST research indicates a problem related to industrial R&D skills. This problem might be related to the fact that (i) industry does not have enough resources for doing nanotechnology -related R&D; or (ii) it does not have collaborations with university researchers to formalize and publish their research results in international journals. Nonetheless, the weak contribution of industry to NST research indicates that although co-publication of university and firm scientists is an important channel of university-industry collaboration, it is not effectively used by universities and firms in the NST field in Turkey.

However, in the literature, there are many studies emphasizing the importance of the integration with the science community from the perspective of firms. Cockburn and Henderson (1998) by using data on co-authorship of scientific papers between pharmaceutical company scientists and publicly funded researchers find that connectedness to open science community has a positive impact on firms' performance in drug discovery. Again Zucker et al (1998b) scrutinize the impact of co-authorships between university and firm researchers in biotechnology and find that for an average firm five articles co-authored by academic stars and the firm's scientists imply about five more products in development and 3.5 more products in the market. On the other hand, discoveries in biotechnology and nanotechnology are characterized by natural excludability[19] and, therefore, involve extensive tacit knowledge (Zucker et al 1998a; Darby and Zucker, 2004). Therefore, in the fields of biotechnology and nanotechnology, for a firm researcher, it is very important to carry out research in the laboratory together with university researchers, and would probably provide more opportunities for learning-by-doing and also will improve the knowledge and technology spillovers between universities and firms. Doing research at laboratory is very important in nanotechnology; however laboratories are heavily used by university researchers, and firm researchers are excluded from this realm of scientific knowledge production. Nonetheless, science-based technologies, especially biotechnology and nanotechnology, needs heavy usage of laboratory facilities and and specialized instruments which are not available at corporate labs. Hence, encouraging firm researchers to actively participate to research projects at university labs will increase the number of articles contributed by firm researchers; collaborations among university and firm researchers; and knowledge and technology spillovers between academia and industry.

As a final point, low patenting level in nanotechnology should be considered as an important indicator of bottlenecks in the commercialization of NST-related research carried out both at universities and firms. However, patenting issues in nanotechnology should be urgently included in national science and technology policies on nanotechnology. There is a very heavy patenting activity in nanotechnology; even a tiny research result is patented and the number of patents issued and the patent applications have been exponentially growing. However, most of these patents are acquired by multinational companies or universities in advanced countries; and unfortunately these patents would not be accessible by firms in developing countries. Even for some developing countries which have good indicators in NST-related research (i.e. China, Brazil, India) the low number of nanotechnology patents is the most examined issue for

[19] Scientific discoveries are achieved by small communities; and people out of these communities can be excluded from making use of these discoveries due to tacit knowledge developed during the process of discovery. Zucker et al (1997) argue that inherent in the discovery itself is its degree of natural excludability; i.e. if the techniques for replication are not widely known prior to the discovery, then any scientist wishing to build on the new knowledge must first acquire hands-on experience. Therefore, scientific discoveries with natural excludability can give rise to localized industrial effects where the information is sufficiently costly to transfer due either to its complexity or tacitness.

catching up. Thus, the patentiability of research results produced at universities should be worked out and encouraged by science policies.

To summarize, in this paper the NST-related research activites at Turkish universities were analyzed by using the articles in ISI WoS SCI-EXPANDED database which were published from 2000 to 2009 by at least with one scholar linked to Turkish institutes. The results indicate that in spite of some bottlenecks in NST related research activities, Turkey has an advantageous position in nanotechnology with the exponentially growing articles in the international literature. Moreover, high amount of investments has been made to establish new research facilities and to improve research infrastructure in the country. Among academicians there is a growing interest towards nanotechnology; and the number of master and PhD programs on interdisciplinary nanotechnology research has also been increasing. Thus, while NST-related research and knowledge capabilities have been growing in universities, how the issue of transfer of these capabilities from academia to industry can be achieved should be included in the agenda; and developing mechanisms facilitating university-industry collaborations should be among the targets of science and technology policy design in nanotechnology in Turkey.

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