The Diffusion of Nanotechnology Knowledge in Turkey

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Abstract

This paper assesses the diffusion of nanoscience and nanotechnology in Turkey in the last decade using bibliometric and Social Network Analysis (SNA) techniques. We extracted a total of 10,062 articles and reviews from Web of Science (WoS) authored by the Turkish scientists between 2000 and 2011. We divided the data set into two 6-year periods (2000-2005 and 2006-2011). Almost three quarters (7,398) of all papers were published between 2006 and 2011. For each period, we compared the number of nanotechnology papers, the universities' output along with their levels of collaboration with one another, the diffusion and adoption of nanotechnology, the most prolific authors and the nanotechnology research topics studied most often by the Turkish researchers. We found that nanotechnology research and development (R&D) in Turkey is on the rise and its diffusion and adoption has increased tremendously in the second period. This is due primarily to the fact that the government identified nanotechnology as a strategic field a decade ago and decided to provide constant support for nanotechnology R&D. Overlay maps showed that nanotechnology R&D in Turkey concentrated primarily in Materials Sciences, followed by Chemistry, Physics, Clinical Medicine and Biomedical Sciences.

Conference Topics

Country-level studies, Mapping and visualization

Introduction[1]

Nanoscience and Nanotechnology is the study of materials at atomic levels within the 1 to 100 nm range (i.e., at a magnitude of 10^{-9} of a meter) (Mehta, 2002). Although Nanotechnology has been introduced more than half a century ago by Feynman (1960), it took some time for the nanotechnology research to pick up. Many countries have invested heavily in nano-related technologies in the past two decades. The US government, for example, has allocated 1.74 billion US dollars to nano-related technologies in 2011 (Sargent, Jr., 2013). European countries under the 7th Framework Program have also heavily invested in joint projects among its members. Consequently, the number of scholarly publications in nano-related technologies in North America, Europe and Far Eastern countries has increased.

Turkey as a developed country prepared its strategic plan by taking nano-related research and development into account. Nanotechnology including nanophotonics, nanoelectronics, and nanoscale quantum computing is one of the eight strategic fields of research and technology mentioned in Turkey's "Vision 2023 Technology Foresight Study" that was prepared as part of the "National Science and Technology Policies 2003-2023 Strategy Document" by the Supreme Council of Science and Technology (SCST) more than a decade ago (Ulusal, 2004, pp. 19-20). Nanotechnology as a research field has been receiving state support since 2007 in Turkey (about one billion Turkish Lira, or circa 500 million USD). The Turkish Scientific and Technological Research Council (TUBITAK) and the Ministry of Development (MoD) support nanotechnology projects financially. For example, MoD continues for more than a decade to invest to improve the infrastructure of nanotechnology research facilities and

[1] This paper is based on the findings of first author's Ph.D. dissertation entitled "Assessing the diffusion of nanotechnology in Turkey: A Social Network Analysis approach." (Darvish, 2014).

supported the establishment of nanotechnology research centers. In addition, it supports several nanotechnology-related projects carried out by research institutes and universities.

Thanks to state support, nanotechnology has become a major field of research in Turkey. Universities invested heavily in nanotechnology in the last decade. More than 20 nanotechnology research centers were set up mostly in universities. Among them are Bilkent, Middle East Technical, Hacettepe, Sabancı, İstanbul Technical and Boğaziçi Universities. More than 10 universities are offering both undergraduate and graduate degrees in nanotechnology. More than 100 commercial companies and start-ups of various sizes have also invested in nanotechnology (e.g., Normtest, Arçelik, Yaşar Holding, Yeşim Textile and Zorlu Energy) and developed commercial nanotechnology products in a number of sectors including surface coating, textile, chemistry, automotive and construction industries, and polymer and composite materials. Turkey has been among the first three countries in terms of the growth of nanotechnology research with some 2,000 scientists working in this field (Bozkurt, 2015, p. 49; Denkbaş, 2015, p. 84; Özgüz, 2013). The number of nanotechnology related scientific papers published by Turkish researchers and listed in Web of Science (WoS) is ever increasing (more than 2,500 in 2014 alone).[2]

This paper aims to assess the diffusion of nanoscience and nanotechnology in Turkey between 2000 and 2011 using bibliometrics and Social Network Analysis (SNA) techniques. It identifies the total production of nano-related publications by Turkish researchers and the key fields in which nanotechnology is applied in Turkey (e.g., biomedicine, pharmacy, and metallurgy). The adoption of nanotechnology by the most prolific universities and the diffusion of nanotechnology knowledge through collaboration among them is also studied.

Literature Review

Scientists have investigated the diffusion of innovation and knowledge in societies from different perspectives. Rogers (2003, p. 5) defines the diffusion of an innovation as "the process by which an innovation is communicated through certain channels over time among the members of a social system." Social interactions between scientific domains and practitioners are instrumental to the diffusion of innovation and knowledge. According to Rogers, the key elements in the diffusion process are: innovation/knowledge, communication channels, time and social systems (p. 7). An innovation starts with a few people and has a few adopters, but eventually it gains the momentum until it reaches its peak. Rogers likens the diffusion process of an innovation to a mathematically-based bell curve (also known as "Rogers adoption/innovation curve") and categorizes the adopters accordingly (i.e., starting from the left tail of the curve to the right, 2.5% of the adopters are called "innovators", 13.5% "early adopters", 34% "early majority", 34% "late majority", and the remaining 16% on the right tail of the curve as "laggards").

Poire (2011) looks at the timeframe of the adoption of innovations along with the impact of innovations on the economy. He argues that "it takes about 28 years for a new technology to become widely accepted, followed by a period of rapid growth lasting about 56 years. Some 112 years after invention, the innovation reaches maturity and grows in-line with population increases" (Roy, 2005, p. 9). Using these yardsticks, he convincingly charted the adoption processes of textiles, railways, automobiles, computers and nanotechnology. He predicts that nanotechnology, which according to him came into being in 1997, will be more widely adopted by 2025, followed by a 56-year long rapid adoption period (until 2081) during which time nanotechnology products will become an integral part of our everyday life like computers.

[2] Search on WoS was carried out on January 11, 2015.

If an innovation is communicated among the members of a social system, as Rogers indicated, then studying social systems is important because scientists work and collaborate within such systems. Assessing social relations among scientists reveals how collaborative they are. Conventionally, Derek de Solla Price (1965) studied the scholarly communication process between scientists, thereby opening the door to the quantitative study of science.

Social Network Analysis is a paradigm in which relational interaction among members signifies the role of people in a network structure (Wellman & Berkowitz, 1997). The diffusion of knowledge in a network of people can thus be studied by exploring the social structure of the network along with the relations and collaboration (or lack thereof) among network members using SNA concepts such as density and centrality. For example, poorly connected "structural holes" in a densely connected network are crucial for connecting "clusters" (groups of people) in a network structure and for the diffusion of knowledge in the network (Burt, 1992). Newman (2000) referred to clustering as "community structure". The value of a person in a social network is therefore linked to his/her potential to establish connections between clusters that are separated by structural holes.

Scientific discovery comes with a group of specialized people who "attend, read and cite the same body of literature and attend the same conferences" (Chen et al., 2009, p. 192). Bibliometric methods such as co-citation (Crane, 1972) or co-author (Girman & Newman, 2002) analyses were used to study the diffusion of knowledge in the network of scientists as well as to track the level of collaboration among different partners along with the emergence of new research areas. As a collaborative model involving universities (research centers), funders and industries, the Triple Helix was proposed to streamline the diffusion of knowledge (Leydesdorff & Etzkowitz, 1998).

Scientometricians use visualizations in addition to other indicators to track or investigate new scientific developments over time. For example, science overlay maps were introduced as a novel approach to illustrate the bodies of research precisely surrounded by global scientific domains (Rafols, Porter & Leydesdorff, 2010). Science overlay maps can represent different types of data and large data sets such as network of authors, publications and universities succinctly and "help benchmark, explore collaborations, and track temporal changes" (Rafols, Porter & Leydesdorff, 2010, p. 1871).

Nanotechnology has been the subject of several studies in the past and reviewing them is beyond the scope of this paper. However, we should mention Milojević (2009, 2012) who studied the coginitive content of nanoscience and nanotechnology as well as its diffusion using SNA techniques and mapped the evolution and socio-cognitive structure of it. We should also mention one particular study that measured the growth and diffusion of nanotechnology on a global level on the basis of the number of publications produced by countries as well as the most prolific institutions and authors along with the most cited authors, papers and journals (Kostoff, Stump, Johnson, Murday, Lau & Tolls, 2006). China, Far Eastern countries, USA, Germany and France were among the most prolific ones.

As mentioned earlier, Turkey is among the first three countries based on the growth of nanotechnology research. Turkey's contribution to nanotechnology literature was also evident at the global level (Kostoff, Koytcheff & Lau, 2007). Recently, the state of nanotechnology centers and companies carrying out research and manufacturing nano-related technologies in Turkey was studied with a view to compare them quantitatively with their counterparts in China, India and Germany, for example (Aydoğan-Duda & Şener, 2010; Aydoğan-Duda, 2012). The present study attempts for the first time to map the nanotechnology output of Turkish universities and investigate the diffusion of nanoscience and nanotechnology knowledge in Turkey at the micro level by means of Social Network Analysis and bibliometrics. The results can be considered as a stepping stone for comparative studies for future studies.

Method

The aim of this research is to assess the diffusion of nano-related technology by mapping of collaborative social structure of scientists in Turkey between 2000 and 2011. We attempted to address the following issues: (a) the most prolific universities publishing nanotechnology research; (b) the rate of diffusion of nanotechnology knowledge and its adoption within universities between 2000 and 2011; and (c) key areas of nanotechnology research.

In order to answer the research issues, we used a compound textual query on nanotechnology modified from Kostoff's[3] and searched (WoS). We retrieved a total of 10,062 papers (with at least one author of each paper affiliated with a Turkish university or research institute) published between 2000 and 2011. We then divided the data set into two 6-year periods (2000- 2005 and 2006-2011) to further assess the diffusion of nano-related technology in Turkey.

We analyzed co-occurrences among universities to capture collaborations in network structures. VOSviewer was used to implement the method of "associative strength" that clustered bibliometric data based on their similarities and mapped the network structure. A geocoder[4] was used to get the geo-coordinates for each city and Google Maps was used to overlay the relationships among cities on a geographic map. Bibexcel was used to calculate the most frequent collaborators from selected universities in the research. The top ranked universities in each period (2000-2005 and 2006-2011) were selected on the basis of their co-occurrence in terms of scientific collaboration on nanotechnology. Gephi, VOSviewer and GoogleMaps were used to map the network structure.

Findings

The number of Turkey's scientific publications on nanotechnology increased from 215 papers in 2000 to 1,748 in 2011, more than an eight-fold increase (Fig. 1). Almost three quarters (7,398) of all papers (articles and reviews) were published between 2006 and 2011 while the rest (2,664) were between 2000 and 2005. This increase is mainly due to Turkey's making nanotechnology a priority field in its 2003-2023 strategic plan and providing state support to nanotechnology research and development starting from 2007. The number of newly-established universities, hence the number of researchers studying nanotechnology, has also increased tremendously in this period.

There are about 180 universities in Turkey, two-thirds being state-funded. Using the fractional counting method, Figure 2 shows the top ranked universities based on the number of nanotechnology papers they published between 2000 and 2011. The Middle East Technical, Hacettepe, İstanbul Technical, Gazi and Bilkent Universities are the top ranking ones. All but four (Bilkent, Koç, Fatih and Sabancı) universities in Figure 2 are state funded.

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[3] Personal communication with Prof. Ronald N. Kostoff (20 April 2012). Search query is available from the authors upon request.

[4] Available from http://www.gpsvisualizer.com/geocoder/.

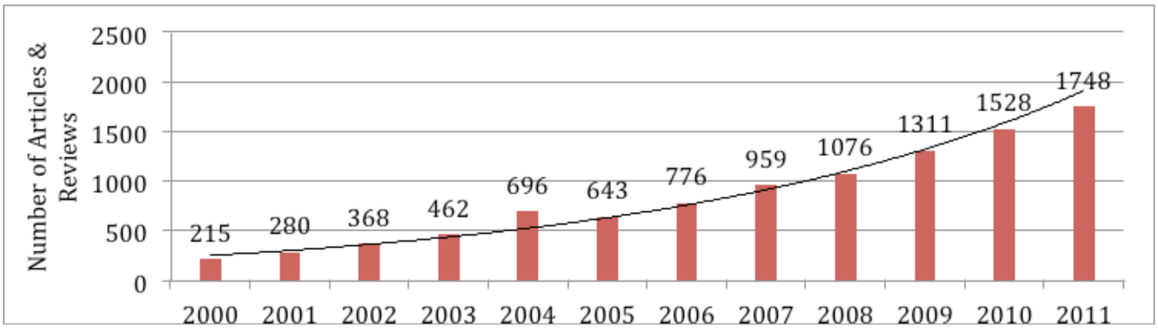

Figure 1. Number of nano-related technologies publications in Turkey: 2000-2011 Source: Thomson's ISI Web of Science as of November 2013.

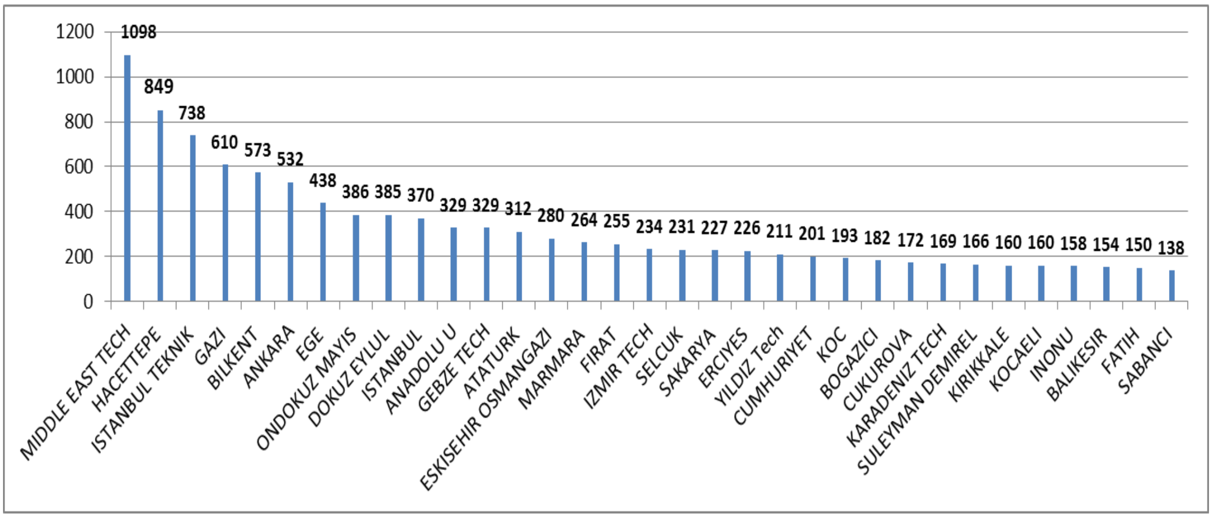

Figure 2. Number of nanotechnology papers of the top Turkish universities between 2000 and 2011 Source: Web of Science as of November 2013.

To assess the level of collaboration and the diffusion of nanotechnology knowledge among universities, we examined the average co-occurrence frequencies of all universities in published papers and created separate networks for the periods of 2000-2005 and 2006-2011 (Fig. 3). The collaboration network was much sparser in the first period with a few universities such as Hacettepe and METU acting as hubs of research on nanotechnology and cooperating with others. The network was much denser in the second period with more universities both acting as hubs of nanotechnology research and collaborating with their counterparts. This is an indication of an increasing level of collaboration among universities in carrying out nanotechnology research within a relatively short period of time.

The diffusion of nanotechnology knowledge in Turkey can be examined from a somewhat different angle by looking at the number of provinces where nanotechnology research took place. Turkey is divided into 81 administrative provinces. The information presented in Figure 4 is less granular than that in Figure 3 due to a few provinces such as İstanbul, Ankara and İzmir having several universities (both old and new). Nevertheless, the number of provinces where nanotechnology research is carried out went up from 40 in the first period (2000-2005) to 72 in the second period (2006-2011). The geographical spread is due to new universities being established in some provinces for the first time and to the government support that enabled researchers both in new and old universities to collaborate further.

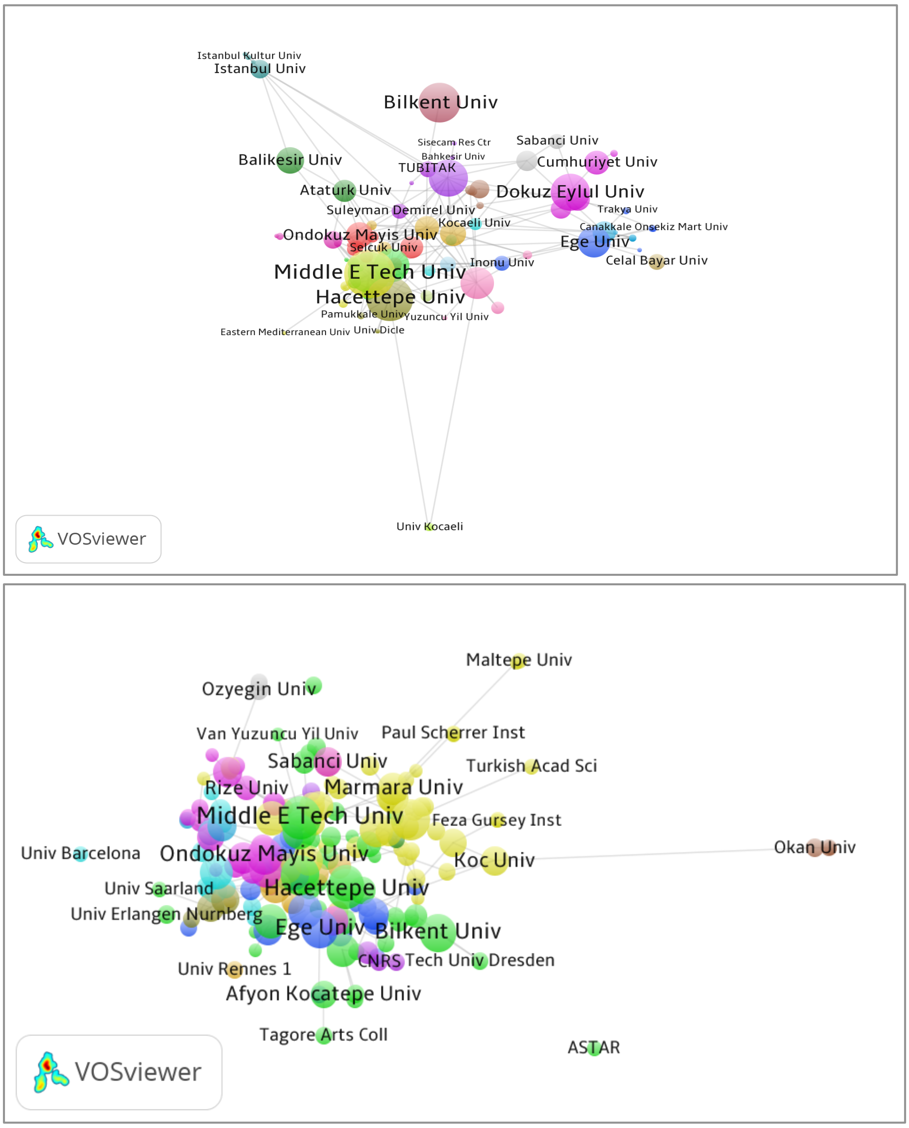

Figure 3. Collaboration of Turkish universities on nanotechnology (top) 2000-2005; (bottom) 2006-2011.

Table 1 shows the top 15 universities with the highest co-occurrence frequencies in both periods. The average co-occurrence frequency for the top 15 universities has almost tripled from 17 in 2000-2005 to 46 in 2006-2011. Note that the top 15 universities in the second period are slightly different from the ones in the first period, as some of the more prolific and more collaborative universities with higher frequencies of co-occurrence replaced the previous ones. We used the fractional counting method and found that the average number of nanotechnology papers published by the top 15 universities in the first period increased from 9 in 2000 to 27 in 2005, and from 35 in 2006 to 77 in 2011 in the second period, indicating more than an eight-fold increase (Table 2).

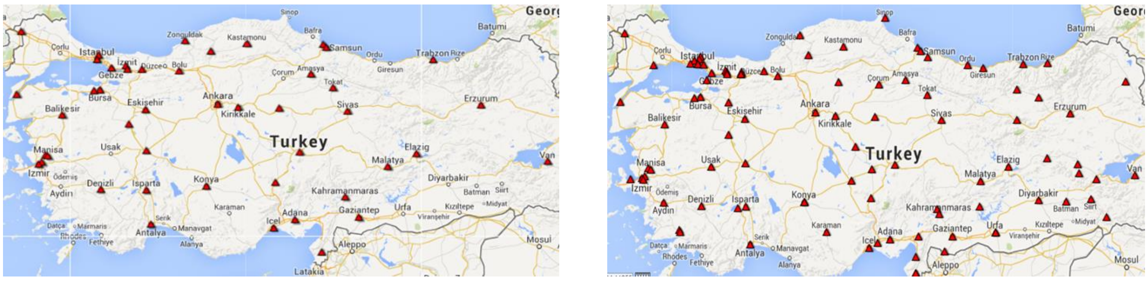

Figure 4. Geographical distribution of nanotechnology research activities in Turkish provinces (l) 2000-2005; (r) 2006-2011.

Table 1. Top 15 Turkish universities with the highest co-occurrence frequencies of collaboration between 2000 and 2011

2000-2005		2006-2011	
University	N	University	N
Hacettepe	30	Hacettepe	63
Middle East Technical	29	Gazi	63
Ankara	21	Middle East Technical	60
Gazi	20	Istanbul Technical	57
Istanbul Technical	18	Ankara	53
Gebze Institute of Technology	17	Gebze Institute of Technology	47
Dokuz Eylül	15	Ondokuz Mayıs	42
Marmara	14	Ege	41
Bilkent	14	Istanbul	41
Abant İzzet Baysal	13	Erciyes	40
Kırıkkale	12	Bilkent	38
Ege	12	Dokuz Eylül	34
Ondokuz Mayıs	11	Anadolu	34
Erciyes	11	Atatürk	33
Kocaeli	11	Fırat	31
Average	**17**	**Average**	**46**

Table 2. Number of papers published by universities with the highest co-occurrence frequencies in the second period (2006-2011)

University	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Hacettepe	79	85	89	97	95	107
Gazi	36	77	95	85	99	98
Middle East Technical	77	93	59	131	143	143
İstanbul Technical	52	64	65	88	91	121
Ankara	40	62	70	49	73	54
Gebze Institute of Technology	20	25	33	45	49	55
Ondokuz Mayıs	37	32	35	55	76	74
Ege	16	39	28	60	95	77
İstanbul	25	28	30	42	57	63
Erciyes	16	12	20	41	32	45
Bilkent	34	41	58	63	61	99
Dokuz Eylül	31	43	35	51	52	58
Anadolu	15	29	39	41	45	55
Atatürk	23	18	37	33	55	53
Fırat	17	19	23	31	45	50
Average	**35**	**44**	**48**	**61**	**71**	**77**

Next, we examined the diffusion of nanotechnology knowledge in Turkey using a more refined approach and identified the new authors collaborating each year in order to find out the adoption rate of nanotechnology research. Regardless of whether they appeared in the same paper or not, each new collaboration between any two authors was counted as one and considered a new adoption. The number of collaborating authors was just 214 at the beginning (2000) whereas it rose to 2,989 in 2011 (Table 3 and Figure 5). The number of new adopters was rather slow in the first period (2000-2005) with an average of 216 collaborations per year but the "tipping point" seems to have been reached in 2006 when the number of new adopters jumped from 282 in 2005 to 1622, an almost six-fold increase. The average number of new adopters in the second period (2006-2011) rose to 1868, more than eight times of what it was in the first period. Altogether, the number of cumulative new adopters soared in 12 years and was 13,692 in 2011. The annual rate of cumulative increase in percentages ranged between 11% (2004) and 54% (2006). Needless to say, the increase in the number of new adopters is primarily due to nanotechnology becoming a major research field in Turkey and nanotechnology research being supported by government funds.

Table 3. Number of new and cumulative adopters between 2000 and 2011

Year	# of new adopters	# of cumulative adopters	Rate of cumulative increase (%)
2000	214	214	0
2001	177	391	45
2002	193	584	33
2003	381	965	39
2004	115	1080	11
2005	282	1362	21
2006	1622	2948	54
2007	1668	4652	37
2008	1907	6559	29
2009	1919	8478	23
2010	2225	10703	21
2011	2989	13692	22

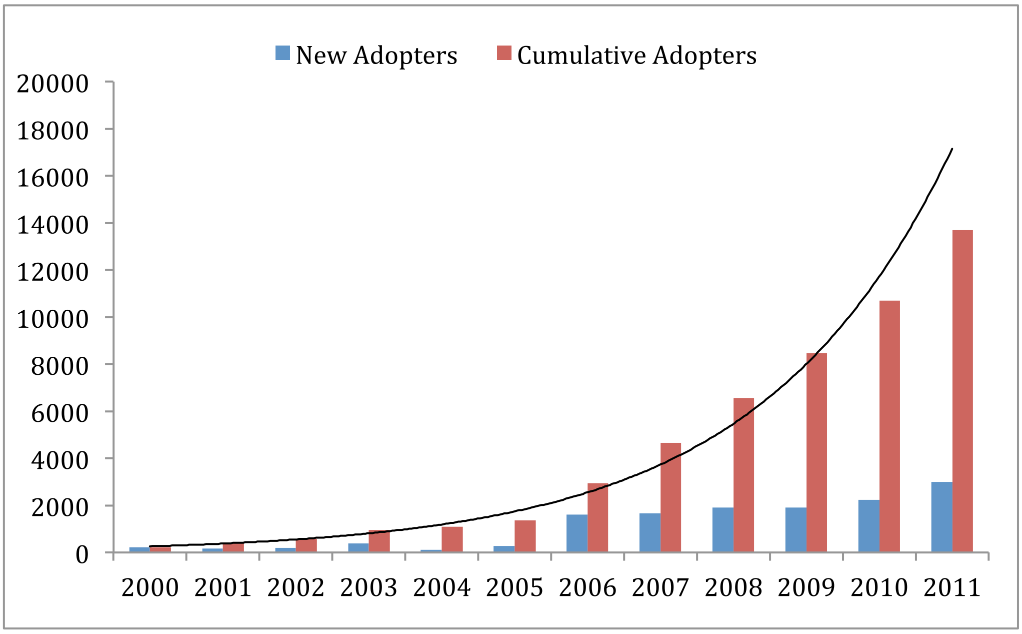

Figure 5. The growth of adoption of nanotechnology knowledge based on the number of collaborating authors (2000-2011).

Next, we identified the most prolific Turkish researchers in nanotechnology between 2000 and 2011 based on the number of papers they authored or co-authored. The fractional counting method was used for co-authored papers. Table 4 shows the top 20 researchers in both periods along with their total number of co-authors. The total number of papers authored or co-authored by the top 20 researchers almost doubled in the second period (from 645 to 1,189). Nine researchers appeared in both periods (italicized in the table) with different ranks. This means that 11 new researchers became more productive than they were in the first period and replaced the less productive ones in the second period or they entered the field anew. O. Buyukgungor of Ondokuz Mayis University, for instance, is at the top of the second period with 149 papers to his credit even though he did not appear in the top 20 of the first period. The top 20 most prolific researchers co-authored more papers with their colleagues in the second period (216 and 315, respectively). The number of co-authors of nine researchers who appeared in both periods increased 42% in the second period, indicating that they were influential in diffusing the nanotechnology knowledge to their colleagues. The same can probably be said for the remaining 11 researchers who appeared in the top 20 list in the second period.

Finally, we identified the research topics in nanotechnology that were studied more often by the Turkish scientists. We created separate overlay maps of research topics for both periods using ISI's 224 Subject Categories listed in WoS records. Both co-authorship networks and overlay maps were shared with five senior and five junior experts in nanoscience whose publications appeared in leading journals and their comments with respect to their places in the network were recorded (not reported here) (Darvish, 2014).

Table 4. The most prolific Turkish scholars in nanotechnology (2000-2011) Source: WoS (as of November 2013)

2000-20005			2006-2011		
N	First author & affiliation	# of co- authors	N	First author & affiliation	# of co-authors
53	Erkoc S (METU)	29	149	Buyukgungor O (Ondokuz Mayıs)	37
49	*Sokmen I (Dokuz Eylül)*	*16*	78	*Yagci Y (ITU)*	*19*
42	*Ciraci S (Bilkent)*	*13*	*75*	*Denizli A(Hacettepe)*	*18*
39	*Denizli A (Hacettepe)*	*12*	72	Yakuphanoglu F (Firat)	28
38	*Yagci Y (ITU)*	*10*	*67*	Ozkar S (METU)	23
37	Celik E (Bilkent)	11	*67*	*Toppare L (METU)*	*15*
37	*Sari H (Bilkent)*	*11*	*64*	*Ozbay E (Bilkent)*	*13*
36	Turker L (METU)	28	62	Yesilel OZ (Osmangazi)	17
30	*Yilmaz VT (Dokuz Eylül)*	*8*	*61*	*Sokmen I (Dokuz Eylül)*	*17*
30	*Toppare L (METU)*	*7*	58	Ozcelik S (Gazi)	12
29	Hascicek YS (Gazi)	8	52	Demir HV (Bilkent)	13
28	Ovecoglu ML (ITU)	7	49	Baykal A (Bilkent)	10
27	Elmali A (Ankara)	8	45	Turan R (METU)	10
26	Elerman Y (Ankara)	8	44	Sahin E (Bilkent)	11
26	Piskin E (Hacettepe)	8	*44*	*Yilmaz VT (Dokuz Eylül)*	*13*
26	*Kasapoglu E (Cumhuriyet)*	*8*	43	Caykara T (Gazi)	15
26	Balkan N (Bilkent)	5	*41*	*Sari H (Ankara)*	*9*
22	Yilmaz F (METU)	6	*40*	*Ciraci S (Bilkent)*	*12*
22	Turan S (Marmara)	8	*39*	*Kasapoglu E (Cumhuriyet)*	*12*
22	*Ozbay E (Bilkent)*	*5*	39	Albayrak C (Ondokuz Mayıs)	11

Each color in the map represents a subject category and the node size is proportional to its co-occurrence frequency with other nodes (Fig. 6). It appears that the nanotechnology papers authored by Turkish researchers in both periods were primarily related with Materials Science (black) followed by Chemistry (blue), Physics (purple), Clinical Medicine (red), Biomedical Sciences (light green), Environmental Science and Technology (orange), and Computer Science (fuchsia). Subject categories appeared in overlay maps clearly show the priorities of Turkey in nanotechnology research and development and are commensurate with the nanotechnology products developed by commercial companies based in Turkey.

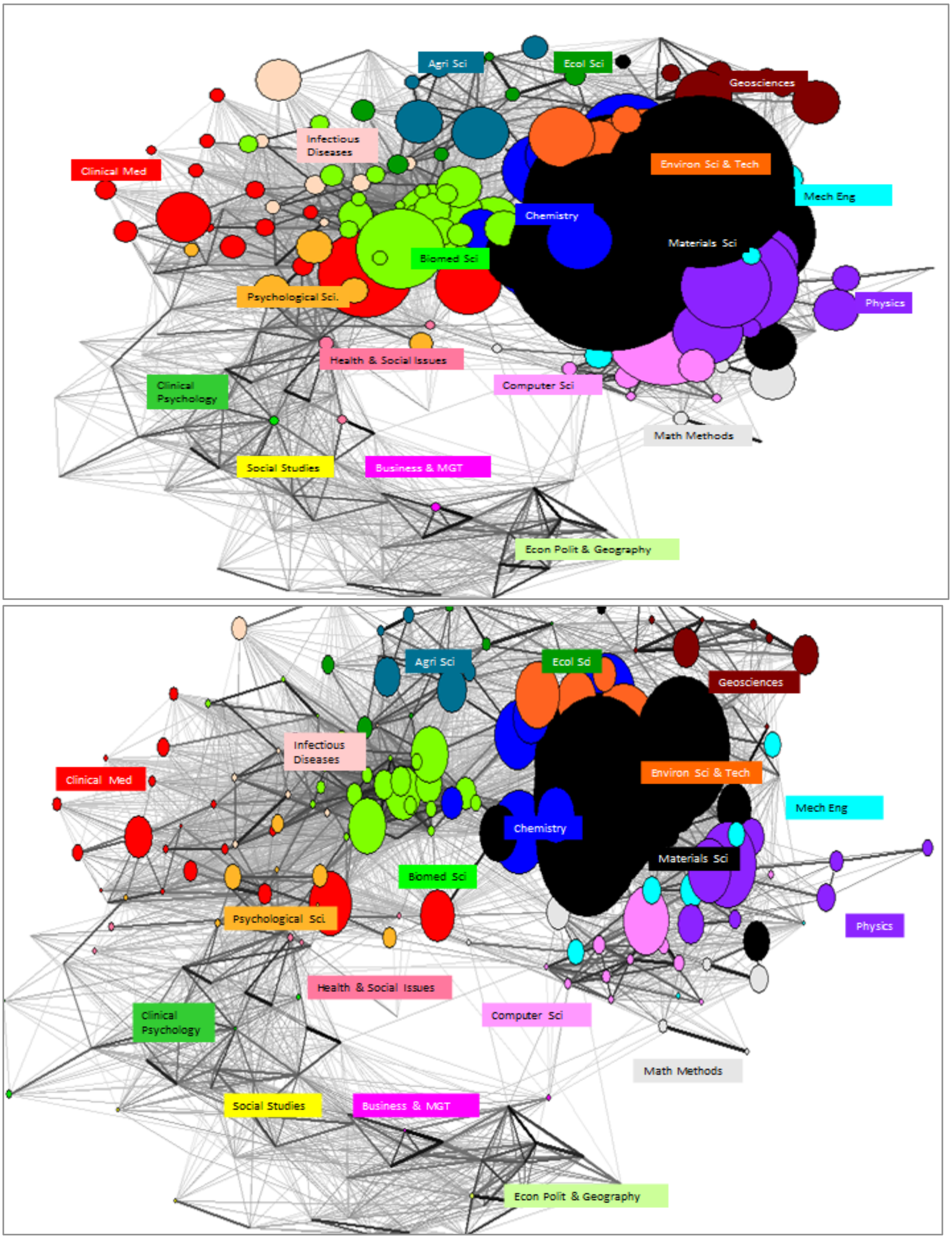

Figure 6. Overlay maps of subject categories of nanotechnology papers authored by Turkish scientists (top) 2000-2005; (bottom) 2006-2011.

Conclusion

Our analysis clearly shows that nanotechnology R&D in Turkey is flourishing. The number of nanotechnology papers published by Turkish scientists has tripled once the Turkish government has identified nanotechnology as one of the eight strategic fields in its national science and technology policy of 2003-2023 and decided to invest in nanotechnology accordingly. This decision has tremendously increased the diffusion and adoption of nanotechnology as a research field. Nanoscientists became more collaborative and more prolific in their research. This is somewhat similar to the experience of India, China, Iran and Latin American countries in that the importance of nanotechnology has increased once they identified it as a promising technology in their national development plans (Aydoğan-Duda, 2012).

The key areas of nanotechnology research and applications in Turkey are primarily in Materials Science, Chemistry, Physics, Clinical Medicine and Biomedical Sciences. All but Clinical Medicine appear in Milojević's list of areas as having the highest number of nanoscience and nanotechnology papers published in the literature (Milojević, 2012). The diversity of nanotechnology research shows that Turkish scientists are well aware of the trans- and interdisciplinary nature of nanotechnology as a discipline, although collaborative nanotechnology research in some areas such as Mathematics, Computer Science and Social Sciences seems to be currently lacking in Turkey.

Nanoscience stimulates scientific research in Physics, Chemistry, Biology and Medicine. Results revealed that notably well-established universities are instrumental in nanoscience research and newer universities are catching up. Turkey recognized the importance of nanotechnology as a strategic field relatively early. Based on Poire's timeframe of innovations becoming the drivers of economy, we can say that the diffusion of nanotechnology and its widespread adoption in Turkey will likely continue to accelerate until early 2030s.

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