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PERSPECTIVES

Measuring nanotechnology development through the study of the dividing pattern between developed and developing countries during 2000–2014

Mostafa Jafari · Hamid Reza Zarghami

Abstract This paper investigates the global nanotechnology and nanoscience (NN) indicators in a developmental context, during three 5-year periods from 2000 to 2014. Through bibliometric analyses of the longitudinal data from well-known databases, the growth patterns of NN articles and patents were investigated. Furthermore, the causal relationships among these indicators and some characteristics of the 105 countries studied were examined using regression and correlation analyses leading to the identification of the top 20 "science and innovation giants," in terms of all indicators, as well as the existence of significant, yet different, correlations among the indicators in developing and developed countries. In general, China's growth rate (GR) in NN publications was found to surpass USA, from 2010 to 2014, leading to a change in the ranking of the top countries and moving China, with about 25 % of world's NN articles, to top. A different trend was distinguished for patents in the area of nanotechnology, where USA, as the origin of over half of the world's granted patents, has been the undisputed leader. The shares of developing countries (i.e., the percent ratios of the number of nanotech patents granted to the citizens of developing countries over the total number of nanotech patents granted worldwide) was found to be incompatible with the countries' shares in the total NN articles, indicating a poor correlation between the two factors. However, developing countries were found to be superior in the GR of both NN articles and patents. Finally, the top countries identified can be regarded as suitable for comparative studies, and benchmarking by researchers and policy makers.

Keywords Nanotechnology · Nanoscience · Global pattern · Longitudinal evaluation · Science and innovation indicators · Developmental context

Introduction

Nanotechnology can reconstruct and control materials at the atomic, molecular, and supra-molecular scales (i.e., 1–100 nm) (Bhushan 2010). It is often viewed as an emerging research field with potentials to offer major advances in science, technology, and innovation (STI); areas which may have significant impacts on improving current products and processes (Wang and Shapira 2011) and our way-of-life (Roco and Bainbridge 2005). Hence, the outcomes of nanotechnology and nanoscience (NN) deserve to be investigated through scientometric methods to help gain a better understanding of the global trends in NN research, as well as the resulting societal and economic implications (Soltani et al. 2011). The results of such studies

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can assist STI policy-makers with assessing their past policies, forecasting future trends based on the previous and contemporary trends, and take new valuable actions to succeed (Gorjiara and Baldock 2014).

So far, several studies have been conducted on evaluating the outputs of NN research and/or innovations of countries or regions, to gain a practical understanding of the trends and growth patterns in terms of different science or innovation indicators (e.g., Huang et al. 2005, 2011; Jiang et al. 2015; Karpagam et al. 2011; Liu et al. 2009).

Previous researchers (e.g., Guan and Liu 2014; Karpagam et al. 2011) focused on the science indicators from academic scientific publications, as these are considered to constitute the major source of knowledge production and transfer from academic research to industrial applications and developing innovations (Beise and Stahl 1999). Web of Science (WoS) bibliometric data are usually used for retrieving and analyzing academic research outputs (e.g., Chen et al. 2013; Gorjiara and Baldock 2014).

Patents, as tangible outputs of technological innovations, have been used as innovation and commercial technology development indicators (Jiang et al. 2015; Sastry et al. 2010). USPTO and EPO, granting numerous patents to applicants from different countries, are two important patent offices, and the information from their databases is hence highly valuable. An interesting trend is that the filing of nanotech patents has shown the fastest growth rate (GR) in the USPTO database since 2001, as compared to all other technological fields (Huang et al. 2005).

In summary, three types of scientometric and bibliometric studies on analyzing NN-related indicators in one or a group of nations, regions, or at global levels, as below, can be found in the literature:

1. Some studies have focused on the analysis of the status of STI through NN-related outputs based on scientific publications (e.g., Karpagam et al. 2011, analyzed the growth pattern of NN-literature in India during 1990–2009, and Guan and Liu 2014, comprehensively explored the scientific research profiles of nano-energy field during 1991–2012; etc.)

2. Some have analyzed NN trends based on patents (e.g., Jiang et al. 2015, tried to model knowledge-sharing and knowledge-transfer processes, examined their correlation, and evaluated the impacts of public funding using the information on patents filed in USPTO during the period of 1991–2010, and Li et al. 2007, evaluated the effectiveness of nanotechnology plans using the data on the patents file in USPTO, EPO, and Japan Patent Office (JPO) during 1976–2004, etc.).

3. Some other studies used the data on both scientific publications (as science indicators) and patents (as technology and innovation indicators) simultaneously (e.g., Chen et al. 2013, analyzed the global development in nanotechnology using longitudinal data related to scientific publications, patents, and NSF funding; Miyazaki and Islam 2007, using NN-related publications and patents, categorized countries into four types in terms of their innovative capabilities, etc.).

Some research explored causal effects of one or some variables on one or more other variables. For example, Jiang et al. (2015) studied the relationship between knowledge sharing and knowledge transfer and the effect of public funding on both of the mentioned variables in nanotech USPTO patents. Chen et al. (2013) presented a longitudinal analysis of the global nanotechnology development based on USPTO patents and WoS publications and identified the effect of basic research funded by NSF on both science and innovation indicators using bibliometric analyses and ANOVA test. They stressed the necessity of causal relationships among indicators. Accordingly, Reiss and Dominguez Lacasa (2008) compared the performance of European countries and USA in the area of biotechnology based on various science, technology, and commercialization indicators. They also analyzed the causal relationship among the indicators using correlation analyses. Also, Choi et al. (2015), using a model of measurement of university–industry–government relationship (Triple Helix Model), analyzed the status of scientific publications originating from different countries in a developmental context. They classified countries as developed and developing based on statistical analyses. Nonetheless, the literature contains few studies, if any, globally examining the NN-related indicators in a development context, also analyzing the causal relationship among the indicators.

Regarding the wide range of science and innovation output and the research gap in examining the causal effects among these indicators and different variables
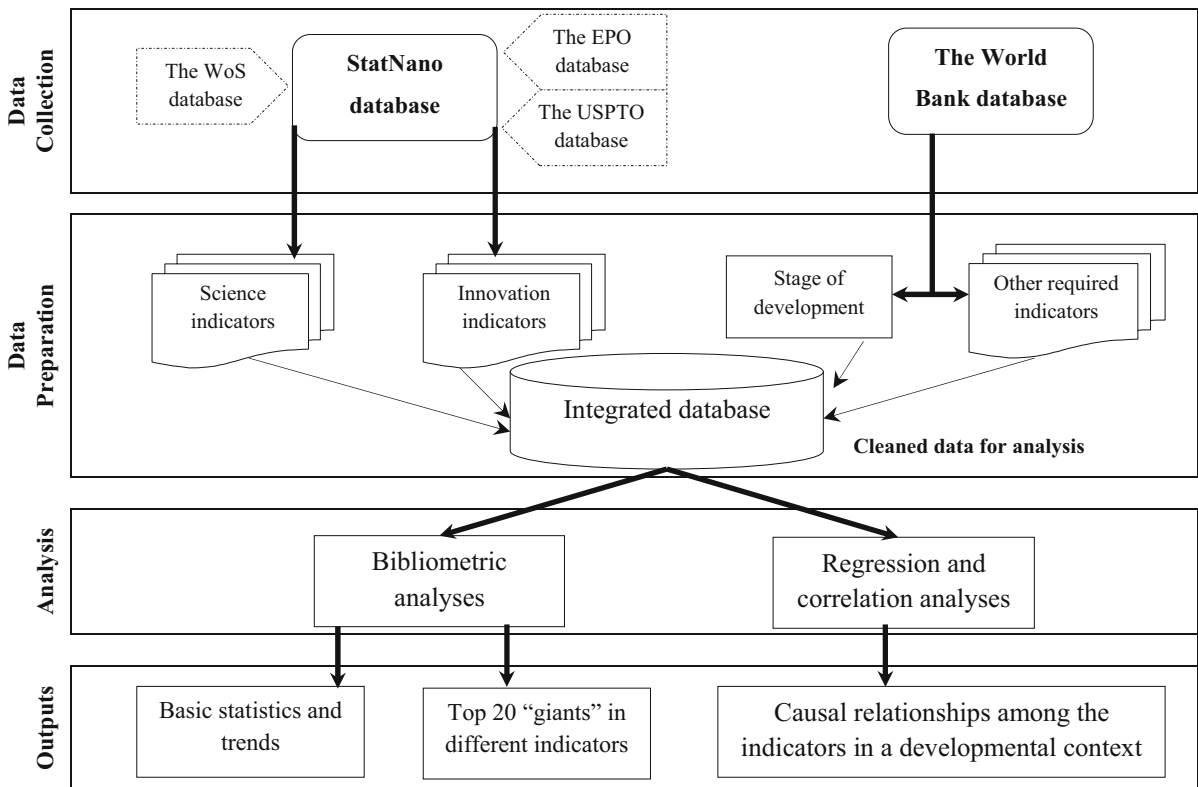
Fig. 1 Research framework

(such as population, stage of development, percentage of R&D expenditures, etc.) contributing in countries ranking in NN indicators, this study tended to analyze the NN outputs of 105 countries in a developmental context and explore the causal relationship among the known indicators and variables. Further, the study analyzed the trends of science and innovation outputs, and identified the top 20 science and innovation giants based on valid bibliometric indicators.

Research framework

As illustrated in Fig. 1, this research has a three-step framework, including data collection, preparation, and analysis.

Data collection

For the purpose of this research, the data on science and innovation indicators were obtained from WoS, USPTO, and EPO databases, through the online version of StatNano databases,[1] which retrieves patent data from USPO and EPO, the data on scientific publications from WoS databases, collectively. To assess the validity of the data, we compared the data on the top and lowest 10 countries in the final rank, with data directly obtained from WoS, USPTO, and EPO databases, using Maghrebi et al.'s (2011) search strategy for retrieving NN-related publications and patents. The comparisons revealed only a slight noncompliance of less than 0.01 in total. This was attributed to fact that the initial number of articles retrieved through search in the WoS is reported approximate.

Maghrebi et al.'s (2011) search string includes a comprehensive set of nano-related keywords as well as exclusion terms, for retrieving NN-related publications and patents. Hence all NN-related articles and patents, which containing the basic and conventional terms in this field, can be obtained from the databases (e.g., WoS, USPTO, etc.) using this search strategy. In

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[1] http://statnano.com/aboutus.

other words, the string covers all the basic concepts of nanotechnology, such as nanocomposite (e.g., used by Gholivand et al. 2016), quantum dot (e.g., used by Alibolandi et al. 2016), nanoparticle (e.g., used by Mottaghitalab et al. 2015), nanostructure and nanofluidic transport (e.g., used by Han et al. 2015), and so on. Search string used for retrieving NN-related publications and patents by Maghrebi et al. (2011) can be seen in Appendix.

Once the data acquired from StartNano was validated compared to the data that obtained from highly trusted WoS, USPTO and, and EPO, this database was used as the source of the data in this study, due to its better accessibility. Also, the World Bank data were used in the case of variables related to population, percentage of R&D expenditures, researchers in R&D, and the stage of the development of the countries.

In line with the previous related studies (e.g., Chen et al. 2013; Huang et al. 2005), in this research, longitudinal data were used for conducting a suitable analysis. Since this type of data is a powerful tool for finding the answers to questions on the changes in the trends of publications and patenting over time (French and Heagerty 2008), such data are also well suited for evaluating the dynamics of scientific outputs of countries.

Data preparation

After retrieving the research data, all NN-related records were exported to Excel 2010, where the data were prepared and refined for analysis based on the requirements and mathematical equations of the utilized indicators (which have been introduced in the next sections). The countries were classified as "developed" and "developing" in terms of the World Bank's GNI per capita data.[2] The GNI per capita data of 2013 were used because of the minimum missing values among the data on the other years. Countries with GNI per capita income of over 10,000 USD were classified as developed, a previously suggested by Choi et al. (2015), too. Finally, 52 developed and 53 developing countries were identified as contributors to NN-related indicators, and the corresponding required indicators were retrieved from the World Bank's databases.

Analysis

The data modified in Excel 2010 further exported to SPSS version 22 and subjected to bibliometric and statistical analyses using both software tools. The bibliometric indicators were used for identifying basic statistics and the trends of science and innovation indicators as well as ranking the top 20 countries as the "giants" in terms of each indicator. Finally, multiple regression analysis was used to explore the causal relationship among the indicators based on the countries' stage of development.

Science indicators

The growth in NN-related publications

Further to the GR, two parameters, namely the relative growth rate (RGR) and doubling time (D_t) as defined by Mahapatra (1985), are commonly used for measuring growth in the number of articles and patents in bibliometric studies (Bajwa et al. 2013; Gorjiara and Baldock 2014; Guan and Liu 2014; Karpagam et al. 2011). GR is the most basic parameter reflecting the percentage of growth from one period to another. RGR is a parameter used to further investigate the trend of growth of publications over time, and D_t is the time required for the number of publications to become twice as many as the existing number (Karpagam et al. 2011). RGR is calculated as the following (Bajwa et al. 2013):

$$\text{RGR} = \frac{(\ln N_2 - \ln N_1)}{T_2 - T_1}, \tag{1}$$

where N_2 and N_1 are the cumulative numbers of publications for years T_2 and T_1.

Since the current study calculates the RGR for successive years and given that $T_2 T_1 = 1$, Eq. (1) can be simplified as Eq. (2):

$$\text{RGR} = \ln N_2 - \ln N_1. \tag{2}$$

D_t, on the other hand, is calculated as Eq. (3) (Karpagam et al. 2011):

$$D_t = \frac{((T_2 - T_1) \times \ln 2))}{\ln N_2 - \ln N_1}; \text{ or}$$
$$D_t = \frac{\ln 2}{\text{RGR}}. \tag{3}$$

Table 1 The number of NN articles during 2000–2014

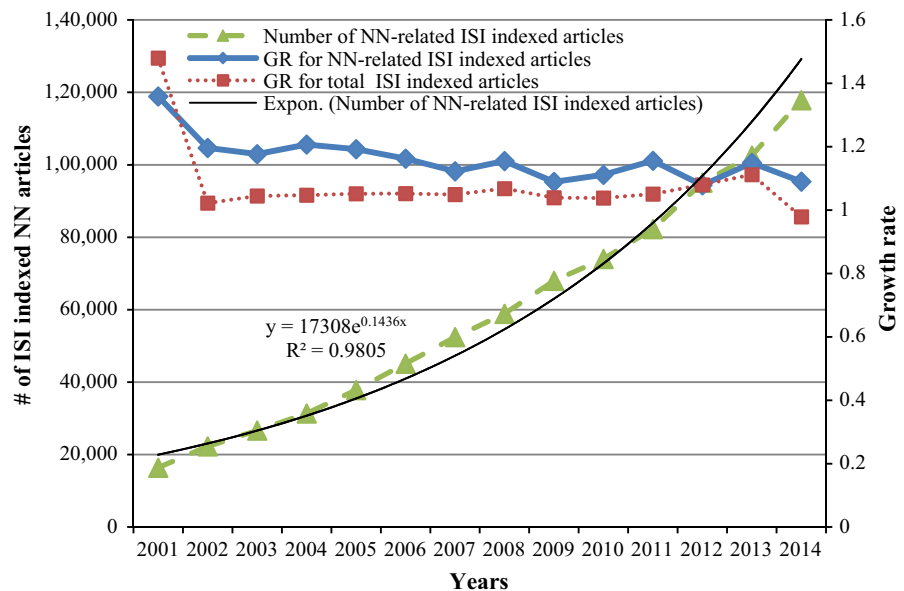| Year	No. of publications	Cumulative	GR	RGR	D_t
2000	16,397	16,397			
2001	22,276	38,673	1.36	0.86	0.81
2002	26,646	65,319	1.20	0.52	1.32
2003	31,354	96,673	1.18	0.39	1.77
2004	37,842	134,515	1.21	0.33	2.10
2005	45,114	179,629	1.19	0.29	2.40
2006	52,438	232,067	1.16	0.26	2.71
2007	58,863	290,930	1.12	0.23	3.07
2008	67,982	358,912	1.15	0.21	3.30
2009	74,033	432,945	1.09	0.19	3.70
2010	82,273	515,218	1.11	0.17	3.98
2011	95,078	610,296	1.16	0.17	4.09
2012	102,553	712,849	1.08	0.16	4.46
2013	117,832	830,681	1.15	0.15	4.53
2014	128,436	959,117	1.09	0.14	4.82

Table 1 shows the number of NN publications retrieved from WoS, as well as the cumulative number of NN publications, GR, RGR, and D_t of NN-articles per year during the period of 2000–2014. Figure 1 shows the chronological trend of NN-related articles and compares the GR of NN-related ISI-indexed articles and the total ISI-indexed articles in all fields. It can be seen that the GR value for NN-related scientific publications has always exceeded 1, as well as the GR of all other ISI-indexed articles (except for 2001). Although the trends of GR in both categories are descending, the GR of NN-related ISI-indexed articles has always been over 1, with negligible fluctuations, while that of the total ISI-indexed articles has been nearly fixed at 1 and even reached below 1 in 2014. The results show that only about 1.7 % of the total number of NN-articles have been published in 2000, while 2.73 % of total ISI articles indexed during 2000–2014 (in all fields) have been published in this year. Therefore, it can be inferred that because of the nature of nanotechnology as an emerging field, the percentage of the published NN articles in the first period is lower than that of other fields. This can be compared against the fact that only about 14, 31.1, and 54.9 % of the all NN articles were published in the first, second, and third 5 years, respectively.

Guan and Liu (2014) have reported similar results on articles in the area of nano-energy. Their study

showed that, of the papers published from 1991 to 2012, 55.02 % were published from 2008 to 2012. Also, D_t being the characteristic time of the exponential growth (Mahapatra 1985), a nearly constant RGR in the second half of the surveyed period revealed the growth pattern for publications to be exponential, which is similar the results on nano-energy fields in Gaun and Liu's (2014) study. The trend of NN-related articles in Fig. 2 verified the exponential nature of the growth pattern ($R^2 = 0.9805$). It can be inferred that NN-related research has passed through the preliminary phase with slow growth and is now almost at the end of the development period with a rapid one (Guan and Liu 2014). As shown in Fig. 2, the number of articles was below the exponential curve and because the distance of the curve was increasing in the last 5 years, it can be predicted that the next probable stage for NN-related publications will be characterized by a constant GR near to 1 or below. It is necessary to note that this prediction is indefinite and it can be changed by the emergence of new research fields or radical innovations in NN fields.

The results revealed the total ISI-indexed articles during 2000–2014, to be 15,302,849. The sum of the articles published by scholars of the developing and developed countries studied was 3,539,773 and 15,493,333, respectively. The fact that the total number of the articles published by scholars from the developed and developing countries is more than the total number of ISI-indexed is the joint publications and international collaboration of authors in published articles. It can be inferred that the shares of the developed and developing countries of the total number of ISI-indexed articles are 81.40 and 18.60 %, respectively (The "share of countries" refers to the percent ratio of their publications over the total global publications). It is interesting that about 6.27 % of the total ISI-indexed articles during 2000–2014 are related to nanotechnology. The total number of NN-related articles originating from developing and developed countries is 386,178 and 769,151, respectively, which leads to shares of 33.43 and 66.57 % for the two groups of countries, respectively. This also shows that the share of the developing countries in NN-related publications has been much more than their share in total ISI index publications. Although the share of the developed countries in NN-related publications has been nearly twice that of the developing countries, the share of the developed countries is

Fig. 2 The trend of GR and the number of NN-related articles and GR of the total ISI-indexed articles

The figure shows plotted data with legend: Number of NN-related ISI indexed articles; GR for NN-related ISI indexed articles; GR for total ISI indexed articles; Expon. (Number of NN-related ISI indexed articles).

$$y = 17308e^{0.1436x}$$
$$R^2 = 0.9805$$

three times more than that of the developing countries in the total ISI-indexed articles.

Table 2 shows the top 20 countries in terms of the number of NN articles and Fig. 3 shows the share and the number of articles originating from the top 20 countries, too. During the period under study, China and the USA took the leading positions in the publication of NN articles. The publications originating from the two countries accounted for more than 45 % of all articles published. Chinese scholars published the majority of these articles by publishing nearly one-fourth of the total NN-related articles worldwide. China and the USA were followed by Japan, Germany, South Korea, France, and India each with shares of above 5 %.

Examining the first GR (G1) for the top 20 countries (i.e., the ratio of the number of NN-articles in the second 5 years (2005–2009) to the same value in the first 5 years (2000–2004)) indicates that Iran, Taiwan, China, India, and Singapore are the five leading countries. Examining the second GR (G2) for these top 20 countries shows that the top five in terms of G2 are Iran, India, China, Australia, and Singapore. Regarding the total GR (i.e., the ratio of the number of NN-articles in the third 5 years, 2010–2014, to that in the first 5 years, 2000–2004), Iran, India, China, Singapore, and Australia are the top five. The total GR for Iran was the highest (140.5), dramatically raising its rank from 49 (with only 134 articles) in the first

5 years to 22 (with 3138 articles) in the second period, and to 8 (with 18,827 articles) in the third period. India's rank jumped from 11 in the first period to 6 in the third period of study. The high total GR of China (7.80) improved the rank of this country from second in the first and second 5 years to first in the third period and in the overall 15 year period. Singapore's rank improved from 21 in the first period to 16 in the third, and finally, Australia's rank changed from 19 to 15.

Table 3 shows the top 20 countries regarding other science indicators including the National Priority in Nanoscience Generation (NPIN), Local Share in Nanoscience Generation (LSIN), Number of Nano-articles Per Million people (NNPM), and the indicators related to the influence of scientific publication (citation-based indicators).

NPIN is defined as the percent ratio of a country's share in the total NN-articles over its share in the total ISI articles, in the same period. LSIN is also defined as the percentage of the total ISI-indexed NN-articles of a country over its total ISI-indexed articles. NPIN and LSIN are calculated using raw data retrieved from StatNano and WoS databases. Moldova ranked first in terms of these two indicators, and 18.13 % of the total ISI-indexed articles from this country are in the area of nanotechnology. The fact that in spite of using different equation formulas the ranking of all countries regarding the two indicators is the same, and is also interesting.

Table 2 The top 20 countries regarding the number of NN articles during 2000–2014

Rank in 2014	Country	Number of WoS scientific publications				Growth rate		Dg/Dd
		All years	2000–2004	2005–2009	2010–2014	G1	G2	
1	China	233,250	19,119	64,866	149,265	3.39	2.30	Dg
2	USA	201,203	33,585	67,572	100,046	2.01	1.48	Dd
6	Japan	81,516	18,355	28,954	34,207	1.58	1.18	Dd
5	Germany	74,411	14,515	24,500	35,396	1.69	1.44	Dd
4	South Korea	58,188	6173	17,633	34,382	2.86	1.95	Dd
8	France	50,540	9469	17,034	24,037	1.80	1.41	Dd
3	India	49,444	3727	12,518	33,199	3.36	2.65	Dg
9	UK	38,805	7243	12,801	18,761	1.77	1.47	Dd
12	Russia	32,916	7046	10,639	15,231	1.51	1.43	Dd
11	Italy	31,667	5251	10,080	16,336	1.92	1.62	Dd
10	Spain	30,058	3882	9392	16,784	2.42	1.79	Dd
13	Taiwan	28,361	2823	9680	15,858	3.43	1.64	Dg
15	Canada	24,218	3365	8017	12,836	2.38	1.60	Dd
7	Iran	22,099	134	3138	18,827	23.42	6.00	Dg
14	Australia	19,549	2019	5627	11,903	2.79	2.12	Dd
16	Singapore	16,423	1638	4988	9797	3.05	1.96	Dd
18	Poland	15,510	2695	5148	7667	1.91	1.49	Dd
20	Switzerland	14,875	2535	4764	7576	1.88	1.59	Dd
17	Brazil	14,384	2070	4309	8005	2.08	1.86	Dd
24	Netherlands	13,999	2587	4544	6868	1.76	1.51	Dd

Dg developing, *Dd* Developed

Fig. 3 The number and share of the top 20 countries in NN-related articles
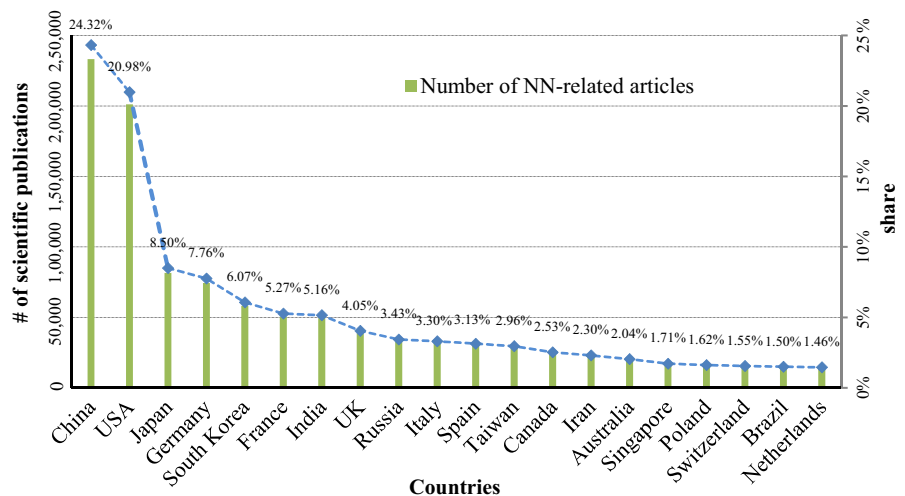
NNPM represents the number of nano-articles per million people. The average populations of countries (based on the World Bank data) during the periods under study were divided by 10^6 before use in the calculation of NNPM. The top five countries with regard to NNPM have been Singapore, Switzerland, Liechtenstein, Sweden, and Finland. The top 20 countries regarding this indicator have all been developed, and from the top 5 in terms of the number of NN-articles, only the first (i.e., China) is not in this

Table 3 The top 20 countries by other science indicators

Rank	NPIN	LSIN	NNPM	SIC	Citation-based indicators			
					TC	AC	H-index	H_m
1	Moldova (Dg, 2.89)	Moldova (Dg, 18.13 %)	Singapore (Dd, 3316.14)	Nepal (Dg, 95.02 %)	USA (Dd, 6,081,532)	USA (Dd, 30.23)	USA (Dd, 283)	Liechtenstein (Dd, 5.022)
2	North Korea (Dg, 2.44)	North Korea (Dg, 15.28 %)	Switzerland (Dd, 1910.21)	Iceland (Dg, 92.78 %)	China (Dg, 3,148,521)	Costa Rica (Dg, 29.69)	China (Dg, 166)	Uruguay (Dd, 4.005)
3	Singapore (Dd, 2.39)	Singapore (Dd, 14.99 %)	Liechtenstein (Dd, 1697.06)	Senegal (Dg, 91.54 %)	Germany (Dd, 1,637,105)	Netherlands (Dd, 29.13)	Germany (Dd, 150)	Netherlands (Dd, 2.174)
4	China (Dg, 2.27)	China (Dg, 14.21 %)	Sweden (Dd, 1306.18)	Qatar (Dd, 90.64 %)	Japan (Dd, 1,468,433)	Switzerland (Dd, 28.35)	Japan (Dd, 144)	USA (Dd, 2.140)
5	Iran (Dg, 2.05)	Iran (Dg, 12.84 %)	Finland (Dd, 1253.87)	Liechtenstein (Dd, 90.10 %)	France (Dd, 957,266)	UK (Dd, 23.43)	UK (Dd, 120)	Switzerland (Dd, 1.907)
6	Belarus (Dg, 1.99)	Belarus (Dg, 12.46 %)	Ireland (Dd, 1190.53)	Philippines (Dd, 88.65 %)	UK (Dd, 909,270)	Denmark (Dd, 22.94)	France (Dd, 112)	Singapore (Dd, 1.792)
7	South Korea (Dg, 1.93)	South Korea (Dd, 12.07 %)	South Korea (Dd, 1180.10)	Peru (Dg, 86.78 %)	South Korea (Dd, 872,617)	Austria (Dd, 22.88)	South Korea (Dd, 112)	Austria (Dd, 1.776)
8	Ukraine (Dg, 1.69)	Ukraine (Dg, 10.58 %)	Slovenia (Dd, 1092.36)	Cuba (Dg, 85.19 %)	India (Dg, 536,677)	Germany (Dd, 22.00)	Netherlands (Dd, 99)	UK (Dd, 1.752)
9	Liechtenstein (Dd, 1.64)	Liechtenstein (Dd, 10.30 %)	Denmark (Dd, 1055.03)	Indonesia (Dg, 84.90 %)	Spain (Dd, 532,067)	Singapore (Dd, 21.93)	Canada (Dd, 96)	Denmark (Dd, 1.745)
10	Iraq (Dg, 1.60)	Iraq (Dg, 10.04 %)	Belgium (Dd, 959.56)	Lebanon (Dg, 84.84 %)	Italy (Dd, 529,395)	Sweden (Dd, 20.92)	Spain (Dd, 93)	Peru (Dg, 1.712)
11	India (Dg, 1.60)	India (Dg, 10.01 %)	Germany (Dd, 909.56)	Luxembourg (Dd, 82.22 %)	Canada (Dd, 494,141)	Canada (Dd, 20.40)	Italy (Dd, 92)	Canada (Dd, 1.693)
12	Saudi Arabia (Dd, 1.58)	Saudi Arabia (Dd, 9.92 %)	Australia (Dd, 890.43)	Oman (Dg, 82.19 %)	Switzerland (Dd, 421,760)	Ireland (Dd, 20.28)	Switzerland (Dd, 89)	Germany (Dd, 1.688)
13	Taiwan (Dg, 1.56)	Taiwan (Dg, 9.78 %)	Austria (Dd, 859.24)	Cyprus (Dd, 81.20 %)	Netherlands (Dd, 407,801)	Belgium (Dd, 19.57)	Singapore (Dd, 87)	Sweden (Dd, 1.670)
14	Bahrain (Dd, 1.55)	Bahrain (Dd, 9.70 %)	Netherlands (Dd, 844.54)	Saudi Arabia (Dd, 79.72 %)	Taiwan (Dg, 383,644)	Peru (Dg, 19.08)	Taiwan (Dd, 83)	Costa Rica (Dg, 1.645)
15	Romania (Dg, 1.54)	Romania (Dg, 9.68 %)	France (Dd, 779.61)	Uzbekistan (Dg, 79.06 %)	Australia (Dd, 367,274)	France (Dd, 18.94)	India (Dg, 82)	Ireland (Dd, 1.619)

Table 3 continued

Rank	NPIN	LSIN	NNPM	SIC	Citation-based indicators			
					TC	AC	H-index	H_m
16	Malaysia (Dd, 1.53)	Malaysia (Dd, 9.61 %)	Iceland (Dd, 738.33)	Bangladesh (Dg, 78.62 %)	Singapore (Dd, 360,197)	Australia (Dd, 18.79)	Australia (Dd, 81)	Finland (Dd, 1.591)
17	Latvia (Dd, 1.46)	Latvia (Dd, 9.13 %)	Canada (Dd, 714.28)	Nigeria (Dg, 77.39 %)	Russia (Dd, 309,558)	Japan (Dd, 18.01)	Sweden (Dd, 72)	Greece (Dd, 1.581)
18	Tajikistan (Dg, 1.43)	Tajikistan (Dg, 8.94 %)	Spain (Dd, 660.07)	Jordan (Dg, 77.19 %)	Sweden (Dd, 255,177)	Finland (Dd, 17.73)	Russia (Dd, 65)	Belgium (Dd, 1.581)
19	Russia (Dd, 1.34)	Russia (Dd, 8.42 %)	USA (Dd, 654.141)	Chile (Dd, 76.52 %)	Belgium (Dd, 204,095)	Spain (Dd, 17.70)	Belgium (Dd, 64)	Japan (Dd, 1.563)
20	Vietnam (Dg, 1.30)	Vietnam (Dg, 8.12 %)	Japan (Dd, 638.91)	North Korea (Dg, 75.76 %)	Brazil (Dd, 165,225)	Estonia (Dd, 16.99)	Austria (Dd, 62)	Australia (Dd, 1.556)

list. It is interesting to know that China with 174.81 nano-articles per million people ranked 45 concerning this indicator. There is a huge difference between NNPM in the two categories of developed and developing countries, with the total NNPM being 509.13 and 86.69 for the developed and developing countries, respectively. This means that approximately 510 and 87 articles per million people have been published in the 52 developed and 53 developing countries.

The share (percentage) of international collaborations in NN-related publications (SIC) has been equal to the share of "collaborative nano-articles," resulting from international collaborations. SIC is calculated by dividing the number of collaborative articles by authors from a country and other countries by the total NN-related articles from the country. The average number of the NN articles originating from the top five economies in terms of this indicator has been only 136.6 during the 15-year period (i.e., 9.10 articles per year per country). This shows that the top countries in terms of this indicator had a poor performance in NN-publications. Probably, most of their NN articles were the result of collaborative research by their academics and students with foreign colleagues. The top countries regarding this indicator did, hence, not have a suitable position based on other NN-related indicators.

The average of SIC for developed and developing countries is 0.62 and 0.58, respectively. The average of SIC for the top 20 countries in terms of the NN-related publications has been 0.44. The status of the developing and developed countries in terms of this indicator is very different. Iran, China, Taiwan, and India (four developing economies which are among the top 20 giants in NN-publications) with SIC from 0.18 to 0.25 are respectively in ranks 20 to 17 regarding this indicator. The average SIC for the other top 16 giants, which are all developed countries, was found to be 0.50. Switzerland and Japan have the highest (0.65) and lowest (0.31) SICs among the 16 countries, respectively.

Indicators related to the influence of NN-publications

In addition to the above-mentioned indicators, Table 3 shows citation-based indicators, which are suitable for analyzing the influence and quality of publications

(Bajwa et al. 2013; Bassecoulard et al. 2007; Guan and Liu 2014). In this paper, the total number of citations to nano-articles (TC), the average citation per NN-published article (AC), the H-index, and Hm is used.

Hirsch (2005) defined the H-index as the number of papers which have been cited more than or equal to h times, as a useful index to characterize the scientific publications. Although the advantage of H-index is considering the quality and quantity of research publications, it suffers the weakness of being dependent on the number of articles, which means countries/institutes with high numbers of articles shall probably have high H-index. Clearly, the H-index can be prone to misinterpretation, since a high h may not reflect high quality, but can also be the result of high number of publications (Molinari and Molinari 2008a). Thus, for normalizing the H-index values in terms of the number of articles, and gaining a better understanding of the quality of research publications of institutions, universities, countries, and journals, H_{m} was defined by Molinari and Molinari (2008a, b) as:

$$H_{\mathrm{m}} = \frac{H_i}{TN_i^{\beta}}, \tag{4}$$

where H_i is H-index of institution i, and TN_i reflects the total number of articles of the institution/country in a certain field. Molinari and Molinari (2008a, b) mathematically proved that a suitable value for β is 0.4, which allows to correct the size effect of institution's/country's publications. In this study, this parameter was calculated as follows:

$$H_{\mathrm{m}} = \frac{H_i}{TN_i^{0.4}}. \tag{5}$$

The results show USA as having a supreme rank in citation-based indicators as compared with the other top 19 giants. Some of the top 20 are very far from the number of NN articles anticipated for them. For example China's ranks in AC and H_{m} are 33 and 53, respectively. Some countries, which previously had lower status regarding the number of NN articles, were found to be among the top 20 in terms of these two indicators. For example, Costa Rica, Liechtenstein, Uruguay, and Peru appeared among the top 20 regarding these indicators, although, during 2000–2014, only 70, 61, 130, and 210 NN articles originated from these countries, respectively. The high

average citations to their publications have probably been the result of the quality of their articles and joint publications with world class researchers.

However, as mentioned earlier, although 4 developing countries have been among the top 20 giants, in terms of the number of publication, none of them has been among the top 20 regarding AC and H_{m}. This can be the result of lack of sufficient focus on the quality of the articles, obsession with the quantity of articles in their domestic science and technology policies, or that these articles have not attracted scholars for citing them, etc. (further research using citation analysis methods can help investigate the underlying reasons to this phenomenon). Although one cannot conclude that the quality of NN articles originating from these developing countries is necessarily not up to standard (given that a portion of these articles enjoy high H-index and TC values), given that some of the countries are even among the top 20 regarding these citation-based indicators, their policy makers and researchers might be able to propose proper reasons for the obtained results.

Innovation indicators

As nanotechnology patents are among the tangible outputs of technological innovation, these documents have been taken into consideration in a number of previous studies (e.g., Jiang et al. 2015; Sastry et al. 2010) as well as the current one.

Table 4 shows number, cumulative number, GR, RGR, and D_{t} of technological innovations (NN-related patents granted in USPTO and EPO) during the period of 2000–2014. The results show that 16.7, 26.8, and 56.5 % of nanotechnology patents were issued during the first, second, and third 5 year periods, respectively. It also indicates a similar result to that of NN-related publication since over half of the patents were issued in the last 5 years (2010–2014). A nearly constant RGR for patents during the last years (as described in the case of NN-articles) demonstrates the exponential growth pattern in the number of patents, as illustrated in Fig. 4 ($R^2 = 0.9793$). The figure also helps compare the trends of NN-related scientific and innovation outputs. It can be seen that the GRs for both patents and scientific publications are almost similar, while the number of nanotech patents is nearly one-fifth of the number of NN-related articles. In other words, the

Table 4 The number of NN patents during 2000–2014

Year	Innovation output	Cumulative	GR	RGR	D_t
2000	4794	4794			
2001	5772	10,566	1.20	0.79	0.88
2002	6755	17,321	1.17	0.49	1.40
2003	7938	25,259	1.18	0.38	1.84
2004	8514	33,773	1.07	0.29	2.39
2005	7909	41,682	0.93	0.21	3.29
2006	10,571	52,253	1.34	0.23	3.07
2007	10,937	63,190	1.03	0.19	3.65
2008	11,631	74,821	1.06	0.17	4.10
2009	13,098	87,919	1.13	0.16	4.30
2010	17,858	105,777	1.36	0.18	3.75
2011	19,376	125,153	1.09	0.17	4.12
2012	22,064	147,217	1.14	0.16	4.27
2013	26,001	173,218	1.18	0.16	4.26
2014	29,084	202,302	1.12	0.16	4.47

Innovation output is equal to the total patents indexed in USPTO and EPO

cumulative number of patents and articles shows that on average 0.21 patents have been granted in EPO and USPTO, per each article. The ratios of the total number of patents to NN articles have been 0.25, 0.18, and 0.22 during the first, second, and third 5-year periods, respectively. The ratios have been 0.24 and 0.02 for the developed and developing countries, respectively.

Inventors from the developed and developing countries received grants for 195,185, and 7954 of their nanotechnology patents, respectively, which

reveals the shares of inventors from of these two categories to be 96.08 and 3.91 % during 2000–2014.

Tables 5 and 6 show the top 20 countries in terms of the number of nanotechnology patents granted in USPTO and EPO, respectively. It should be noted that 164,634 (81.38 %) and 37,668 (18.62 %) of the total nanotechnology patents were issued in USPTO and EPO, respectively. As shown in Fig. 5, during the entire 15-year period covered, the USA was the top "giant" regarding this indicator, having issued the highest number of nanotech patents (115,043; 56.87 %), followed by Japan (with 28,063; 13.87 %), Germany (12,824; 6.34 %), France (7918; 6.34 %), and South Korea (6941; 3.43 %). Taiwan and China have been the only developing economies among the top 20 in terms of the number of nanotech patents and all other 18 countries were developed. In terms of the total GR of the number of nanotechnology patents issued by both patent offices during the second 5 years as opposed to the first 5 years, the top 5 countries have been China (with GR1 = 8.62), South Korea (4.58), Taiwan (3.58), Singapore (3.01), and the Netherlands (2.80).

The top five countries regarding the second GR (G2) have been China (5.93), South Korea (3.06), Denmark (3.06), Singapore (2.83), and Taiwan (2.75), while in terms of the total GR (the ratio of the number of patents in the third to that of the first 5 years) the top five countries have been China, South Korea, Taiwan, Singapore, and Denmark.

Concerning the number of nanotech patents among the top five countries, only South Korea was among the top 5 in terms of the first and second GRs. So, regarding the share of the countries of the total number

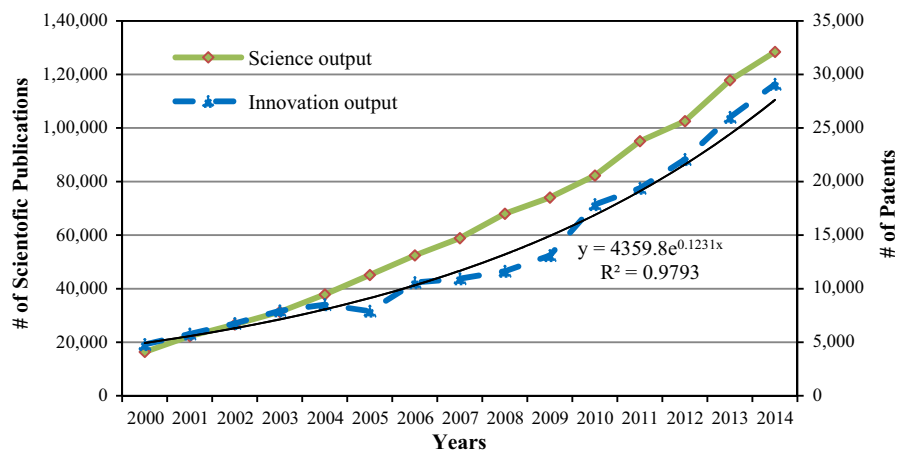**Fig. 4** The trend of NN-related outputs

$$y = 4359.8e^{0.1231x}$$
$$R^2 = 0.9793$$

Table 5 The top 20 countries by the number of nanotechnology USPTO patents

Rank in 2014	Country	Number of USPTO patents				Growth rate		Dd/Dg
		All years	2000–2004	2005–2009	2010–2014	G1	G2	
1	USA	101,307	19,366	27,667	54,274	1.43	1.96	Dd
2	Japan	23,350	3527	5857	13,966	1.66	2.38	Dd
4	Germany	6677	1102	1662	3913	1.51	2.35	Dd
3	South Korea	6144	338	1387	4419	4.10	3.19	Dd
5	Taiwan	5033	353	1252	3428	3.55	2.74	Dg
6	France	4403	930	982	2491	1.06	2.54	Dd
8	Netherlands	3013	271	836	1906	3.08	2.28	Dd
11	Canada	2028	478	467	1083	.98	2.32	Dd
7	China	1899	32	271	1596	8.47	5.89	Dg
9	UK	1838	327	394	1117	1.20	2.84	Dd
16	Australia	1586	285	622	679	2.18	1.09	Dd
10	Switzerland	1549	202	300	1047	1.49	3.49	Dd
13	Belgium	795	109	196	490	1.80	2.50	Dd
12	Singapore	735	67	175	493	2.61	2.82	Dd
14	Sweden	735	137	183	415	1.34	2.27	Dd
15	Italy	709	142	166	401	1.17	2.42	Dd
17	Denmark	411	50	85	276	1.70	3.25	Dd
19	Finland	396	71	85	240	1.20	2.82	Dd
20	Ireland	330	45	65	220	1.44	3.38	Dd
17	India	301	34	71	196	2.09	2.76	Dg

of patents granted by EPO and USPTO, a decrease can be predicted in the gap between South Korea and the higher ranking countries. Regarding the fact that half of the total patents have been granted by both patent offices, the USA is the undisputed first rank. Furthermore, the high GR values of the top countries during the first, and second periods as well as their total GRs reveal that their high ranks cannot be accidental, and that at least the top 5 have been improving their status in innovative outputs through intelligent and planned policies.

Figure 6 shows the trend of global GR and GR of the developed and developing countries for nanotech patents to be different from those of NN publications. It can be seen, as expected, that the curves showing the trends of global GR and GR of developed countries overlapped. This shows that the global GR is only affected by the GR of the developed countries because most of the patents belong to assignees from these countries. It is necessary to note that of the total number of patents of developing countries 90.60 % is granted to Taiwanese and Chinese applicants. So, the

trend of GRs for developing countries almost overlaps with the trend of their overall GR for patents. As it was expected based on the top rank of these two countries, the GR curve of the developing countries is almost over that of the total GR throughout the overall period.

Causal relationship analysis

Regarding the very small number of patents and articles originating from some countries and the huge gap between them and other countries, and in order to prevent the errors caused in the results of causal relationships, only the top 20 developed and top 20 developing countries were analyzed, which means the data of a sum of 40 countries were entered into regression and correlation analyses in order to achieve robust and reliable results.

It is interesting to note that, respectively, 756,203 (98.32 %) and 192,108 (98.42 %) of the total articles and patents originating from the developed countries were the result of collaborations among the selected top 20 developed countries. The top 20 developing

Table 6 The top 20 countries by the number of nanotechnology EPO patents

| Rank in 2014	Country	Number of USPTO patents				Growth rate		Dd/Dg
		All years	2000–2004	2005–2009	2010–2014	G1	G2	
1	USA	13,736	2553	4122	7061	1.61	1.71	Dd
2	Germany	6147	858	1913	3376	2.23	1.76	Dd
3	Japan	4713	631	1269	2813	2.01	2.22	Dd
4	France	3515	716	1026	1773	1.43	1.73	Dd
5	Switzerland	1657	237	512	908	2.16	1.77	Dd
6	Netherlands	1448	178	420	850	2.36	2.02	Dd
7	UK	1341	241	403	697	1.67	1.73	Dd
8	South Korea	797	16	236	545	14.75	2.31	Dd
10	Italy	705	92	235	378	2.55	1.61	Dd
9	Belgium	645	61	196	388	3.21	1.98	Dd
11	Canada	524	106	174	244	1.64	1.40	Dd
12	Sweden	472	79	138	255	1.75	1.85	Dd
15	Denmark	355	22	86	247	3.91	2.87	Dd
13	Austria	339	66	85	188	1.29	2.21	Dd
16	Australia	252	24	72	156	3.00	2.17	Dd
17	Finland	232	35	79	118	2.26	1.49	Dd
17	Spain	199	19	57	123	3.00	2.16	Dd
19	Ireland	183	26	60	97	2.31	1.62	Dd
14	China	166	2	22	142	11.00	6.45	Dg
24	Norway	136	28	47	61	1.68	1.30	Dd
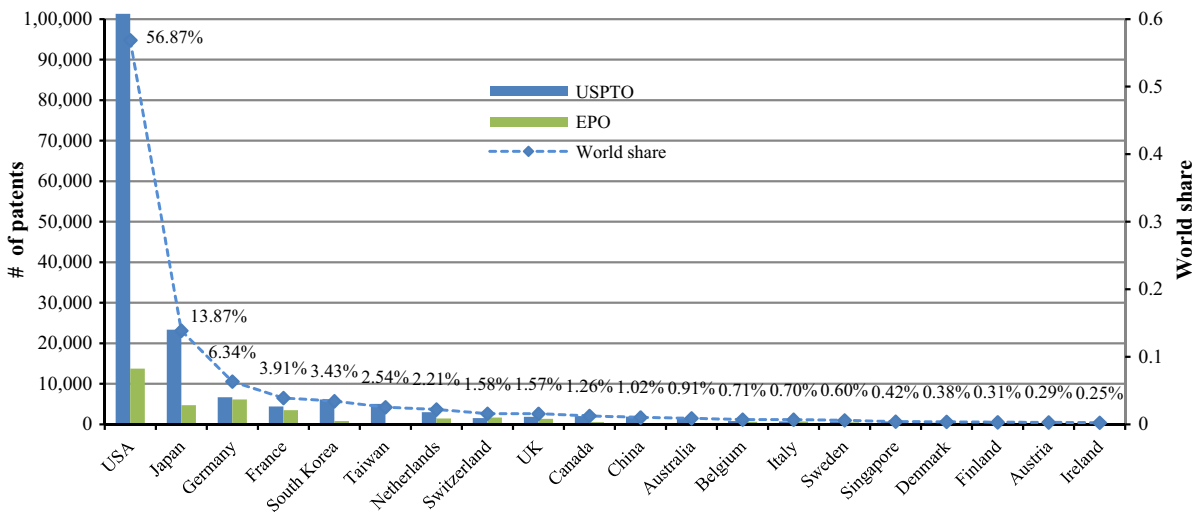
Fig. 5 The number of USPTO patents, EPO patents, and world share for the top 20 countries

countries studied were found to have collaborated in about 380,691 (98.58 %) and 7927 (99.66 %) of the total articles and patents originating from the developing countries, respectively. So, the share of the studied countries is over 98 % of the total number of articles and patents originating from both the

Fig. 6 The growth trend of innovation output
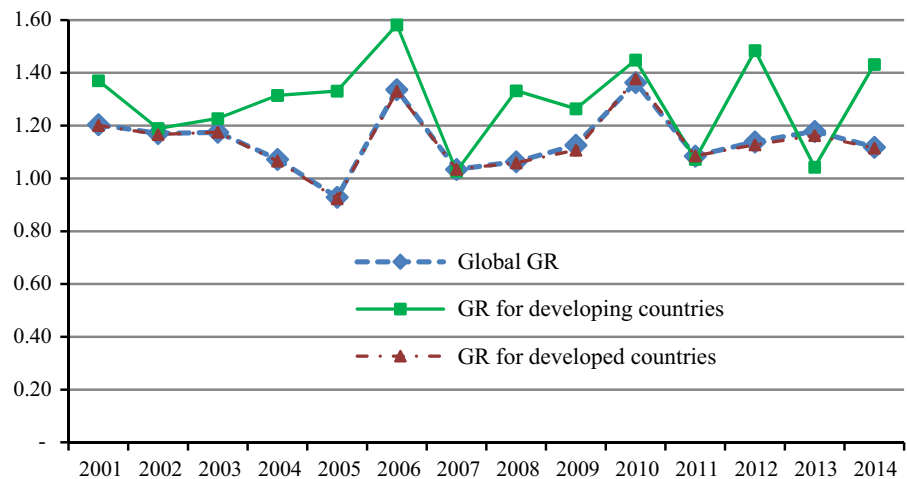
Table 7 Results of regression of the estimation of innovation (number of granted patents)

Model	All countries	Developing countries	Developed countries
Constant	0.78 (0.28)	119.38 (2.80)*	2162.26 (1.75)
Scientific publication	0.17 (19.19)**	0.03 (19.10)**	0.30 (13.21)**
Number of years	15	15	15
F	368.37**	364.89**	174.60**
Adj. R^2	0.96	0.96	0.93

Figures in parentheses are t values

* Significant at 5 % level

** Significant at 1 % level

developed and developing countries. About 30 other countries in both categories were found to have collaborated in only less than 2 % of science and innovation output.

It is expected that patents and publications (being the tangible outputs of innovative and research activities, respectively) grow hand in hand (Geuna and Nesta 2006; Grimm and Jaenicke 2015). Table 7 shows the results of regression of these two outputs form all of the selected countries during 2000–2014. Three models were used for all the selected 40 (the top 20 developed, and developing countries).

As can be observed, the F-value of the regression in all cases is significant at the 1 % level, which shows the independent variable to be valid for predicting the dependent variable in all the 3 models. More than 90 % of all variations in the dependent variable (innovation output) are due to the independent variables (publications) in the regression models (the values of Adj. R^2 in all cases are more than 0.90). Although innovation can be estimated in all cases and all models are significant at the 1 % level, the coefficient associated with the developing countries is much lower than that of the developed. This result was expected because of the very low ratio of patents to articles (0.02) for the developing countries.

Tables 8 and 9 present the multiple regression models for estimating the number of NN scientific publications and patents in terms of countries' stage of development. For a better understanding of the trend of changes in the relationship among the variables, the results have been presented based on longitudinal data in three 5-year periods.

Population, the number of R&D workers per million people, the percentage of R&D expenditure from GDP, and the share of international collaborations (SIC) in NN-related publications were used as the common predictors in the two tables. Additionally,

Table 8 Results of regression on the estimates of NN publications

Model	All countries			Developing countries			Developed countries		
	2000–2004	2005–2009	2010–2014	2000–2004	2005–2009	2010–201	2000–2004	2005–2009	2010–2014
Constant	5036.38 (1.25)	5365.91	6767.95	1839.92	6611.42	8614.26	7523.39	16744.76	27422.39
		(0.62)	(0.50)	(0.62)	(0.61)	(0.43)	(0.94)	(1.46)	(1.76)
Population	1.00E5	3.11E5	6.58E5	9.27E6	2.93E5	5.26E	8.70E5	0.00	0.00
	(2.84)**	(3.78)**	(5.12)**	(4.17)**	(3.27)**	5 (2.20)*	(4.51)**	(5.56)**	(5.90)**
Researchers in R&D	2.09	2.30	1.05	1.30	4.16	6.16	1.40	2.85	4.28 (1.60)
	(1.75)	(0.91)	(0.29)	(0.75)	(0.65)	(0.43)	(1.22)	(1.35)	
% R&D expenditure	17.62	2574.70	8698.36	1979.36	7154.42	38343.70	1784.30	2733.15	3917.95
	(.01)	(0.59)	(1.35)	(0.66)	(0.65)	(1.94)	(0.91)	(0.78)	(0.87)
SIC	11159.06	16418.23	26150.34	177.16	1004.93	13947.67	526.50	4055.27	10484.66
	(1.90)	(1.26)	(1.21)	(0.05)	(0.07)	(0.46)	(0.04)	(0.23)	(0.43)
No. of countries	38	37	37	18	17	17	20	20	20
F	9.62**	11.39**	17.35**	9.80**	9.43**	13.21**	14.78**	14.28**	14.16**
Adj. R^2	0.48	0.54	0.64	0.67	0.68	0.75	0.74	0.74	0.74

Figures in parentheses are t values

* Significant at 5 % level

** Significant at 1 % level

Table 9 Results of regression on the estimates of the number of innovation output (patents)

Model	All countries			Developing countries			Developed countries		
	2000–2004	2005–2009	2010–2014	2000–2004	2005–2009	2010–2014	2000–2004	2005–2009	2010–2014
Constant	1115.92	3381.11	11013.37	17.58	16.43	96.74	7943.66	5976.83	8410.83
	(0.67)	(0.89)	(1.16)	(2.14)	(0.47)	(0.83)	(1.93)	(1.23)	(1.01)
# of articles	0.53	0.37	0.33	0.00	0.00	0.01	0.34	0.34	0.43
	(8.15)**	(6.56)**	(3.82)**	(0.90)	(8.76)**	(22.68)**	(2.97)*	(4.01)**	(3.97)**
Population	4.40E6	8.62E6	1.61E5	3.03E8	5.27E8	6.30E9	2.42E5	1.94E5	4.47E5
	(3.05)**	(2.63)*	(1.83)	(4.08)**	(4.36)**	(0.20)	(1.88)	(1.10)	(1.51)
Researchers in R&D	0.02	0.39	1.77	0.00	0.00	0.04	0.41	0.26	1.00
	(0.04)	(0.44)	(0.82)	(1.06)	(0.02)	(1.66)	(0.77)	(0.35)	(0.68)
% R&D expenditure	1570.99	1229.11	2925.96	14.86	8.65	82.51	1140.68	428.41	476.77
	(1.89)	(0.85)	(0.86)	(2.25)*	(0.55)	(2.05)	(1.15)	(0.39)	(0.26)
SIC	210.84	2680.99	11828.24	17.23	10.56	12.48	2624.62	1326.90	9269.30
	(0.09)	(0.58)	(0.91)	(2.12)	(0.51)	(0.18)	(0.42)	(0.21)	(0.65)
Citation per article	88.36	42.00	282.58	0.17	0.19	15.15	143.07	176.64	1083.70
	(2.41)*	(0.41)	(0.31)	(0.84)	(0.19)	(0.98)	(2.63)*	(1.88)	(1.71)
NPIN	310.35	3007.40	7239.06	0.41	0.29	165.97	187.49	1100.42	5084.35
	(0.71)	(1.91)	(1.79)	(0.27)	(0.02)	(5.07)**	(0.18)	(0.71)	(1.52)
No. of countries	38	34	34	18	14	14	20	20	20
F	17.11**	9.76**	4.27**	11.19**	192.18**	725.85**	20.85**	23.23**	26.73**
Adj.R^2	0.75	0.65	0.41	0.81	0.99	1.00	0.88	0.89	0.91

Figures in parentheses are t values

* Significant at 5 % level

** Significant at 1 % level

the number of articles, citation per article, and NPIN are used in Table 9 for estimating countries' number of patents.

As can be observed, the F-value of all regression models is significant at the 1 % level, which reveals that the independent variables are valid for predicting the dependent variables in all models. About more than 50 % of all variations in the dependent variables are explained by the independent variables used in the regression models (Adj. R^2 in Tables 8 and 9).

Table 8 indicates the only statistically significant coefficient during all periods and for all regression models is the population of the countries. One of the significant points that can be concluded from these results is that the population coefficient associated with developed countries is near to zero and lower than that of the developing countries. This implies that the number of NN-related publications originating from the developing countries is more population dependent.

Table 9 shows rather different results. The interesting result is that the significant coefficient values for developed countries are almost contrary to those of developing countries. While the population coefficient for the developed countries has not been significant, this coefficient has been significant during the first and second 5 years for the developing countries. Furthermore, the coefficients associated with "the number of articles" in the case of the developing countries have been lower than those of the developed, which is in line with the previous results (Table 7). For more comprehensive understanding and analyses, the other

results that can be inferred from Tables 8 and 9 will be discussed, after discussing correlation analysis.

Tables 10 and 11 show how science and innovation indicators are linearly related in the case of the developed and developing countries. Since the distribution of the data is not normal, the "Spearman coefficient," (a nonparametric version of the "Pearson correlation") has been used to determine the significance of the correlation among the indicators. Spearman's coefficient is based on the ranks of data rather than the actual values (Hollander et al. 2013).

There is an extremely negative correlation between SIC and the number of both patents and articles in the developing countries. It indicates that the high rankings of some developing countries in terms of their SIC on NN-related research projects (and the corresponding publications) have probably originated from their interest in collaborative work due to their inferior R&D infrastructures and capabilities. Hence, these collaborations do not have an effect on improving innovation (patents).

The existence of an extremely positive correlation among the citation-based indicators (H-index and citation per article) and the number of patents in both the developed and developing countries implies the importance of the effect of the quality of research on the countries' ranking in terms of NN innovation. Thus, countries with a higher number of quality papers (indicated by citation-based indicators) ranked higher than those of others in the number of patents.

There is no significant correlation among the NPIN and any other indicators in the developing countries.

Table 10 Correlation among the indicators for the top 20 developed countries

Indicators	1	2	3	4	5	6	7	8	9
No. of articles (1)									
No. of USPTO patents (2)	.646**								
No. of EPO patents (3)	.588**	.901**							
NPIN (4)	.423	.092	.097						
Average population (5)	.603**	.160	.158	.006					
% R&D expenditure (of GDP) (6)	.235	.689**	.641**	.264	.253				
Researcher in R&D (7)	.298	.627**	.412	.273	.287	.776**			
SIC (8)	.408	.048	.215	.210	.662**	.290	.131		
H-index (9)	.821**	.890**	.865**	.175	.288	.482*	.469*	.035	
citation per article (10)	.027	.457*	.460*	.163	.504*	.461*	.484*	.621**	.390

* Significant at 5 % level

** Significant at 1 % level

Table 11 Correlation between indicators for the top 20 developing countries

Indicators	1	2	3	4	5	6	7	8	9
No. of articles (1)									
No. of USPTO patents (2)	.825**								
No. of EPO patents (3)	.768**	.837**							
NPIN (4)	.362	.348	.453						
Average population (5)	.639**	.512*	.452	.065					
% R&D expenditure (of GDP) (6)	.346	.334	.293	.181	.072				
Researcher in R&D (7)	.028	.175	.238	.252	.540*	.587*			
SIC (8)	.878**	.702**	.688**	.322	.561*	.267	.060		
H-index (9)	.966**	.867**	.797**	.420	.690**	.210	.063	.883**	
citation per article (10)	.389	.825**	.596*	.218	.298	.073	.108	.396	.509*

* Significant at 5 % level

** Significant at 1 % level

One of the interesting results that can be inferred from correlations among NPIN and other indicators in Table 9 is the negative relationship among the NPIN and the number of patents in the developing countries during 2010–2014. By focusing on the content of Table 3 and this result, it can be inferred that some of developing countries with high ranks in terms of their share of NN-related articles and NPIN had unfavorable positions in terms of the number of patents, resulting in negative regression coefficients for the developing countries.

Probably, the reason for the weakness of some of these countries in innovation indicators is related to insufficient attention to other technological fields. This conclusion is based on the multidisciplinary nature of STI in this era. Thus, there is a need to coherently and systematically pay attention to all emerging and fundamental fields. On the other hand, another situation might stem from the lack of funds for filing patents in USPTO or EPO in the developing countries. Therefore, this aspect can be improved only if the local patent data base of the developing countries is considered and used in the statistical evaluation of various aspects of inventions and transfer technologies.

Exploring the reasons behind these results can be the subject of various detailed research, with a focus on the top ranking countries in terms of NPIN, which have a relatively low number of patents.

No significant correlations were found among the percentage of R&D expenditure and any NN-related indicators in developing countries. This shows that using these expenditures in these countries has probably been not productive. On the other hand, there is an extremely positive correlation among this indicator and the number of both patents and citation-based indicators. The similar results about the correlation among the number of R&D workers and science and innovation indicators can be observed in Tables 10 and 11.

It is clear that, with the developed countries, there is a good status and higher productivity regarding value creation from R&D expenditures. Moreover, the developed countries used their NN-related research capabilities more efficiently. So, it can be inferred that mere increases in the amount of R&D expenditure and the number of R&D workers in these countries cannot lead to innovations because this is more dependent on the effective use of the financial and intellectual properties through robust and supportive structures.

Conclusions and further research

This study aimed at identifying a comprehensive global pattern of NN-related indicators in a developmental context by analyzing the longitudinal data of the past 15 years (as longitudinal data are powerful tools for showing the trend of changes in publications and patenting over time). Although there are numerous researches on the bibliometric analysis of NN-related scientific publications and patents, the literature lacks

research examining the indicators in a developmental context and analyses the causal relationships among the indicators. The present study is a first step toward filling these research gaps by discovering the presence of a global dividing pattern in the field of NN. The results can be interesting for STI policy makers and academic researchers of both developed and developing countries. Also, from the statistical analysis point of view, one of the novelties of this study is analyzing the causal relationship among NN outputs for the first time.

The results imply a decreasing trend in GR for NN publications in a way that the number of NN articles is under the fitted exponential curve in the last 5 years. Consequently, it was predicted that an increasing trend in GR for NN publications depends on probable radical innovations and changes; that otherwise, based on the results, a decreasing trend and a value of lower than 1 for GR in the next years are anticipated. It is interesting that the GR curve of the global NN publications has been over that of the total global ISI publications. It is noteworthy that, unlike the case of NN publications, the trend of GR for nanotechnology patents is not a decreasing one. Understanding the reasons for yearly changes and the nonlinear trend of the GR curve needs further in-depth studies.

China's higher GR compared to that of the USA, helped China to surpass the USA in the past years, as well as through the total 15-year period of the study. It is interesting that although China's and Japan's shares have been almost similar in the first 5 years, because of the high GR for China's publications, a huge gap was created between the total number of articles of the two countries, in a way that nearly one-fourth of publications worldwide belonged to China, while the share of Japan was 8.5 %. Nonetheless, the status of China and other developing countries in patenting has not been suitable. However, China ranked 1 in terms of GR of nanotechnology patents worldwide, resulting in a decrease in the gap between its share and those of other leading countries. In other words, patenting activities by the Chinese is increasing. However, USA is certainly the undisputed leader in terms of the number of patents granted to their nationals, which account for more than half of the total nanotech patents granted by USPTO and EPO during the period of 2000–2014.

The total GR of the developing countries in both research and innovation outputs has been more than that of the developed countries. This increased the rank of some of the developing countries, which did not have an appropriate ranking in the first years, and helped them to appear among the leading and top 20. For example, Iran has had the highest total GR among all the countries studied in terms of NN publications, which increased its rank from 49 (with only 134 articles) in the first 5 years to 7 in 2014 and 14 during 2000–2014. The fastest NN publication GR growth was for Iran.

The USA has been the leading country in terms of all citation-based indicators, surpassing other top 20 in NN publications. However, the rank of the developing countries in AC and H_m has been very low and to the extent that the best developing country in terms of NN publications (i.e., China) ranked, respectively, 33 and 53 in terms AC and H_m. Also, the weak performance of the developing countries in patenting shows that, unlike the developed countries, there are no coherent policies for innovation in these countries, despite the fact that they showed high capability for research (i.e., China and Iran as two known developing countries in terms of NN publications, respectively, ranked 11 and 37 with 2065 and 38 granted patents during 2000–2014). On the other hand, the presence of some emerging countries among the top countries (i.e., Singapore and South Korea) in terms of almost in all indicators shows that they enjoy coherent policies for improving NN activities.

The correlation and regression results showed clearly distinct patterns in developed and developing countries. These, in addition to setting the ground for new research studies, brings effective points into the spotlight, which can be used by STI policy makers in developing countries. So, it is recommended that the distinct patterns discovered among developed and developing countries, can be used for properly engaging catch-up strategies by focusing on the results of this study. Also, the developed countries can conduct comparative studies by concentrating on the data of their countries and comparing them with those of the leading countries so that they can improve their STI status in terms of NN activities. For example, in addition to USA, some countries with high ranks in terms of indicators related to quality of research output and patent/article ratios (e.g., Switzerland, Netherland, France, UK, Belgium, etc.) are suitable cases for comparative studies or benchmarking STI policies.

One of the challenges of this study was the limitation of the used data to usual databases (WoS, USPTO, and EPO). This is a limitation of the current study, since some of the NN outputs (especially patents) of different countries may have been missed due to the fact that they have been indexed in their domestic national databases. Further research can analyze the national patent and article databases (especially with some of the above-mentioned countries, the NN outputs originating from which was extraordinary given their science and innovation capacities). Another challenge of the research was only relying on statistical methods for analyzing the causal relationships. Some detailed research can use other methods such as social networking analyses for investigating the effects of causal relationships among the studied indicators. Also, further studies are needed for investigating the reasons for low citation to NN outputs originating from developing countries, which can be done through citation analysis as well as other potential research methods (as previously mentioned, surprisingly, none of the 4 top developing countries among the top 20 countries in NN-related publications have been among the top 20 countries in terms of AC and H_m).

As mentioned in the section on correlation results, further research can investigate the reasons for the negative correlation between the ranks of developing countries in NPIN and their innovation outputs. Also, for gaining a better understanding on the reason why some of the developing countries, included in Table 3, are not in other tables of this paper, future studies with more focus on the local patents databases of the target countries and in-depth historical reviews for identifying the national and contextual factors are suggested.

Regarding the lack of significant correlation between R&D expenditures and researchers in R&D and any science and innovation indicators in developing countries, identifying the fundamental structures that can help better use the financial and intellectual properties is another area for future research. These can be done through comparative analyses among some selected developed and developing countries.

Definitely, a thorough analysis of the world's NN publications and patents is needed. Such an analysis should focus on the total number of existing patents, or to the number of patents already leading to commercialized products by companies, or to the transfer of knowledge and intellectual property to various enterprises. All these are to be of interest for policy makers and are therefore very complex and may need to be evaluated by researchers in future studies. As mentioned in the section on "science indicators," the above-mentioned descriptions and further studies are needed in the case of LSIN and SIC, too.

Appendix

Search string used for retrieving NN-related publications and patents (Maghrebi et al. 2011) (nano* not nano2 not nano3 not nanog not nanosecond* not nanomol* not nanogram* not nanoplankton* or "atom* scale" or "atomic layer deposition*" or "giant magnetoresist*" or graphen* or dendrimer* or fulleren* or "c-60" or "langmuir blodgett*" or mesopor* or "molecul* assembl*" or "molecul* wire*" or "porous silicon*" or "quantum dot*" or "quantum well*" or "quantum comput*" or "quantum wire*" or qubit* or "self assembl*" or supramolecul* or supermolecul* or "ultrathin film*" or "ultra thin film*").

References

Alibolandi M, Abnous K, Sadeghi F, Hosseinkhani H, Ramezani M, Hadizadeh F (2016) Folate receptor-targeted multimodal polymersomes for delivery of quantum dots and doxorubicin to breast adenocarcinoma: in vitro and in vivo evaluation. Int J Pharm 500(1–2):162–178

Bajwa R, Yaldram K, Rafique S (2013) A scientometric assessment of research output in nanoscience and nanotechnology: Pakistan perspective. Scientometrics 94(1):333–342

Bassecoulard E, Lelu A, Zitt M (2007) Mapping nanosciences by citation flows: a preliminary analysis. Scientometrics 70(3):859–880

Beise M, Stahl H (1999) Public research and industrial innovations in Germany. Res Policy 28(4):397–422

Bhushan B (2010) Springer handbook of nanotechnology. Springer Science & Business Media, New York.

Chen H, Roco M, Son J, Jiang S, Larson C, Gao Q (2013) Global nanotechnology development from 1991 to 2012: patents,

scientific publications, and effect of NSF funding. J Nanopart Res 15(9):1–21

Choi S, Yang J, Park H (2015) Quantifying the Triple Helix relationship in scientific research: statistical analyses on the dividing pattern between developed and developing countries. Qual Quant 49(4):1381–1396

French B, Heagerty PJ (2008) Analysis of longitudinal data to evaluate a policy change. Stat Med 27(24):5005–5025

Geuna A, Nesta LJJ (2006) University patenting and its effects on academic research: the emerging European evidence. Res Policy 35(6):790–807

Gholivand MB, Mohammadi-Behzad L, Hosseinkhani H (2016) Application of a Cu–chitosan/multiwalled carbon nanotube film-modified electrode for the sensitive determination of rutin. Anal Biochem 493:35–43

Gorjiara T, Baldock C (2014) Nanoscience and nanotechnology research publications: a comparison between Australia and the rest of the world. Scientometrics 100(1):121–148

Grimm H, Jaenicke J (2015) Testing the causal relationship between academic patenting and scientific publishing in Germany: Crowding-out or reinforcement? J Technol Transf 40(3):512–535

Guan J, Liu N (2014) Measuring scientific research in emerging nano-energy field. J Nanopart Res 16(4):1–15

Han HC, Lo HC, Wu CY, Chen KH, Chen LC, Ou KL, Hosseinkhani H (2015) Nano-textured fluidic biochip as biological filter for selective survival of neuronal cells. J Biomed Mater Res Part A 103(6):2015–2023

Hirsch JE (2005) An index to quantify an individual's scientific research output. Proc Natl Acad Sci USA 102(46):16569–16572

Hollander M, Wolfe D, Chicken E (2013) Nonparametric statistical methods. Wiley, New York

Huang Z, Chen H, Yan L, Roco M (2005) Longitudinal nanotechnology development (1991–2002): national science foundation funding and its impact on patents. J Nanopart Res 7(4–5):343–376

Huang C, Notten A, Rasters N (2011) Nanoscience and technology publications and patents: a review of social science studies and search strategies. J Technol Transf 36(2):145–172

Jiang S, Gao Q, Chen H, Roco MC (2015) The roles of sharing, transfer, and public funding in nanotechnology knowledge-diffusion networks. J Assoc Inform Sci Technol 66(5):1017–1029

Karpagam R, Gopalakrishnan S, Ramesh Babu B (2011) Mapping of nanoscience and nanotechnology research in India: a scientometric analysis, 1990–2009. Scientometrics 89(2):501–522

Li X, Lin Y, Chen H, Roco M (2007) Worldwide nanotechnology development: a comparative study of USPTO, EPO, and JPO patents (1976–2004). J Nanopart Res 9(6):977–1002

Liu X, Zhang P, Li X, Chen H, Dang Y, Larson C et al (2009) Trends for nanotechnology development in China, Russia, and India. J Nanopart Res 11(8):1845–1866

Maghrebi M, Abbasi A, Amiri S, Monsefi R, Harati A (2011) A collective and abridged lexical query for delineation of nanotechnology publications. Scientometrics 86(1):15–25

Mahapatra M (1985) On the validity of the theory of exponential growth of scientific literature. In Proceedings of the 15th IASLIC conference, Bangalore (pp. 61–70)

Miyazaki K, Islam N (2007) Nanotechnology systems of innovation—an analysis of industry and academia research activities. Technovation 27(11):661–675

Molinari A, Molinari JF (2008a) Mathematical aspects of a new criterion for ranking scientific institutions based on the H-index. Scientometrics 75(2):339–356

Molinari JF, Molinari A (2008b) A new methodology for ranking scientific institutions. Scientometrics 75(1):163–174

Mottaghitalab F, Farokhi M, Shokrgozar MA, Atyabi, Hosseinkhani H (2015) Silk fibroin nanoparticle as a novel drug delivery system. J Controlled Release 206:161–176

Reiss T, Dominguez Lacasa I (2008) The performance of European countries in biotechnology: how does Europe compare to the USA? Int J Biotechnol 10(4):303–326

Roco MC, Bainbridge WS (2005) Societal implications of nanoscience and nanotechnology: maximizing human benefit. J Nanopart Res 7(1):1–13

Sastry K, Rashmi HB, Rao NH (2010) Nanotechnology patents as R&D indicators for disease management strategies in agriculture. J Intellect Prop Rights 15:197–205

Soltani A, Tabatabaeian S, Hanafizadeh P, Bamdad Soofi J (2011) An evaluation scheme for nanotechnology policies. J Nanopart Res 13(12):7303–7312

Wang J, Shapira P (2011) Funding acknowledgement analysis: an enhanced tool to investigate research sponsorship impacts: the case of nanotechnology. Scientometrics 87(3):563–586