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Knowledge transfer from science to technology: the case of nano medical device technologies

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Knowledge Transfer from Science to Technology—The Case of Nano Medical Device Technologies

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This study explores to what extent scientific knowledge has contributed to the development of industrial technologies. Backward citation is used to track the contribution of scientific research to technologies, and forward citation is adopted to evaluate the impact of these technologies. Patents are classified in two different groups (citing and not citing scientific publications) and a special attention has been given to the comparisons between countries, different types of organizations and different subfields. Our result reveals that, in the field of nano medical device technologies, knowledge transfer from the academic domain to the industrial domain is on the rise. The forward citations received by science-based patents are 1.6 times higher than those received by non-science-based patents. Our results also show that interconnections between science and technology are especially important for patents invented by firms compared with those developed by universities. At country level, all the six studied countries (USA, Germany, UK, Japan, France, and China) have been applying more and more scientific knowledge to develop nano medical device technologies. The linkage between science and technology is strongest in the USA, while it is weakest in the latecomer country China.

Keywords: knowledge transfer, science and technology, patent, citations, impact, countries, organizations

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INTRODUCTION

Public science has been regarded as an important driving force behind industrial technologies (Mansfield, 1980, 1991; Griliches, 1986; Rosenberg, 1990; Narin et al., 1997; McMillan et al., 2000). Exploring the linkage between science and technology is considered as an important subject which helps understand the nature of inventions (Nelson and Winter, 1977). By tracing the scientific citations referenced by patents, a group of scholars find that scientific research contributes substantially in stimulating industrial innovations and that science-based patents receive more citations (Malo and Geuna, 2000; Sorenson and Fleming, 2004). However, there are also studies showing that the interplay of science and technology does not always lead to impactful inventions (Appio et al., 2017), in particular in some regions (Acosta and Coronado, 2003).

We argue that the linkage between science and technology depends on the organizational, regional, and sectoral settings. It is crucial to keep several aspects in mind. First, the incentives and importance of patenting are subject to the ownership of the patents. University-owned patents are more related to scientific questions while corporate-owned patents are more connected with direct commercial goals (Sterzi, 2013). Commercial patents from firms that "build upon the scientific and engineering base created by university research" are believed to be more economically important than those from generated directly by universities (Henderson et al., 1998). Second, due to the heterogeneity of regional features in developing industrial technologies, the linkage between science and technology tends to vary across regions/countries (Acosta and Coronado, 2003; Wong and Wang, 2015). Based on the studies of several autonomous regions in Spain, Acosta and Coronado (2003) show that the interconnection between science and technological systems depends on the regional setting, e.g., technological complexity and specialization. The degree of scientific contribution to innovation is higher in regions that are specialized in sectors using more intensive technologies (e.g., Madrid) than in regions with low technological complexity (e.g., Catalonia). Third, the scientific contribution to technology development also involves a sectoral dimension. The intensity of science–technology interrelation varies across sectors and there is a sector-specific characteristic in knowledge flows (Meyer, 2000). McMillan et al. (2000) find that technologies in the biotechnology industry are more reliant on public science than those in the pharmaceutical industry, and Popp (2017) suggests that there is more scientific research applied in patenting in biofuels than in wind research.

Despite the increasing attention to the science–technology linkage, existing studies have mainly focused on the technologically leading countries, such as the USA and several other developed countries (Narin et al., 1997; McMillan et al., 2000; Acosta and Coronado, 2003). This is largely due to the availability of patent data from the major patent offices, such as the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO), the European Patent Office (EPO), etc.

However, little is known about the science–technology linkage in emerging economies, in particular the differences across countries and types of organizations. It is widely acknowledged that innovation is crucial in the catching up process (Fu et al., 2011). We argue that, to fully understand the science–technology linkage, it is of great importance to include both advanced and less advanced countries. This study aims to fill this gap by exploring the interconnection between science and technology in developed and developing countries, while also comparing different types of organizations and different technology classes.

Nano medical device technology is chosen as a case study, in which numerous medical disciplines benefit from innovation enabled by nanotechnologies.[1] It is expected that the innovative medical applications of nanotechnologies will have a profound impact on health care in the near future (Bleaker et al., 2014; RIVM, 2015).[2] In this paper, we examine what is the trend of science-based technology development in nano medical device, whether application of scientific knowledge is associated with a high value of such technologies, and whether there are differences across organizations, countries and subfields.

DATA AND METHODS

Data Collection

In this study, patent data of nano medical devices were collected from the Derwent World Patents Index (DWPI) *via* the platform Derwent Innovation (previously known as Thomson Innovation). Derwent Innovation provides access to data from more than 50 patent issuing authorities, which were converted into a standard format and with English translations from 30 languages.[3] We used a keyword search method and applied the SSTO = (nano* and "medical device*") query to the title and abstract of each patent.[4] Considering the time lag in forward citation (FC) data and the fact that there were too few filed patents in the earlier years, we limited our dataset to the period between 2003 and 2012. After extracting the matched patents (37,904 records), we expanded the list to the same patent families and obtained 330,022 patent applications. After removing all duplicate records, the total number of patent applications for the period 2003–2012 was 108,468. According to the information of assignees, we classified the patents into three organization types: corporate patents, university patents, and corporate–university collaborated patents. Country codes were extracted based on the addresses of inventors.

We extracted the International Patent Classification (IPC) code of each patent and summarized at the second hierarchical level of the classification, e.g., A61, B05, C07, etc. For the 108,468 patents, there are in total 118 two-digit class numbers. The 10 highest ranked patent types, which cover 98% of total patents, were selected for the backward and FC analysis.

Both backward and FCs for all harvested nano medical device patents were collected. Backward citations include both patent citations and non-patent citations (NPCs). NPCs consist of various types of references, including scientific articles, withdrawn patents, technical manuals, databases, web-based information, news, etc. By applying Automatic identification combined with the artificial recognition method, we managed to extract only the scientific articles as the valuable science-based citations.

Methodology and Indicators

Based on the content of the references made by patents, this study classifies the patents[5] into two groups. One is the group of patents which have cited scientific publications in their references (P_s), the other is the group of patents which did not cite any scientific publications ($P_{\text{non-s}}$). As illustrated in **Figure 1**, the former group (P_s) developed patents grounded on both technological and scientific bases, while the latter group ($P_{\text{non-s}}$) developed patents with only a technological basis.

The degree to which science has contributed to the development of nano medical device technologies can be measured by the scientific knowledge application index (SKAI):

$$\text{SKAI}_t = \frac{P_{t,s}}{P_{t,s} + P_{t,\text{non-}s}}, \tag{1}$$

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[1] See more discussions in (RIVM, 2015).

[2] Nano medical devices have contributed to the treatment of cardiovascular disease, cardiac arrhythmia, diagnostic tests in detection of cancer, and in the treatment in neurology, etc. (RIVM, 2015).

[3] See more at https://clarivate.com/products/derwent-innovation/.

[4] The data were extracted in July 2016.

[5] Patents refer to nano medical device patents.

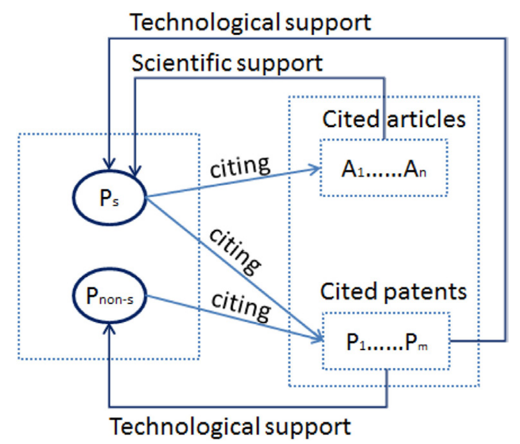

FIGURE 1 | Schematic diagram of science-based and non-science-based patents.

where $P_{t,s}$ is the number of patents filed at year t citing scientific publications and $P_{t,\text{non}-s}$ is the number of patents filed at year t without citing scientific publications. A higher level of *SKAI* indicates a higher influence from science to technological development.

Six countries (USA, Germany, UK, Japan, France, and China) are chosen to represent both advanced and emerging economies. The USA, Germany, UK, Japan, and France are technologically leading countries that represent the former group. For the emerging economies, the patent number of many countries (e.g., India, Russia, Brazil, etc.) is very low. Therefore, we choose China as a representative of the latter group. Given that each country has its own pattern in developing industrial technologies (Wong and Wang, 2015), we normalize the SKAI by dividing one country's SKAI value by the global average. In other words, we assume that the global average level is equal to 1 and the positions of all the studied countries will be compared with the average level. The normalized scientific knowledge application index (NSKAI) of country i at year t, $\text{NSKAI}_{i,t}$, can be expressed as follows:

$$\text{NSKAI}_{i,t} = \frac{P_{i,t,s} / \left(P_{i,t,s} + P_{i,t,\text{non-}s}\right)}{P_{t,s} / \left(P_{t,s} + P_{t,\text{non-}s}\right)}, \tag{2}$$

where $P_{i,t,s}$ is the number of patents in country i at year t citing scientific publications; $P_{i,t,\text{non-}s}$ is the number of patents in country i at year, t not citing scientific publications; $P_{t,s}$ is the number of patents in all countries at year t citing scientific publications; and $P_{t,\text{non-}s}$ is the number of patents in all countries at year t not citing scientific publications.

If one country's *NSKAI* value is higher than 1, it means that nano medical device technologies in this country have a higher science base than that of the worldwide average. Similarly, a value less than 1 indicates that the linkage between science and technology[6] is weaker in this country.

Next, to examine the value or social impact of patents, we collect the information of FCs for each patent. The citation difference between the science-based and non-science-based patents can be captured by the forward citation differentiation index (FCDI). For instance, the FCDI for country i is defined as

$$\text{FCDI}_i = \frac{\sum \text{FC}_{i,s} / \sum P_{i,s}}{\sum \text{FC}_{i,\text{non-}s} / \sum P_{i,\text{non-}s}}. \tag{3}$$

The numerator is the number of FCs per patent (from country i) which cited scientific publications, and the denominator presents the number of FCs per patent (from country i) which did not cite scientific publications.

Similarly, we also calculate this index at organization level, namely for corporate patents, university patents, and corporate–university collaborated patents.

RESULTS

Trend of Scientific Bases in NMD Technologies

In the evolution of nano medical device technologies, the contribution of science has changed over the years. **Figure 2** provides the ratio of patents citing non-patent publications. The y-axis represents for the SKAI, i.e., the degree to which science has contributed to the development of nano medical device technologies, which was explained in the earlier section.

Figure 2 shows that more and more inventions have been developed with a scientific knowledge basis. Among the three organizations, university patents have the highest share. This can be due to the fact that, in some cases, researchers from universities or research institutes publish and invent at the same time (Van Looy et al., 2006). It is logical that they intend to cite their own scientific publications while patenting. Even if the cited papers are not from themselves, working in an academic environment, these researchers are more aware of the relevant scientific papers than inventors from firms. On the contrary, inventions from firms have a relatively low share in citing scientific publications. Such commercial patents have been developed with an industrial orientation rather than a scientific one. Corporate–university collaborated patents are located in the middle, with SKAI values lower than university patents and higher than corporate patents. In general, patents in all three types of organizations present an increasing value of scientific knowledge application over time.

Normalized Scientific Knowledge Application Index (NSKAI)

To explore the difference between countries in patenting activities, as explained in the previous section, we take the worldwide average into consideration and normalize the SKAI value for the studied countries. This assumes that the worldwide average SKAI value stays constant, at the level of 1. An *NSKAI* value >1 indicates a higher degree of applying scientific knowledge to develop patents in the country concerned. By contrast, an *NSKAI* value <1 suggests that less scientific knowledge has been applied into the studied technologies in this country.

The dynamic values of the NSKAI by country are presented in **Figure 3**.

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[6] This refers only to nano medical device technology.

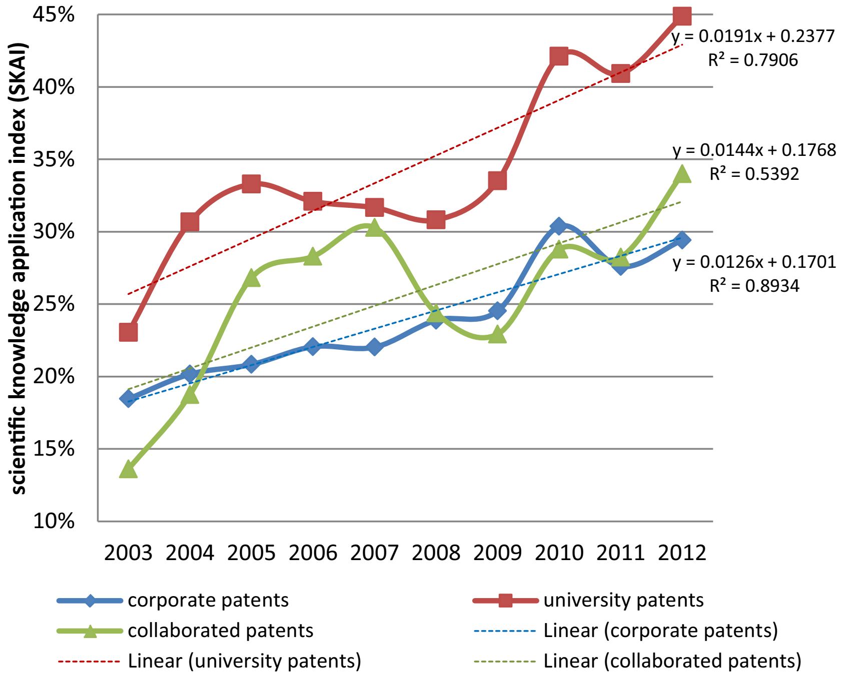

FIGURE 2 | Scientific knowledge application index (SKAI) by year. Note: See Eq. 1 for the calculation of this indicator.

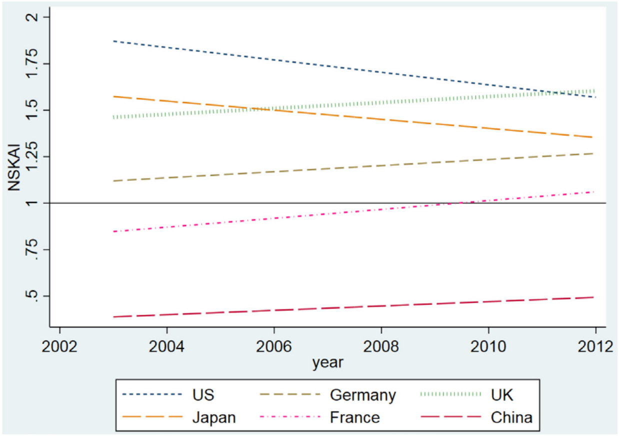

FIGURE 3 | Standardized scientific knowledge application index by country and by year. Note: The trend is plotted by lfit function in a linear regression. Original data for each year can be found in Figure A1 in Supplementary Material.

Figure 3 shows that the USA had the highest NSKAI value, suggesting that scientific knowledge contributed extensively to nano medical device patenting in the USA. In 2003, the NSKAI value in the USA was almost twice as high as the worldwide average. However, the NSKAI value decreased over time in the USA, which was mainly caused by an increase of the global average. In other words, other countries have increased their science application in patents more rapidly than the USA.

Similar to that of the USA, the *NSKAI* value of Japan was also higher than the average level, but with a decreasing trend moving closer to the average line. The UK and Germany both were above the average line, and still increased their values in the studied period. France had a relatively low starting point, but slowly moved upward.

Compared with other countries, China presented the lowest *NSKAI* value, which was far below the global average line 1. This indicates that patents filed by Chinese inventors were more industry-oriented than science-based. Nevertheless, in the long run, the *NSKAI* value in China has been improving steadily.

Effect of Scientific Bases for Patent Development

Acknowledging that more and more scientific knowledge has been applied to develop nano medical device technologies, one may wonder whether the application of science is associated with an improvement of patent quality.

Due to the time lag in FCs, patents filed in later years generally receive fewer citations than those filed earlier. Hence, we take patent age into consideration while investigating the value of patents (number of FCs). In our sample, the oldest patents were filed in 2003 (14 years old) and the youngest patents were filed in 2012 (5 years old). Because of the citation time lag, the number of FCs shows a decreasing trend in the **Figure 4**.

For patents from the same type of organization, the number of FC received by patents citing scientific publications was always higher than that of those received by patents not citing scientific publications. Taking the corporate patents filed in 2003 (14 years old) as an example, on average the number of FCs was 53 per

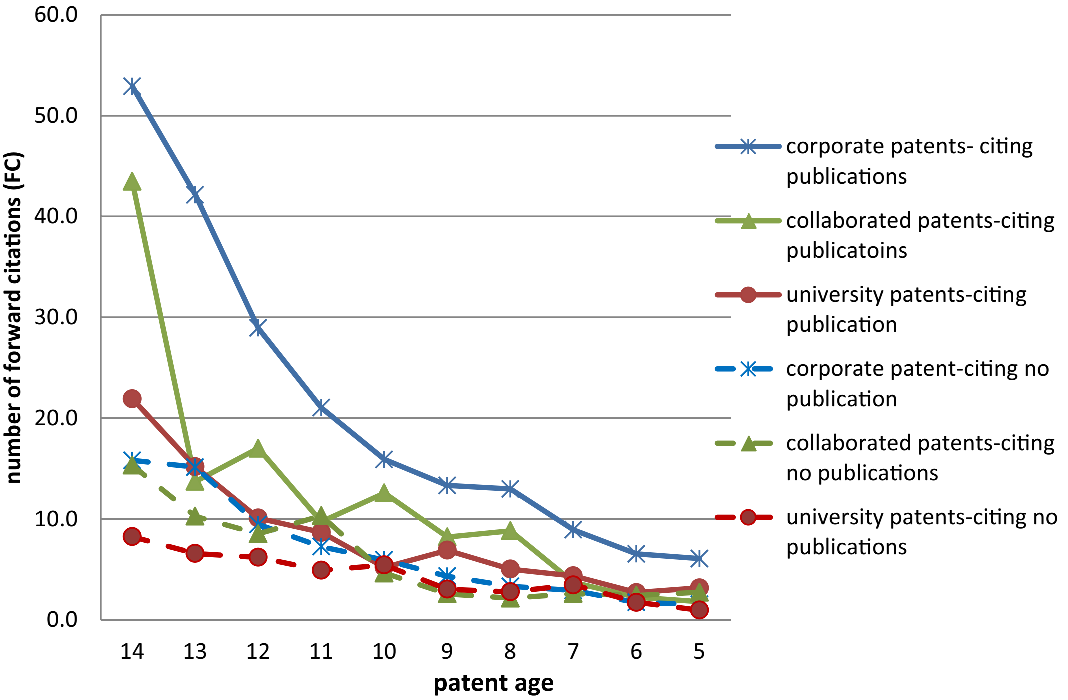

FIGURE 4 | The value of patent (forward citations) by patent age.

patent in the group of patents citing publications, while it was 16 in the group of patents not citing publications. Namely, the FC in the former group was 2.3 times higher than the latter one.

The FCDI was less pronounced in university patents. For example, for the 14-year-old university patents, the average FC number was 22 for patents citing publications and 8 for patents not citing publications. The differentiation index for corporate–university collaborated patents was in the middle, lower than that of corporate patents, and higher than that of university patents.

On average, if all patents filed in the studied period (2003–2012) are included, the FCDI value was 2.73 for corporate patents, 1.62 for university patents, and 1.65 for corporate–university collaborated patents. This indicates that if commercial patents were developed by firms based on scientific knowledge, the value (or the social impact) of such patents can be amplified the most. For university patents, however, such added value was relatively low. Nevertheless, it is clear that, irrespective of the type of organization, it is valuable to apply scientific knowledge in developing technologies (see **Table 1**).

Effect of Scientific Bases for Patent Development—Comparison of Different Countries

Given that the quality of patents from different countries varies widely (Hall et al., 2001), in this section we provide a comparison of scientific applications by country.

At the worldwide level in the period 2003–2012, the average number of FCs was 19.42 for patents citing scientific publications and 7.46 for patents without citing scientific publications (see **Table 2**). Thus, the differentiation index (FCDI) was 2.60, indicating that the value of the former patent group was 1.6 times higher than that of the latter patent group. In the studied six countries, the FCDI values in the UK, France, and the USA were relatively high, while Germany, Japan, and China presented relatively low FCDI values. However, it is worth noting that, in spite of having similar FCDI values, patents from these three countries received a different number of FCs. In China, the average FC received by science-based patents is merely 1.78, in contrast to 8.71 in Germany and 5.72 in Japan.

Table 2 also shows that the USA had the highest SKAI value (Col. 8), which indicates that a large share (i.e., 41%) of US patents cited academic research. Following that, the UK and Japan also exhibited a high value of SKAI, emphasizing the importance of scientific contribution in developing technologies in these countries. China, however, had the lowest value, merely 12.1%. This shows that inventions in China were not much grounded on scientific bases.

The low level of the SKAI value in China seems to be in line with regional features, as studied by Acosta and Coronado (2003). From a geographical perspective, Acosta and Coronado (2003) find that the diffusion from scientific knowledge to innovations is stronger in regions using more intensive technologies than in regions with low technological complexity. Our results indicate that, compared with the studied five advanced countries, the interconnection between science and technology was low in latecomer countries such as China. This may be due to the fact that, on average, the technological complexity in nano medical devices is lower in China than in other developed countries.

TABLE 1 | Comparison of scientific knowledge application by organization type, 2003–2012.

Types of organization	Total patents (1)	Patents citing publications			Patents not citing publications			Scientific knowledge application index (SKAI) (8)	Forward citation differentiation index (FCDI) (9) = (4/7)
		Number of patents (2)	Forward citations (3)	Average of forward citations (4)	Number of patents (5)	Forward citations (6)	Average of forward citations (7)		
All	108,468	26,099	506,791	19.42	82,369	614,477	7.46	24.1%	2.60
Corporate	99,571	23,189	48,4990	20.9	76,328	586,157	7.7	23.3%	2.73
University	6,992	2,419	16,903	7.0	4,573	19,758	4.3	34.6%	1.62
Collaborated	1,905	491	4,898	10.0	1,414	8,562	6.1	25.8%	1.65

See Eqs 1 and 3 for details about SKAI and FCDI indicators.

TABLE 2 | Comparison of scientific knowledge application in six studied countries, 2003–2012.

Country	Total patents (1)	Patents citing publications			Patents not citing publications			Scientific knowledge application index (SKAI) (8)	Forward citation differentiation index (FCDI) (9) = (4/7)
		Number of patents (2)	Forward citations (3)	Average of forward citations (4)	Number of patents (5)	Forward citations (6)	Average of forward citations (7)		
All countries	108,468	26,099	50,6791	19.42	82,369	614,477	7.46	24.1%	2.60
USA	39,206	16,090	397,519	24.71	23,116	410,970	17.78	41.0%	1.39
Germany	4,297	1,247	10,863	8.71	3,050	23,257	7.63	29.0%	1.14
UK	1,392	523	6,990	13.37	869	7,527	8.66	37.6%	1.54
Japan	1,037	370	2,118	5.72	667	3,555	5.33	35.7%	1.07
France	1,728	422	6,342	15.03	1,306	12,712	9.73	24.4%	1.54
China	5,302	643	1,144	1.78	4,659	7,086	1.52	12.1%	1.17

See Eqs 1 and 3 for details about SKAI and FCDI indicators.

Effect of Scientific Bases for Patent Development—Comparison of SubFields

As discussed in the section "Introduction," the intensity of linkage between science and technology differs from area to area.

Table 3 documents the two-digit patent classes with the highest numbers in nano medical device patents. The 10 highest ranked patent types, which cover 98% of total patents, were selected for the backward and FC analysis. Explanations on the categories of these IPC classes and sections are provided in Table A1 in Supplementary Material.

The major type of nano medical device patents belongs to the A61 class, representing medical, veterinary science, and hygiene technologies in the subsection of Health, Life-saving, and Amusement category (see Table A1 in Supplementary Material). Although the patent numbers in other types (IPC codes of C08, C12, C07, B05, B29, A01, G01, C09, and B32) were relatively low, the scientific knowledge application indices were all higher than the index for the type A61. Technologies related to organic chemistry, IPC code C07, had the highest SKAI value (46.2%). Namely, this type of technology tended to cite scientific research more than others.

Patents in the C09 class, i.e., dyes, paints, polishes, etc., in the Chemistry section have the highest FCDI value (8.81), suggesting that science-based patents in this subfield received far more FCs (on average 16.7 per patent) than non-science-based patents (on average 1.9 per patent). On the contrary, technologies related to measuring and testing (G01) and technologies related to layered products (B32) exhibited an FCDI value <1. This shows that, in these two categories, non-science-based patents receive more FCs than science-based patents. Hence, a higher level of application of scientific knowledge in some types of technologies does not seem to be associated with higher patent impact.

DISCUSSION AND CONCLUSION

Using DWPI patent data between 2003 and 2012, this study explores whether (and to what extent) scientific knowledge has been contributing to the innovation activities in the field of nano medical device technologies. Our results show that there is an increasing link between science and technology in this field. That is, more and more nano medical device technologies have been developed based on science. By examining the FCs in two different patent groups (citing and not citing scientific publications), we find that knowledge transfer from science correlates with the impact of patents. This emphasizes that generally science has played an important role in stimulating technology.

On the other hand, this study underlines the multifaceted nature of the science–technology linkage, depending on the sectoral, organizational, and regional setting. In line with Meyer (2000) and McMillan et al. (2000), this paper points out that there are sector-specific characteristics in technology transfer from science to technology. Certain types of technologies are more science-based than others. At organizational level, we find that the FCDI presents a higher value in corporate patents than in university patents. Namely, application of science has brought higher added value to patents developed by firms than those developed by universities.

TABLE 3 | Comparison of scientific knowledge application in 10 subfields, 2003–2012.

		Patents citing publications			Patents not citing publications				
Top subfields	Total patents (1)	Number of patents (2)	Forward citations (3)	Average of forward citations (4)	Number of patents (5)	Forward citations (6)	Average of forward citations (7)	Scientific knowledge application index (SKAI) (8)	Forward citation differentiation index (FCDI) (9) = (4/7)
A61	82,910	17,197	394,362	22.93	65,713	520,446	7.92	20.7%	2.9
C08	581	196	1,779	9.08	412	829	2.01	32.2%	4.5
C12	394	157	748	4.76	237	728	3.07	39.8%	1.6
C07	195	90	251	2.8	105	168	1.6	46.2%	1.74
B05	188	43	519	12.1	145	410	2.8	22.9%	4.27
B29	143	53	596	11.2	90	229	2.5	37.1%	4.42
A01	156	38	334	8.8	118	223	1.9	24.4%	4.65
G01	209	81	297	3.7	128	774	6.0	38.8%	0.61
C09	93	28	467	16.7	65	123	1.9	30.1%	8.81
B32	63	25	202	8.1	38	499	13.1	39.7%	0.62

At national level, our study shows that countries have different patterns in applying scientific knowledge to industrial technologies, at least in the nano medical device field. Among the six countries studied in this paper, the linkage between science and technology is strongest in the USA and weakest in the emerging country China. Although China's nanoscience has developed rapidly over the past decades (Zhou and Leydesdorff, 2006), such scientific knowledge has not been intensively transferred to the development of related industrial technologies. This reveals that latecomer countries may choose a different path from advanced countries. Due to the data limitation, unfortunately, we are unable to test the science–technology linkage in other emerging economies, such as India, Russia, and Brazil. Future studies on more developing countries would be encouraged.

AUTHOR CONTRIBUTIONS

LW designed the project. ZL collected the data. LW and ZL conducted the analysis. LW and ZL wrote the paper.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at http://www.frontiersin.org/articles/10.3389/frma.2018.00011/full#supplementary-material.

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