Journal of Informetrics 8 (2014) 241–251

Contents lists available at ScienceDirect

Journal of Informetrics

journal homepage: www.elsevier.com/locate/joi

Technological impact factor: An indicator to measure the impact of academic publications on practical innovation

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ARTICLE INFO

Article history:
Received 16 August 2013
Received in revised form 6 December 2013
Accepted 9 December 2013
Available online 31 December 2013

Keywords:
Technological impact fact
Patent reference
Journal impact factor

ABSTRACT

This study established a technological impact factor (TIF) derived from journal impact factor (JIF), which is proposed to evaluate journals from the aspect of practical innovation. This impact factor mainly examines the influence of journal articles on patents by calculating the number of patents cited to a journal divided by the number of articles published in that particular journal. The values of TIF for five-year (TIF_5) and ten-year (TIF_{10}) periods at the journal level and aggregated TIF values (TIF_{AGG_5} and TIF_{AGG_10}) at the category level were provided and compared to the JIF. The results reveal that journals with higher TIF values showed varied performances in the JCR, while the top ten journals on JIF_5 showed consistent good performance in TIFs. Journals in three selected categories – Electrical & Electronic Engineering, Research & Experimental Medicine, and Organic Chemistry – showed that TIF_5 and TIF_{10} values are not strongly correlated with JIF_5. Thus, TIFs can provide a new indicator for evaluating journals from the aspect of practical innovation.

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1. Introduction

It is important to identify the degree of importance of information as well as its impact in this era in which we are saturated in information. Due to time and financial constraints, bibliometric methods are often employed to retrieve high-value information. Developed by the founder of the Institute for Scientific Information (ISI), journal impact factor (JIF) is an indicator used to measure the impact of a specific journal and thus illustrate knowledge flow among papers (Garfield, 1995). A JIF value is calculated by first aggregating the citations received from other articles during a given time span to all articles published in a given journal during a given period and then dividing this aggregation by the number of articles published by the journal during that period. JIF indicates the degree of importance and impact of the dissemination of information to the scientific disciplines in which the journal is indexed, and has become an important indicator for evaluating the influence of a journal on scientific research. JIF has also been employed by librarians for journal selection and purchase. While JIF is calculated based on the citations received from journal articles, knowledge flows exist not only among scientific journal articles but also in other subjects, such as patents and the Web. Hence, many studies have examined the relationships among patents using patent citation analysis.

Scientific journal articles influence not only other scientific research, but also industrial research and development. Because a patent may refer to or credit a scientific article through its references, the concept of science linkage is proposed

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http://dx.doi.org/10.1016/j.joi.2013.12.004

to calculate the number of papers cited per patent in order to measure the impact of a scientific article on a certain patent. Building upon the concept of science linkage, technological impact factor (TIF), derived from the JIF method, is proposed as a new indicator for evaluating journals from the aspect of practical innovation and for examining the impact of scientific journals on patents. The practical application and limitations of the TIF will also be discussed in this study. TIF values for the five-year (TIF_5) and ten-year (TIF_{10}) periods are calculated for each category and journal indexed in the Journal Citation Report (JCR). Then, three categories were selected from the top 15 categories to examine the performance of journals in each category. In addition, the JIF for five years (JIF_5) of publication in JCR 2011 is presented in this study to compare with TIF_5 and TIF_{10} values.

2. Literature review

2.1. Journal impact factor (JIF)

Journal impact factor (JIF) was first developed by Eugene Garfield. It is calculated using the Journal Citation Report (JCR) and now published by Thomson Reuters. The report covers more than 8000 journals in science and technology and more than 2600 journals in the field of social science (Thomson Reuters, 2012a, 2012b). The JIF is widely adopted in many disciplines. For example, librarians employ the JIF to select journals for library collections, and some studies have adopted JIF to measure the quality of research. For example, Glynn et al. (2012) adopted two-year JIF as an indicator to evaluate search yields within the laryngeal cancer field during the period from 1945 to 2010. Other medical-related studies also employed the JIF to evaluate the methodological and ethical quality of research in controlled trials in surgical research (Bridoux et al., 2012), with their results indicating that the JIF of a biomedical journal was directly related to the journal's ethical requirements for publication. Some studies examined the applicability of the JIF in particular fields. For instance, Saha et al. (2003) measured the quality of general medical journals and indicated that JIF was a reliable indicator for journal evaluation. Smith (2010) adopted the JIF to examine the impact factor trends of five selected core journals in occupational medicine, stating that citation data provides useful information on citation rates and publishing trends.

Despite the diverse implications of the JIF in evaluating academic performance, researchers have noticed that JIF varies across fields and over different timespans (Althouse, West, Bergstrom, & Bergstrom, 2009). The sizes of each category, which in the ISI are comprised of various sub-categories, are strikingly different. Moreover, citation behaviors and the nature of each discipline also vary across categories (Balaban, 2012; Garfield, 1999; Kokko & Sutherland, 1999; Moed, 2005a, 2005b; Sen, 1992; Sen & Shailendra, 1992). There are many arguments regarding the reliability of deploying JIF as an objective indicator for journal evaluation, despite the fact that the JIF is widely employed as an indicator for the selection of journals and the evaluation of the academic performance of individuals and institutions. Some studies have questioned the reliability of citations, the primary measurement unit of JIF, because not all citations mean to acknowledge previous studies (Balaban, 2012). Authors may cite an article to criticize or correct errors in that article. Other limitations, such as language bias, self-citation, and different sizes of research fields, have also been raised to argue against the applicability of the JIF. Furthermore, the number of citations received by each article is not consistent in different databases, such as JCR, Scopus, and Google Scholar.

Seglen (1997), Russell and Singh (2009), Dempsey (2009), and Lee and Lin (2013) mentioned some deficiencies in the JIF. First, these researchers found that the JIF was not statistically correlated to individual academic performance. Journals with high JIFs did not always publish papers in which authors received more citations. Conversely, authors that received large numbers of citations did not always submit their papers to high-impact journals. Second, review articles were generally highly cited, and different types of articles and journals receive varied numbers of citations. In addition, citations present a skewed distribution, in which a small number of journals receive most of the citations. Hence, it is questionable whether JIF can be used to compare the academic performance across journals. To improve the accuracy of the JIF, some studies have proposed alternative methods derived from the JIF. For example, Eigenfactor and Article Influence have been used to estimate the relative influence of articles based on cross-citation data (Bergstrom, West, & Wiseman, 2008). Some research articles have also proposed different indicators to evaluate the impact of journals. Bornmann, Marx, Yuri, & Gasparyan (2012) reviewed the limitations of the JIF alongside alternative metrics, such as SCImago Journal Rank, and the *h*-index. Leiden University adopted the Scopus database by Elsevier to provide CWTS journal indicators, with source normalized impact per paper (SNIP), the most well-known indicator (Centre for Science and Technology Studies, 2013).

2.2. Science–technology interaction

In the past, science and technology were often considered separate entities that rarely communicated with each other. Recently, science has played an important role in the development of technologies (Schmoch, 1997). Many studies have focused on the relationship between patents and papers (or journal articles). Academic papers can now contribute not only to the development of scientific theory, but also to the progress of economic activity (Narin, Hamilton, & Olivastro, 1997). In addition, Von Looy et al. (2003) indicated that the number of papers referenced in patents could be employed to examine the science intensity of a technology domain. To measure the impact of papers on patents, "science–technology interaction" and "science linkage", defined as the number of papers cited per patent, were proposed as measurements (Tamada, Naito, Kodama, Gemba, & Suzuki, 2006).

Meyer (2000) examined the relationship between publications and patents in nanotechnology and stated that the development of this technology is often linked with research articles in natural sciences and multidisciplinary sciences. Tamada et al. (2006) analyzed science linkage based on 1200 Japanese patents and found that the classification "microorganisms or enzymes: compositions thereof" received the highest science linkage, with an average of 14.6 paper citations. Science linkage was further adopted to examine a country's technological performance (Von Looy et al., 2003). Schmoch (1997) referred to the report by Grupp, Münt, and Schmoch (1995) in his literature review, noting that Grupp et al. derived a relative index that evaluates the level of the relative non-patent literature (RNPL) for a specific area related to the average level for all technologies from the mean of the non-patent literature (NPL). The study found that Biotechnology, Pharmaceutics, and Semiconductors were the top three technology domains in terms of the closeness of their relationships to the sciences. Verbeek, Debackere, and Luwel (2003) also indicated that science could greatly contribute to the development of new technologies such as biotechnology. Genetic engineering is another field considered highly dependent on scientific research. Moreover, the science linkage in the field of genetic engineering became more intensive when related research was booming (Lo, 2010).

This interaction between science and technology was likely accelerated by Triple Helix, a coordination by industry, academia and government (Verbeek et al., 2003). Meyer, Debackere, and Glanzel (2010) indicated that, in the field of nanotechnology, there were some platforms where funding instruments linked industry and academia together. However, some researchers have questioned the appropriateness of viewing science linkage as a form of knowledge flow. For example, Roach and Cohen (2013) mentioned that sometimes firms cited journal articles to strengthen and validate patents, and hence argued that patent citations to papers could not be an indicator of knowledge flow. Hung (2012) also mentioned that analyzing science linkages through bibliometric methods could not capture all figures of scientific research's impact on technology development. Nevertheless, he still considered science linkage a useful tool for measuring the flow of knowledge from science to technology.

3. Methodology

3.1. Data collection

The United States Patent and Trademark Office (USPTO) is one of the world's major patent offices, and the patent database of the USPTO is an important source for patent analysis. This study adopted the USPTO as the data source and downloaded the "Other References" from the "References Cited" of each patent issued in 2011. Each reference was identified based on its document type. If a reference was an article published in a specific journal, it was matched with the journal list of the 2011 Journal Citation Report (JCR). The number of references from each journal were then calculated. Since this study mainly examined the impact of the articles published during the past five and ten years, these references were all published during the periods of 2006–2010 and 2001–2010 respectively.

There are two main limitations of applying the journal list published by the JCR. First, only references published in the journals indexed in JCR 2011 could be calculated. Second, references are only calculated for the period in which the journals are indexed by JCR. If a reference was published in a year when the journal was not indexed, this reference can then not be included in the dataset, even if the journal was indexed in JCR 2011.

3.2. Measures: TIF and aggregate TIF

The TIF, an indicator that was drew upon the concept of the JIF, was calculated to demonstrate the impact of journal articles on patents. In this study, five-year TIFs and ten-year TIFs were calculated to compare the performance of each journal in 2006–2010 and 2001–2010 respectively. The formulas were derived from Vinkler's study (2004) and are shown below:

$$\mathrm{TIF}_5 = \frac{C_t^i}{\sum_{p=1}^{5} A_{t-p}^i}$$

where C_t^i is the number of citations that journal i received in year t from patents issued in 2011, and A_{t-p}^i is the number of articles indexed in the JCR in the year $t-p$ According to the JCR's explanation of journal source data, only articles were included in the dataset. Other items, including reviews, editorials, letters, news items, and meeting abstracts, were not counted in JCR (Thomson Reuters, 2012a, 2012b). TIF_{10} was further expressed by simplifying the function of TIF_5:

$$\mathrm{TIF}_{10} = \frac{C_t^i}{\sum_{p=1}^{10} A_{t-p}^i}$$

where the number of articles in the period of ten years is the denominator.

In order to select three important JCR categories and show the TIF performance of journals in these categories, the TIF for disciplinary categories was computed using "Aggregate TIF" (TIF_{AGG}) based on the TIF for journals. The TIF_{AGG} was calculated

Table 1
Top ten TIF_5 journals across categories with their corresponding TIF_{10} and JIF $_5$values.

Journal	2006–2010			2001–2010			JIF_5
	TIF_5	Paper	Patent citations	TIF_{10}	Paper	Patent citations	
Expert Opinion on Therapeutic Patents	0.2624	484	127	0.3905	1027	401	2.12
ACM Computing Surveys	0.2535	71	18	1.6000	130	208	9.17
Nature Biotechnology	0.2522	567	143	1.1788	1275	1503	28.16
IEEE Journal of Solid-State Circuits	0.2055	1411	290	0.4144	2741	1136	3.55
European Cells & Materials	0.1690	71	12	0.1690	71	12	4.95
Nature Nanotechnology	0.1645	468	77	0.1645	468	77	33.78
Drug Discovery Today	0.1596	633	101	0.2294	1177	270	7.16
Geochemical Transactions	0.1569	51	8	0.1333	60	8	2.63
Current Opinion in Drug Discovery & Development	0.1567	319	50	0.1794	457	82	3.77
International Journal of Parallel Programming	0.1441	118	17	0.1152	217	25	0.56

by adding together the numbers of citations from patents to journal *i* that belonged to a specific JCR category and then dividing by the number of papers in that category. This study calculated the values of TIF_{AGG} for both five and ten years:

$$TIF_{AGG\_5} = \frac{\sum_{i=1}^{I} C_t^i}{\sum_{i=1}^{I} \sum_{p=1}^{5} A_{t-p}^i}$$

$$TIF_{AGG\_10} = \frac{\sum_{i=1}^{I} C_t^i}{\sum_{i=1}^{I} \sum_{p=1}^{10} A_{t-p}^i}$$

4. Result

There were 158,950 patents issued in 2011 with journal articles as references retrieved as a dataset in this study, and 10,649 journals indexed in JCR 2011 in one or more of the 225 JCR categories.

4.1. Top ten journals on TIF_5 and JIF_5

The TIF_5 and TIF_{10} of the top ten journals and the numbers of papers and citations in the period of 2006–2010 and 2001–2010 are shown in Table 1. This table shows the JIF_5 values of each journal retrieved from JCR 2011. The top three journals were *Expert Opinion on Therapeutic Patents*, *ACM Computing Surveys*, and *Nature Biotechnology* with TIF_5 values which came to 0.2624, 0.2535, and 0.2522 respectively. Although the TIF_5 values of these three journals were only slightly different, the numbers of papers and citations varied dramatically. During the period of 2006–2010, *Expert Opinion on Therapeutic Patents* published 484 papers and received 127 citations, and *Nature Biotechnology* published 567 papers and received 143 citations. *ACM Computing Surveys*, on the other hand, published only 71 papers and received only 18 citations. This discrepancy in the numbers of papers is also seen in other journals. *IEEE Journal of Solid-State Circuits* ranked 4th and showed the highest number of papers published (1411) and citations received (290).

Disparities between TIF_5 and TIF_{10} values were also observed in Table 1. *ACM Computing Surveys*, *Nature Biotechnology*, and *IEEE Journal of Solid-State Circuits* are the top three journals when employing TIF_{10}. Compared to their TIF_5 values, the TIF_{10} values of *ACM Computing Surveys* and *Nature Biotechnology* are considerably higher, at 1.6000 compared to 0.2532 and 1.1788 compared to 0.2522 respectively. Although the numbers of papers during the 2001–2010 period are only twice those of the 2006–2010 period, the numbers of citations were ten times greater. From the perspective of TIF_{10}, six of the top ten journals show TIF_{10} values higher than their TIF_5 values in Table 1. Note that the numbers of papers and citations in *European Cells & Materials* and *Nature Nanotechnology* were identical during the two periods, as the former has been indexed in JCR since 2008 and the latter since 2006. Furthermore, *Geochemical Transactions* published nine more papers during the period of 2001–2010 compared to the 2006–2010 period as the journal has been indexed since 2005. The JIF_5 of the top ten journals by TIF_5 ranged from 0.56 to 33.78. Among these ten journals, *Nature Nanotechnology* showed the highest JIF_5 at 33.78, which is much higher than the JIF_5 of the other journals. The JIF_5 of *International Journal of Parallel Programming* was the lowest (0.56), corresponding to its ranking by TIF_5 and TIF_{10}. In addition, *Nature Biotechnology* showed the least disparity between JIF_5 and TIF_5 at 28.16 and 0.2522 respectively.

Table 2 shows the ranking of the top ten journals in different categories in JCR 2011. These ten journals were indexed in 11 categories in the JCR 2011 report. The top ten journals by TIF_5 were also the top journals in their own disciplinary categories. Three of the top ten journals were indexed in Pharmacology & Pharmacy and two in Theory & Methods Computer Science. Comparing the rankings among these ten journals, none performed as satisfactorily as their ranks on TIF_5. As shown in the Percentile Rank column, six journals ranged between 75.01% and 99.99% by JIF_5 in JCR 2011, two ranged between 50.01% and 75.00%, one journal in the range of 25.01% and 50.00%, and no journals in the bottom quartile. For example, the *International Journal of Parallel Programming* ranked 2nd in the JCR category of Theory & Methods Computer Science based on

Table 2
Top ten TIF_5 journals across categories with corresponding JCR and percentile ranks.

Journals	TIF_5	Category	JCR rank	Percentile rank (%)
Expert Opinion on Therapeutic Patents	0.2624	Chemistry, Medicinal	10/59	83.05
		Medicine, Legal	1/15	99.99
		Pharmacology & Pharmacy	54/261	79.31
ACM Computing Surveys	0.2535	Computer Science, Theory & Methods	1/99	99.99
Nature Biotechnology	0.2522	Biotechnology & Applied Microbiology	2/157	97.73
IEEE Journal of Solid-State Circuits	0.2055	Engineering, Electrical & Electronic	15/244	93.85
European Cells & Materials	0.1690	Biochemistry & Molecular Biology	126/289	56.40
		Materials Science, Biomaterials	7/25	72.00
Nature Nanotechnology	0.1645	Nanoscience & Nanotechnology	2/231	99.13
		Materials Science, Multidisciplinary	1/66	99.99
Drug Discovery Today	0.1596	Pharmacology & Pharmacy	11/261	95.79
Geochemical Transactions	0.1569	Geochemistry & Geophysics	37/76	51.32
Current Opinion in Drug Discovery & Development	0.1567	Pharmacology & Pharmacy	39/261	34.94
International Journal of Parallel Programming	0.1441	Computer Science, Theory & Methods	71/99	28.29

Percentile rank $= \frac{\text{the number of all journals in the category} - \text{JCR rank}}{\text{the number of all journals in the category}}$.

TIF_5; however, it was 71st out of 99 journals in the JCR report. The inconsistency of TIF_5 and JIF_5 among the top ten journals again indicates that the frequencies of journal citations from journals and patents may be different.

The TIF_5 performance of the top ten journals by JIF_5 in JCR 2011 is further investigated. As shown in Table 3, the top three journals by JIF_5 were *CA-A Cancer Journal for Clinicians*, *New England Journal of Medicine*, and *Reviews of Modern Physics*. Most of these journals were categorized in different JCR categories, except for *CA-A Cancer Journal for Clinicians* and *Nature Reviews Cancer*, which were both indexed in Oncology. Furthermore, only *Nature Materials* was categorized into multiple JCR categories, specifically into four categories. A comparison between the results in Tables 2 and 3 reveals some differences. First of all, with the exception of for Materials Science, Multidisciplinary, the top ten categories were different by TIF_5. Second, these nine journals ranged between 75.01% and 99.99% on their TIF_5, with *Physiological Reviews* being the only journal that ranged between 50.01% and 75.00%. Based on the results of Tables 2 and 3, this study shows that journals with higher JIF_5 values demonstrate better performance in TIF_5; however, journals with high TIF_5 values show inconsistent performance in JIF_5. In brief, a journal may receive diverse values and ranks in both TIF and JIF.

4.2. Comparison among TIF_5, TIF_{10}, and JIF_5 in Electrical & Electronic Engineering, Research & Experimental Medicine, and Organic Chemistry

Due to diversity of the number of citations in each disciplinary category, this study selected only three out of the top 15 JCR categories by TIF_5, TIF_{10}, and JIF_5 value for investigation. Three categories were selected from the top 15 JCR categories by TIF_{AGG_5}. Table 4 shows the top 15 categories based on TIF_{AGG_5}. The top three categories were Multidisciplinary Sciences, Legal Medicine, and Medicinal Chemistry, with TIF_5 values of 0.0286, 0.0277, and 0.0253 respectively. The numbers of papers and patent citations in 2011 varied across disciplinary categories. For example, the numbers of papers in Multidisciplinary Sciences and Medicinal Chemistry were nearly ten times that in Legal Medicine. In addition, the numbers of patent citations in the former two categories were far greater that of Legal Medicine. Therefore, the selected categories should have the greatest

Table 3
Top ten JIF_5 journals across categories with their corresponding TIF_5 and percentile ranks.

Journals	JIF_5	Category	TIF_5 rank	Percentile rank (%)
CA-A Cancer Journal for Clinicians	67.41	Oncology	18/193	90.67
New England Journal of Medicine	50.08	Medicine, General & Internal	1/153	99.99
Reviews of Modern Physics	44.44	Physics, Multidisciplinary	9/84	89.29
Annual Review of Immunology	42.90	Immunology	32/139	76.98
Nature Reviews Molecular Cell Biology	42.51	Cell Biology	14/180	92.22
Chemical Reviews	42.05	Chemistry, Multidisciplinary	15/152	90.13
Nature Reviews Cancer	38.46	Oncology	3/193	98.45
Nature Materials	36.73	Chemistry, Physical	1/134	99.99
		Materials Science, Multidisciplinary	2/230	99.13
		Physics, Applied	2/125	98.40
		Physics, Condensed Matter	1/69	99.99
Nature	36.24	Multidisciplinary Sciences	3/55	94.55
Physiological Reviews	36.17	Physiology	22/79	72.15

Percentile rank $= \frac{\text{the number of all journals in the category} - \text{JCR rank}}{\text{the number of all journals in the category}}$.

Table 4
Top 15 JCR categories by TIF_{AGG_5} with their corresponding TIF_{AGG_10} values.

JCR category	2006–2010			2001–2010		
	TIF_{AGG_5}	Paper	Patent citations	TIF_{AGG_10}	Paper	Patent citations
Multidisciplinary Sciences	0.0286	50,122	1432	0.0941	87,644	8247
Medicine, Legal	0.0277	5589	155	0.0446	10,551	471
Chemistry, Medicinal	0.0253	50,720	1281	0.0648	82,373	5340
Materials Science, Biomaterials	0.0237	16,468	391	0.0796	24,793	1974
Engineering, Biomedical	0.0161	36,007	581	0.0526	57,155	3004
Physics, Applied	0.0147	204,341	3008	0.0381	346,069	13,183
Materials Science, Coatings & Films	0.0138	29,040	402	0.0318	50,837	1617
Engineering, Electrical & Electronic	0.0136	172,426	2351	0.0392	288,966	11,335
Electrochemistry	0.0135	43,545	590	0.0307	67,999	2089
Medicine, Research & Experimental	0.0124	57,113	706	0.0423	98,896	4187
Nanoscience & Nanotechnology	0.0123	75,664	927	0.0360	103,236	3713
Chemistry, Organic	0.0120	97,124	1170	0.0326	179,393	5844
Cell & Tissue Engineering	0.0119	5364	64	0.0317	6904	219
Oncology	0.0114	123,629	1409	0.0285	217,450	6196
Chemistry, Multidisciplinary	0.0111	175,231	1937	0.0323	295,315	9543

values of both TIF values and numbers of papers and patent citations during the two periods, excluding multidisciplinary categories. Based on these selection criteria, Applied Physics, Electrical & Electronic Engineering, Research & Experimental Medicine, and Organic Chemistry were selected. Because nearly one-third of the journals in Applied Physics were also indexed in Electrical & Electronic Engineering, this study decided to analyze journals in the Electrical & Electronic Engineering category only. These three categories – Electrical & Electronic Engineering, Research & Experimental Medicine, and Organic Chemistry – are from different fields, namely Engineering, Medicine, and Chemistry.

The TIF_5, TIF_{10}, and JIF_5 of journals in three selected JCR categories are shown in Tables 5–7, and the ranks of the top 30 journals by each indicator are marked in bold. As shown in Table 5, the values of TIF_{10} are two to six times those of TIF_5 in Electrical & Electronic Engineering. Looking at the top 30 journals by TIF_5, the TIF_{10} values of 18 journals were double their TIF_5 values. The TIF_{10} of *IEEE Signal Processing Magazine* was six times its TIF_5. In contrast, the TIF_{10} values of *IEEE Transactions on Energy Conversion* and *IETE Technical Review* were lower than their TIF_5 values. Differences between the JIF_5 and two TIF values were also investigated. Ten of the top 30 journals by TIF_5 were not among the top 30 by TIF_{10}. Furthermore, only 12 journals were included in the top 30 by JIF_5. In other words, the JIF_5 values of journals presented a greater discrepancy with both TIF_5 and TIF_{10}. For example, the *IEEE Journal of Solid-State Circuits* ranked the first in both TIF_5 and TIF_{10}; however, the journal only ranked 14th when employing JIF_5. The *Bell Labs Technical Journal* ranked 12th by TIF_5, 37th by TIF_{10}, but 168th by JIF_5. *Solid State Technology* was another example, ranking 13th and 21st by TIF_5 and TIF_{10} respectively, but only 208th by JIF_5.

Rankings of journals in Research & Experimental Medicine also varied when employing TIF_5, TIF_{10}, and JIF_5. Sixteen journals in JCR showed TIF_{10} values five times higher than their TIF_5 values. *Nature Medicine* showed the greatest discrepancy, with values of 0.1120 and 0.5727. Seven of the top 30 journals by TIF_5 were not included in the top 30 by TIF_{10}; 13 journals were not included in the top 30 by JIF_5. For example, *Acta Medica Okayama* had the greatest disparity between rankings by TIF_5 (30th), TIF_{10} (35th) and JIF_5 (85th). Inconsistency of rankings on three indicators also existed in the Research & Experimental Medicine category.

Table 7 shows the rankings in Organic Chemistry, with TIF_{10} values increasing to two to six times that of the TIF_5 values. Due to the small value of its TIF_5, *Current Organic Chemistry* showed the most dramatic difference at 0.0019 and 0.0243 for TIF_5 and TIF_{10} respectively. In contrast, the *Journal of Carbohydrate Chemistry*, *Natural Product Reports*, and *Petroleum Chemistry* showed smaller values for TIF_{10} than TIF_5. Seven of the top 30 journals by TIF_5 were not also ranked in the top 30 by TIF_{10}, and 11 journals were not included in the top 30 by JIF_5. As shown in Table 7, *Bioorganic & Medicinal Chemistry Letters* ranked 1st and 3rd using TIF_5 and TIF_{10} respectively, but ranked 22nd using JIF_5. In contrast, *Aldrichimica Acta* did not receive any patent citations in last five years ($TIF_5 = 0.0000$), despite the fact that this journal ranked the 1st by both TIF_{10} and JIF_5. *Advances in Carbohydrate Chemistry and Biochemistry* also showed a TIF_5 of 0.0000 but ranked much higher by TIF_{10} and JIF_5.

5. Discussion

As mentioned in the literature review section, due to differences in sizes and features across disciplines, journal impact factors, numbers of papers, and paper citations in different disciplinary categories vary. Despite the minor disparity among TIF_{AGG_5} values among the top ten categories, patent citations of journals are different across disciplinary categories. According to Narin and Olivastro (1992), science linkages occur more frequently in pharmaceutical, chemical and electronic patents. Furthermore, in the same paper, Narin and Olivastro stated that around 90% of journal references were from basic or applied scientific journals, as opposed to journals in the engineering field. In this study, Table 4 shows that in the top ten categories (excluding multidisciplinary categories), two are from medicine, two are from material science, two are from engineering,

Table 5
The top 30 TIF_5, TIF_{10}, JIF_5 journals in the Electrical & Electronic Engineering category.

Journal	TIF_5		TIF_{10}		JIF_5	
	TIF_5	Rank	TIF_{10}	Rank	JIF_5	Rank
IEEE Journal of Solid-State Circuits	0.2055	**1**	0.4144	**1**	3.55	**14**
IEEE Transactions on Power Electronics	0.1374	**2**	0.2059	**5**	4.66	**7**
IEEE Design & Test of Computers	0.0725	**3**	0.1109	**13**	1.66	82
IEEE Wireless Communications	0.0705	**4**	0.1789	**7**	3.13	**23**
IEEE Electron Device Letters	0.0702	**5**	0.2015	**6**	2.71	**30**
Proceedings of the IEEE	0.0683	**6**	0.2698	**4**	6.46	**3**
IEEE Transactions on Broadcasting	0.0633	**7**	0.0898	**20**	1.89	63
IEEE Transactions on Pattern Analysis and Machine Intelligence	0.0582	**8**	0.1560	**9**	6.09	**4**
IEEE Communications Magazine	0.0570	**9**	0.2899	**2**	3.27	**19**
IEEE Transactions on Electron Devices	0.0516	**10**	0.1288	**12**	2.48	39
IEEE Signal Processing Magazine	0.0465	**11**	0.2851	**3**	6.52	**2**
Bell Labs Technical Journal	0.0426	**12**	0.0491	37	0.64	168
Solid State Technology	0.0398	**13**	0.0890	**21**	0.25	208
IEEE Transactions on Image Processing	0.0389	**14**	0.0963	**17**	3.77	**13**
IEEE Transactions on Nanotechnology	0.0381	**15**	0.0632	**30**	2.14	52
IEEE Transactions on Device and Materials Reliability	0.0369	**16**	0.0393	47	1.67	80
IEEE Transactions on information Forensics and Security	0.0369	**17**	0.0369	50	2.16	50
IEEE Transactions on Energy Conversion	0.0363	**18**	0.0356	52	3.43	**16**
IEEE Photonics Technology Letters	0.0352	**19**	0.0726	**27**	1.86	64
Journal of Microelectromechanical Systems	0.0346	**20**	0.1642	**8**	2.51	36
Etri Journal	0.0337	**21**	0.0426	44	0.78	151
IEEE Journal on Selected Areas in Communications	0.0287	**22**	0.1032	**15**	4.84	**6**
IEEE Microwave Magazine	0.0287	**23**	0.0871	**22**	1.75	70
IETE Technical Review	0.0283	**24**	0.0154	85	0.36	195
IEEE Sensors Journal	0.0280	**25**	0.0341	57	1.73	73
Materials Science in Semiconductor Processing	0.0269	**26**	0.0430	42	0.94	132
Journal of Lightwave Technology	0.0266	**27**	0.0589	32	2.68	31
IEEE Transactions on Semiconductor Manufacturing	0.0249	**28**	0.0566	34	1.10	121
IEEE Journal of Selected Topics in Quantum Electronics	0.0248	**29**	0.0773	**25**	3.51	**15**
IEEE Transactions on Microwave Theory and Techniques	0.0242	**30**	0.094	**19**	2.06	55
IEEE Transactions on Medical Imaging	0.0241	31	0.1455	**10**	4.11	**11**
IEEE Transactions on Circuits and Systems for Video Technology	0.0222	33	0.1417	**11**	2.49	37
IEEE Transactions on Computers	0.0204	34	0.1008	**16**	1.63	84
IEEE-ACM Transactions on Networking	0.0171	42	0.0833	**23**	2.81	**28**
IEEE Transactions on Communications	0.0163	44	0.0761	**26**	1.79	68
IEEE Transactions on Information Theory	0.0135	50	0.0692	**28**	4.12	**10**
IEEE Transactions on Consumer Electronics	0.0134	52	0.0957	**18**	0.96	130
IEEE intelligent Systems	0.0120	57	0.1073	**14**	2.32	44
Signal Processing-Image Communication	0.0000	–	0.0799	**24**	1.31	109
Computer Vision And Image Understanding	0.0000	–	0.0639	**29**	2.49	38

one is from physics, and one is from chemistry. In addition, Applied Physics was the JCR category with the highest number of patent citations, followed by Electrical & Electronic Engineering. However, these two JCR categories showed relatively higher number of papers, and tended to receive a greater number of patent citations.

Narin and Olivastro's study indicated that journal articles were generally cited by patents three to five years after the articles were published. However, in this study, TIF_{10} values were shown to be twice as high as TIF_5 values, as shown in Table 4. Furthermore, Tables 5–7 also showed that most TIF_{10} values in Electrical & Electronic Engineering, Research & Experimental Medicine, and Organic Chemistry are more than double their TIF_5 values. The TIF_{10} values in these tables may suggest that journal articles receive more patent citations after they have been published for more than five years.

The relations between TIF_5, TIF_{10}, and JIF_5 in these three categories are shown in Figs. 1–3. As presented in the figures, TIF_5 values in these three categories positively correlated with TIF_{10} and JIF_5. However, the R^2 values were different. In terms of TIF_{10}, R^2 value showed the highest values in Electrical & Electronic Engineering (0.7372) but the lowest in Organic Chemistry (0.4449). However, R^2 values were low in all three categories, which indicates that TIF_5 values may not positively correlated to JIF_5.

Considering the great differences in the numbers of journals among the three categories, correlation testing among TIF_5, TIF_{10}, and JIF_5 values was conducted. As shown previously, it is possible that the TIF_5, TIF_{10} and JIF_5 values of a journal show no positive correlation; hence, Spearman's rank correlations based on the top 30 journals by TIF_5 were conducted among the three indicators for the three selected JCR categories. As shown in Table 8, the results of the Spearman's correlation test revealed that Organic Chemistry was the only one of the categories in which the journal rankings by TIF_5 showed no significant correlation with its JIF_5. The TIF_5, TIF_{10} and JIF_5 values in the other two JCR categories all significantly correlated with each other at the 0.05 level. Even though most of the values were significant, the relationship between JIF_5 and TIF values is comparably weak among all three categories.

Table 6
Top 30 TIF_5, TIF_{10}, JIF_5 journals in the Research & Experimental Medicine category.

Journal	TIF_5		TIF_{10}		JIF_5	
	TIF_5	Rank	TIF_{10}	Rank	JIF_5	Rank
Nature Medicine	0.1120	**1**	0.5727	**1**	26.42	**1**
Journal of Clinical Investigation	0.1051	**2**	0.2567	**2**	15.43	**2**
Trends in Molecular Medicine	0.0689	**3**	0.2000	**3**	9.84	**7**
Molecular Therapy	0.0475	**4**	0.1290	**5**	6.28	**9**
Current Opinion in Molecular Therapeutics	0.0464	**5**	0.1194	**7**	2.89	36
Expert Opinion on Biological Therapy	0.0456	**6**	0.1266	**6**	2.93	35
Journal of Experimental Medicine	0.0446	**7**	0.1901	**4**	14.67	**3**
Human Gene Therapy	0.0389	**8**	0.1085	**9**	3.96	**20**
Journal of Immunotherapy	0.0364	**9**	0.1144	**8**	3.23	**29**
Experimental and Molecular Medicine	0.0233	**10**	0.0258	**18**	2.38	49
Journal of Molecular Medicine-JMM	0.0216	**11**	0.0705	**10**	4.70	**13**
Translational Research	0.0205	**12**	0.0205	**23**	2.69	41
Melanoma Research	0.0195	**13**	0.0244	**20**	2.27	53
Wound Repair and Regeneration	0.0186	**14**	0.0312	**15**	3.42	**26**
Annual Review of Medicine	0.0178	**15**	0.0590	**11**	10.71	**4**
European Journal of Clinical Investigation	0.0168	**16**	0.0202	**24**	2.80	37
Cancer Gene Therapy	0.0145	**17**	0.0260	**17**	2.51	46
Indian Journal of Medical Research	0.0138	**18**	0.0172	**25**	2.19	56
Stem Cells and Development	0.0131	**19**	0.0265	**16**	4.38	**17**
Journal of Biomedicine and Biotechnology	0.0126	**20**	0.0135	32	2.36	50
Journal of Cellular and Molecular Medicine	0.0115	**21**	0.0244	**19**	4.48	**15**
Science Translational Medicine	0.0107	**22**	0.0107	34	7.81	**8**
Vaccine	0.0106	**23**	0.0391	**12**	3.70	**24**
Journal of Biomedical Science	0.0105	**24**	0.0360	**13**	1.97	61
Experimental Biology and Medicine	0.0090	**25**	0.0091	37	2.80	38
Journal of Gene Medicine	0.0090	**25**	0.0355	**14**	2.59	44
Stem Cell Reviews and Reports	0.0090	**27**	0.0090	38	3.74	**22**
Laboratory Investigation	0.0082	**28**	0.0139	31	4.41	**16**
Journal of Translational Medicine	0.0081	**29**	0.0081	39	3.69	**25**
Acta Medica Okayama	0.0078	**30**	0.0106	35	0.78	85
International Journal of Molecular Medicine	0.0065	33	0.0237	**21**	1.75	68
Clinical Science	0.0000	–	0.0222	**22**	4.18	**18**
Clinical and Experimental Medicine	0.0000	–	0.0172	**26**	1.85	65
Advances in Therapy	0.0019	39	0.0158	**27**	1.50	71
Journal of Investigative Medicine	0.0042	35	0.0152	**28**	1.71	69
Biomedicine & Pharmacotherapy	0.0072	32	0.0143	**29**	2.34	51
Molecular Medicine	0.0000	–	0.0141	**30**	4.60	**14**

While the results of this study also showed that TIF_5 and TIF_{10} positively correlate with JIF_5 at a significant level, this study identified a trend that is slightly different from the results of previous studies. For example, Glanzel and Zhou (2011) and Guan and He (2007) indicated that articles receiving great numbers of patent citations may also have high impacts on their own scientific categories. Meyer et al. (2010) further indicated that this trend also exists at the journal level. This study, however, identified a trend opposite to these statements. As shown in Table 3, the top ten journals by JIF_5 across categories did generally performed well on TIF_5, however, Table 2 shows that the top ten journals by TIF_5 were not as good as by JIF_5.

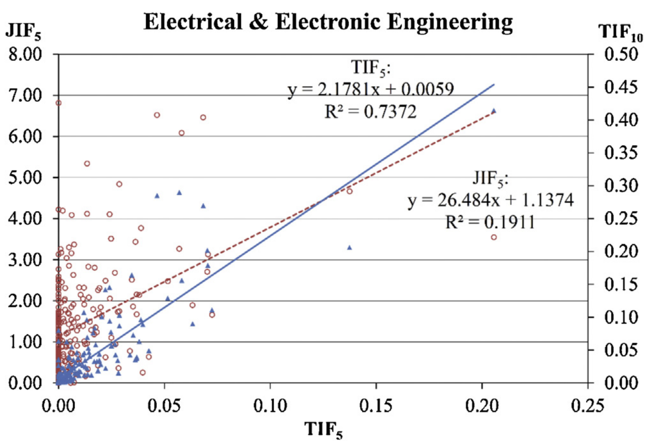

Fig. 1. Scatter plots and trend lines for TIF_5, TIF_{10}, and JIF_5 in Electrical & Electronic Engineering.

Table 7
The top 30 TIF_5, TIF_{10}, JIF_5 journals in the Organic Chemistry category.

Journal	TIF_5		TIF_{10}		JIF_5	
	TIF_5	Rank	TIF_{10}	Rank	JIF_5	Rank
Bioorganic & Medicinal Chemistry Letters	0.0644	**1**	0.1468	**3**	2.54	**22**
Bioconjugate Chemistry	0.0643	**2**	0.1549	**2**	5.22	**8**
Biomacromolecules	0.0382	**3**	0.1078	**4**	5.65	**5**
Bioorganic & Medicinal Chemistry	0.0211	**4**	0.0683	**5**	3.16	**16**
Journal of Organic Chemistry	0.0146	**5**	0.0510	**6**	4.20	**9**
Organic Process Research & Development	0.0141	**6**	0.0423	**7**	2.38	**26**
Tetrahedron Letters	0.0130	**7**	0.0361	**10**	2.59	**20**
Tetrahedron	0.0125	**8**	0.0411	**9**	3.06	**17**
Journal of Fluorine Chemistry	0.0116	**9**	0.0339	**13**	1.95	32
Tetrahedron-Asymmetry	0.0090	**10**	0.0341	**11**	2.65	**19**
Current Organic Synthesis	0.0088	**11**	0.0252	**15**	3.84	**11**
Mini-Reviews in Organic Chemistry	0.0069	**12**	0.0299	**14**	2.28	**27**
Bioorganic Chemistry	0.0058	**13**	0.0340	**12**	1.55	34
Journal of Organometallic Chemistry	0.0057	**14**	0.0156	**18**	2.09	**30**
Journal of Heterocyclic Chemistry	0.0055	**15**	0.0085	**22**	1.07	38
Journal of Carbohydrate Chemistry	0.0055	**15**	0.0022	38	0.93	41
Synthetic Communications	0.0040	**17**	0.0143	**19**	1.09	37
Heterocyclic Communications	0.0037	**18**	0.0073	**24**	0.30	53
Natural Product Reports	0.0034	**19**	0.0021	39	9.67	**2**
Beilstein Journal of Organic Chemistry	0.0030	**20**	0.0030	35	2.08	31
Petroleum Chemistry	0.0028	**21**	0.0014	42	0.41	52
Synthesis-Stuttgart	0.0028	**21**	0.0032	33	2.45	**23**
Organometallics	0.0027	**23**	0.0036	31	3.79	**12**
European Journal of Organic Chemistry	0.0024	**24**	0.0167	**17**	3.29	**15**
Organic Letters	0.0023	**25**	0.0091	**20**	5.56	**6**
Current Organic Chemistry	0.0019	**26**	0.0243	**16**	3.47	**14**
Russian Journal of Organic Chemistry	0.0017	**27**	0.0088	**21**	0.64	48
Advanced Synthesis & Catalysis	0.0017	**27**	0.0083	**23**	5.90	**4**
Journal of Physical Organic Chemistry	0.0016	**29**	0.0063	**25**	1.65	33
Letters in Organic Chemistry	0.0014	**30**	0.0031	34	0.79	44
Heterocycles	0.0005	34	0.0048	**27**	1.01	40
Aldrichimica Acta	0.0000	35	0.2419	**1**	16.88	**1**
Advances in Carbohydrate Chemistry and Biochemistry	0.0000	35	0.0417	**8**	5.56	**6**
Organic Preparations And Procedures International	0.0000	35	0.0049	**26**	1.04	39
Russian Journal of Bioorganic Chemistry	0.0000	35	0.0042	**28**	0.62	50
Chemistry of Natural Compounds	0.0000	35	0.0041	**29**	0.87	42
Chinese Journal of Organic Chemistry	0.0000	35	0.0037	**30**	0.59	51

Furthermore, the Spearman's test also revealed that TIF_5 had a positive, yet weak, correlation with JIF_5. On the other hand, TIF_{10} had a stronger positive relationship with JIF_5.

This study proposed a technological impact factor for journals, which is not only an "impact factor," but can also serve as an indicator for measuring the level of a journal's contribution to industries and technology development. Industries can focus on particular journals with higher TIFs in relevant categories to improve technologies. Furthermore, TIFs can provide a new reference for journal purchases by the libraries of private firms in areas where patents are important, since TIFs perform

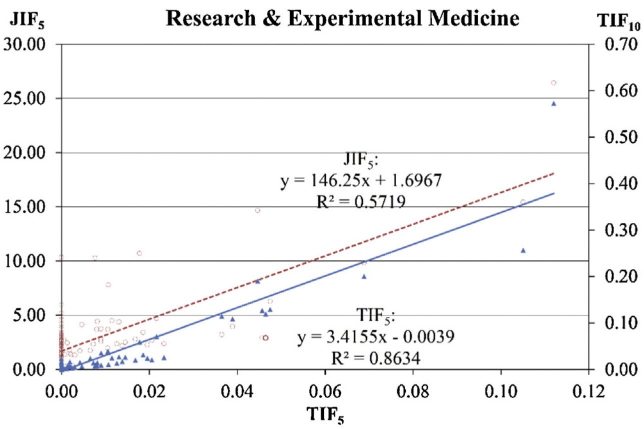

Fig. 2. Scatter plots and trend lines for TIF_5, TIF_{10}, and JIF_5 in Research & Experimental Medicine.

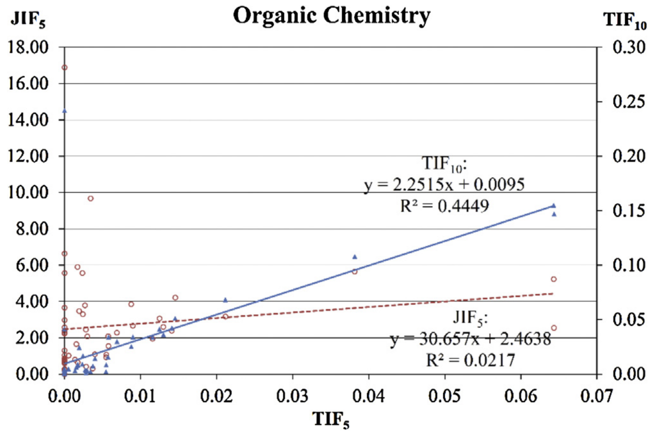

Fig. 3. Scatter plots and trend lines for TIF_5, TIF_{10}, and JIF_5 in Organic Chemistry.

Table 8
Spearman correlations between the TIF_5, TIF_{10} and JIF_5 for the three JCR categories.

	Electrical & Electronic Engineering		Research & Experimental Medicine		Organic Chemistry	
	TIF_5	TIF_{10}	TIF_5	TIF_{10}	TIF_5	TIF_{10}
TIF_{10}	.661**	–	.832**		.801**	
JIF_5	.363*	.657**	.418**	.506**	.236	.380*

* Correlation is significant at the 0.05 level.
** Correlation is significant at the 0.01 level.

differently from JIFs. When employing TIFs, however, there are some limitations worth noting. First, citation behavior and the nature of categories vary across categories. As seen in the tables of the top ten TIF_5 journals across categories, the TIF values of each journal vary by category. Hence, TIFs should be used carefully when comparing values across categories. Second, citation window period should be noted. From Tables 5–7, we see that some journals were highly cited more than five years after publishing. Moreover, due to differences in technology cycle time in each category (Kayal & Waters, 1999), the nature of categories should also be considered when setting citation windows.

6. Conclusion

This study developed a technological impact factor (TIF), derived from the journal impact factor method, which divides the number of citations received from patent by the number of journal articles. TIF is mainly used to examine the impact of journal articles on patents and could be a new indicator for evaluating journals from the aspect of practical innovation. To investigate the TIF values of journals in different disciplinary categories, the study collected patents issued in 2011 which had references to academic articles in journals indexed in the 2011 Journal Citation Report (JCR). The TIF values were calculated for each journal and TIF_{AGG} for each JCR category. This study calculated TIF values for both five-year and ten-year periods, since patent citations to journal articles are not shown as frequently as journal article citing each other. The JIF_5 values published by JCR 2011 were also collected for further comparison with the two TIFs.

This study shows that on the category level, most of the top ten categories were from basic and applied sciences, such as Medicine, Chemistry, Material Science, and so forth. Second, on the journal level, the top ten journals by TIF_5 showed a diversity of performance in JCR; however, the top ten journals by JIF_5 generally performed well in terms of TIF value. Third, most of the TIF_{10} values in Electrical & Electronic Engineering, Research & Experimental Medicine, and Organic Chemistry were twice those of TIF_5. However, the rankings of the journals by the three types of impact factors were not consistent. In other words, the top 30 journals by TIF_5 are different from the top 30 journals by TIF_{10}. Moreover, the discrepancy of the rankings was even greater between the two TIFs and JIF_5. By Spearman's analysis, the rankings by TIF_5 then became significantly, but weakly, correlated with the rankings by JIF_5 in Electrical & Electronic Engineering and Organic Chemistry. Generally, the values and rankings by TIF_{10} correlated more with those by JIF_5.

Based on these results, calculating impact factors based on patent citations to journal may show similar features and limitations as paper citations. For example, when calculating the TIF, differences in the sizes of categories should be considered. In addition, the results also show that the differences between the values of TIF_5 and those of TIF_{10} varied across categories. Therefore, the half-life of the patent citation may also be different. The discrepancy of the TIFs and JIF_5 in the same category is a suggested direction for further study.

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