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Influences of counting methods on country rankings: a perspective from patent analysis

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Abstract The counting of patents and citations is commonly used to evaluate technological innovation and its impact. However, in an age of increasing international collaboration, the counting of international collaboration patents has become a methodological issue. This study compared country rankings using four different counting methods (i.e. whole counting, straight counting, whole-normalized counting, complete-normalized counting) in patent, citation and citation-patent ratio (CP ratio) counts. It also observed inflation depending on the method used. The counting was based on the complete 1992–2011 patent and citation data issued by United States Patent and Trademark Office. The results show that counting methods have only minor effects on country rankings in patent count, citation count and CP ratio count. All four counting methods yield reliable country ranks in technology innovation capability and impact. While the influences of counting methods vary between patent count, citation count and CP ratio count, counting methods may exert slightly greater effects on CP ratio counts than on patent and citation counts. As for the inflation, the distributions of higher and lower inflation by the four counting methods are different in patent, citation and CP ratio counts.

Keywords Counting methods · Country rankings · Inflation · Patent

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Introduction

The counting of patents and citations is the most commonly used method for country-level evaluation of technological innovation and its impact. However, as international technological collaboration increases, it becomes more conceptually and methodologically challenging to conduct counting of international patents to demonstrate each country's contribution. At present, three major counting approaches exist (Gauffriau et al. 2005, 2007, 2008; Huang et al. 2011). The first one is the all counting approach, which accredits each collaborator one full credit. There are two calculation methods in all counting: one being whole counting and the other being complete counting. The difference between whole counting and complete counting lies in the following example. When a patent is co-invented in four addresses of three countries, two in the United States, one in Germany and one in China, each of the three countries receives one credit using whole counting. However, the United States would receive two credits, while Germany and China would each receive one if using complete counting. The second is straight counting, in which only the most prominent collaborator receives one full credit, while the others receive none. The third is fractional counting, in which one credit is equally shared by all collaborators. None of the aforementioned approaches are ideal or perfect for innovation capability assessment, but they are frequently used in evaluation programs due to the availability of data and the ease of computation.

In order to provide a more accurate picture of country rankings, many scholars have dedicated themselves to the issues involved in different counting methods and how counting methods influence the evaluation on country level. The whole counting method, which belongs to the all counting method, is widely used in paper counting and is also the de facto method for several well-known evaluation programs (Academic Ranking of World Universities 2010; Higher Education Evaluation and Accreditation Council of Taiwan 2012; Huang 2011; Quacquarelli Symonds 2011). Yet, the whole counting method unavoidably produces a higher number of paper count than straight or fractional counting, introducing the problem of counting inflation. Gauffriau and Larsen found that a country's publication number reduction rate could be as high as 10–32 % between whole counting and fractional counting on a country-level assessment using U.S. National Science Foundation statistics (Gauffriau et al. 2005). They also found that with increased research collaboration from 1981 to 2002, whole counting has led to chronologically greater counting inflation (Gauffriau et al. 2008).

Another problem associated with counting method is rank dependency. Whole counting and fractional counting are rank independent, disregarding the order of authorship and accrediting each collaborator with an equal share of credit. Straight counting is rank dependent because it accredits only the most prominent collaborator (e.g. the first author or the corresponding author), hence some scholars have criticized the crudeness of accreditation for lacking scrupulous differentiation and weighting of collaborators' contributions (Nudelman and Landers 1972; Egghe et al. 2000). Accordingly, Pravdi′c and Olui′c-Vukovic suggested a "dual approach", which combines whole counting and modified straight counting for assessment. In the modified straight count, each paper as a unit is allocated to the more productive author, rather than the first author. However, identification of more productive authors needs sophisticated computation of the authors' collaboration links (Pravdi′c and Olui′c-Vukovic 1986, 1991). Tol (2011) proposed Pareto weights to objectively attribute citations to co-authors. Pareto weights is based on citation records of the co-authors, which is proportional to the probability of the number of citations obtained. Liu et al. developed a citation allocation scheme, between equally fractional counting and one that employs inverse of author rank. Parento weights uses a parameter to adjust the credit distribution among the different authors, which can either be used independently to indicate one's performance in a paper, or can be applied in the modification of h-index and g-index to represent the overall achievement of a scientist (Liu et al. 2012).

In order to reveal the influence of counting methods on country rankings, Gauffriau and Larsen compared whole counting and fractional counting based on paper count and citation count. The results showed that rankings based on different counting methods cannot be compared, though fractional counting is preferred (Gauffriau et al. 2005). In another study, they pointed out that whole counting is favorable in certain countries, especially countries with high levels of international cooperation (Gauffriau et al. 2008). Based on a set of information science papers, Persson compared author citations with first author citations. He demonstrated that all author citation counts are preferred when visualizing the structure of research fields, though both methods tends to give the same results under the subfield structure (Persson 2001). Huang, Lin, and Chen systematically studied five commonly used methods using the complete 1989–2008 paper and citation data of the physics journals. They found that the selection of counting methods had a minor influence on country rankings, but the influences of counting methods varied between paper count and citation count. Meanwhile, they suggested that the popular counting method (whole counting) may not be the best method to be employed. Straight counting or fractional counting that accredits each collaborator with partial and weighted credit may be better options (Huang et al. 2011).

Although, as mentioned, many studies have been done on counting methods, these papers focused on paper counts and paper citation counts, which are used to assess scientific research productivity and impact. Little research has attempted to study the influence of different counting methods on patent count and patent citation count. Patents reflect the latest technological inventions as well as a country's innovativeness. Accordingly, patent count and patent citation count are two basic bibliometric indicators that assess technological innovation and its impact. According to the United States Patent and Trademark Office (USPTO) convention, the nationality of a patent is determined by the address of the first inventor, which employs the straight counting method extracting the first inventor (Trajtenberg 2001). With the implicit assumption that the first inventor is the most important in undertaking the inventive work in the patent, the inventive/innovative activity and capability in a country can be distinguished using this approach. Meanwhile, it can rectify the inflation problem (Bhattacharya 2004). That straight counting method using the first inventor has also been a common approach due to ease of programming (Thompson and Fox-Kean 2005). However, some scholars have questioned whether this is the best method regardless of the situation (Trajtenberg 2001). We are interested in whether different counting approaches might influence the country rankings of national technological innovation capability and impact, and to what extent patent and citation numbers may inflate when different approaches are used.

Thus, we systematically study the influence of four commonly used methods on country rankings and on counting inflations using patent and citation data from 1992 to 2001 issued by USPTO. The goal of this is to offer a highly accurate picture of how counting methods influence country rankings and the degrees of counting inflation, in the evaluation of technological innovation and particular impacts.

Methodology

The data

The USPTO is the federal agency responsible for granting patents and registering trademarks. Founded in 1802, the USPTO has granted more than 4,000,000 patents since 1976. Patents granted by the USPTO provide a relatively accurate picture of the world's technology distribution: Approximately half of the inventions of U.S. patents are foreign-owned, and numbers of U.S.-granted invention patents in each country are roughly proportional to the country's gross domestic product (GDP) (Narin 1991). Taking the quality factors into consideration, USPTO-granted patents have higher technological value than foreign patents and, and can to some extent indicate higher invention quality (Hinze and Schmoch 2004; Soete and Wyatt 1983). Among various types of patents (e.g. utility patents, design patents, and plant patents), utility patents best reflect a country's R&D and innovation capability. Additionally, the USPTO provides elaborate citation data, which can be used for impacts assessment. Thus, the patent data for this study has been retrieved from the USPTO database and downloaded online on November 19th, 2012, consisting of all the USPTO-issued utility patents from 1992 to 2011.

Patents of a country can be identified in the USPTO database via the patents of assignee country and the patents of inventor country (Bhattacharya 2004). International co-invented patents are those that are co-invented by two or more inventors with addresses located in different countries. International co-assigned patents are those that are co-assigned in two or more assignees in different countries. Usually, people employ inventor country patents (i.e. patents attributed to a country based on address of any of the inventor belonging to it), as these patents reveal the inventive/innovative ability of a country. The number of international co-invented patents is far greater than that of international co-assigned patents in the data mentioned above. There are 3,006,937 patents in total during the past 20 years, of which 150,120 are international co-invented patents, while there are only 20,352 international co-assigned patents. Accordingly, the influence of different counting methods on country rankings would be more significant when using international co-invented patents rather than using international co-assigned patents. Thus, the present study uses 'inventor country' patents to explore the influence of different counting methods on country rankings as well as the inflation problem.

The counting methods

Based on the dataset, four counting methods are employed to study the country rankings from the perspective of patent count, citation count and patent-citation ratio, respectively, as seen in Table 1. We are interested in whether different counting methods may generate different country rankings as well as to what extent the ranking results vary. Additionally, the inflation rates by different counting methods are elaborated. The four counting methods are as follows, which represent the three counting approaches introduced earlier: all counting, straight counting and fractional counting.

1. Whole counting (Method A): each collaborating country receives one full credit. There are two types of all-counting methods: whole counting and complete counting. The difference between them can be shown with an example: in a country-level assessment, a patent is co-invented in four addresses of three countries, two in the United States, one in Germany and one in China. Using whole counting, each of the three countries receives

Table 1 The four counting methods and their definitions

	Counting methods	Definition
Method A	Whole counting	Each collaborating country receives one full credit
Method B	Straight counting	Only the first inventor's country receives one full credit, while other collaborating countries receive none
Method C	Whole-normalized counting	Each collaborating country receives an equal share of the credit
Method D	Complete-normalized counting	All inventor addresses are used as the basis for counting. Each of them receives an equal share of one credit, and the fractional credits of each country are added and form that country's share

one credit. Using complete counting, the United States would receive two credits, while Germany and China each receive one. This study does not consider complete counting as a reasonable method, as it doesn't make sense to say the United States has invented two patents when there is just one patent from the USA. So in this study, we decided to employ the whole counting method. The whole counting method is widely used in paper counting and is also the de facto method for several well-known evaluation programs as mentioned above. Note that, however, this method is not additive.

2. Straight counting (Method B): using the first inventor: only the first inventor's country receives one full credit, while other collaborating countries receive none.
3. Whole-normalized counting (Method C): regardless of the number of inventor addresses, only the number of nationalities are considered. Each collaborating country receives an equal share of the credit. Using the previous example mentioned in whole counting, when whole-normalized counting is used, the United States, Germany and China each receive one-third of the credit.
4. Complete-normalized counting (Method D): all inventor addresses are used as the basis for counting. Each of them receives an equal share of one credit, and the fractional credits of each country are added and form that country's share. Using the previous example again, when complete-normalized counting is used, the United States will receive one half while Germany and China each receive one-fourth.

Indicators

Citation-patent ratio (CP ratio)

CP ratio is the number of citations per patent within a certain period. CP ratio is mainly used to measure the impact of each patent, and displays the influence of patents on scientific and technical progress. It is worth noting that a fixed citation window would better evaluate the citations of patents. For countries whose patents occurred late in the period, citations and CP ratio tends to be lower than the true long-term citation rates. This is because most of the patents are recent and lack sufficient time to accumulate citations over any given citation window.

$$\mathrm{CP}_{\mathrm{ratio}} = \frac{\mathrm{NC}}{\mathrm{NP}}$$

where NC is the sum of citations within a certain period, NP is the total number of patents within the same period, CP ratio is the number of citations per patent within a certain period.

Ratio of counting inflation

The ratio of counting inflation is obtained by dividing patent count (or citation or CP ratio) from Method A (whole counting) by those from Methods B to D, respectively.

In patent counting, countries with low inflation may have not been involved as much as the other countries in international collaboration. While, countries with higher inflation would probably serve supporting or facilitating roles rather than being the first inventor when participating in international collaboration,

In citation counting, countries with high inflation may suggest that a larger portion of their cited patents are collaborative works by several countries/regions, while countries with low inflation indicate that these countries/regions may not have been involved as much as the other countries in international collaboration in impactful research.

In CP ratio counting, inflation ratios lower than 1.00 may be observed, also known as "counting deflation". Some countries may have proportionally produced higher number of impactful patents as the first inventor, thus the whole counting method (Method A) would underrate their research impact per patent.

Country rank changes and counting inflation

Patent count

Country rank changes

Table 2 shows country/region rankings based on patent counts using different methods. The distributions of country/region rankings were rather similar when employing the four counting methods. Despite the slight variation, the top 30 countries/regions maintain their positions in the rankings using these counting methods. Additionally, more than twenty countries/regions' rankings were maintained across the four methods employed, notably the top 5 countries/regions: the United States (1), Japan (2), Germany (3), Taiwan (4) and South Korea (5).

Detailed studies of those countries with varied ranks revealed four clusters of countries with adjacent ranks. Within each cluster, country ranks varied across different methods. But the rankings are interchangeable only within the same cluster (e.g., the cluster of United Kingdom and France) and rank difference did not exceed 2. This pattern has also been identified in earlier studies based on paper counts (Huang et al. 2011). Huang et al. investigated the country rank changes based on paper counts using different counting methods and identified similar cluster phenomena. This indicates that in patent counts, the country rankings are not greatly affected by counting methods, same as in paper counts.

Previous studies on paper counts show that whole counting (Method A) favored Western countries while straight counting (Methods B) and fractional counting (Methods C and D) better represented East Asian and other emerging countries (Huang et al. 2011). This tendency, however, is not observed in patent counts. Comparing the results of different methods, it can be seen that Methods C and D result in the same country/region rankings in patent counts. Method B, most of the time, exhibited the same results as Methods C and D. This study shows that fractional counting methods will obtain the same results for country/region ranks in patent counts, whether it is whole-normalized counting or complete-normalized counting.

Table 2 Patent counts and country/region rankings by different counting methods

		1992-2011 Patent numbers by different counting methods				Country rank by patent count				Ratio of counting inflation		
		A	B	C	D	A	B	C	D	A/B	A/C	A/D
United States		1586582	1552593	1537269	1542445	1	1	1	1	1.02	1.03	1.03
Japan		639998	629421	631315	631248	2	2	2	2	1.02	1.01	1.01
Germany		201536	185505	186056	186277	3	3	3	3	1.09	1.08	1.08
Taiwan		93957	90462	90981	90811	4	4	4	4	1.04	1.03	1.03
South Korea		91644	89658	89885	89815	5	5	5	5	1.02	1.02	1.02
United Kingdom	-	78217	65447	67255	66312	*6*	*7*	*7*	*7*	1.20	1.16	1.18
France	+	77782	68856	69953	69328	*7*	*6*	*6*	*6*	1.13	1.11	1.12
Canada		72204	63377	64446	63897	8	8	8	8	1.14	1.12	1.13
Italy		32437	29336	29858	29687	9	9	9	9	1.11	1.09	1.09
Switzerland		32103	25221	25831	25633	10	10	10	10	1.27	1.24	1.25
Netherlands	-	29004	23733	24484	24183	*11*	*12*	*11*	*11*	1.22	1.18	1.20
Sweden	+	26302	23735	23910	23849	*12*	*11*	*12*	*12*	1.11	1.10	1.10
Israel		20975	18557	18816	18739	13	13	13	13	1.13	1.11	1.12
Australia		20344	18132	18465	18270	14	14	14	14	1.12	1.10	1.11
China P.Rep.	-	17610	13499	14240	14139	*15*	*16*	*15*	*15*	1.30	1.24	1.25
Belgium	-	15613	11553	12090	11756	*16*	*17*	*17*	*17*	1.35	1.29	1.33
Finland	+	15043	13849	13941	13987	*17*	*15*	*16*	*16*	1.09	1.08	1.08
Austria		11519	9594	9786	9655	18	18	18	18	1.20	1.18	1.19
Denmark		9231	7866	8011	8012	19	19	19	19	1.17	1.15	1.15
India		9212	6721	7258	7009	20	20	20	20	1.37	1.27	1.31
Singapore		7226	5692	5869	5803	21	21	21	21	1.27	1.23	1.25
Spain		6701	5148	5519	5377	22	22	22	22	1.30	1.21	1.25
Norway		5209	4471	4526	4479	23	23	23	23	1.17	1.15	1.16
Russian Federation		4756	3176	3458	3509	24	24	24	24	1.50	1.38	1.36
Ireland		3702	2685	2840	2774	25	25	25	25	1.38	1.30	1.33
New Zealand		2563	2133	2191	2163	26	26	26	26	1.20	1.17	1.18
Brazil	-	2545	1936	2081	1997	*27*	*28*	*28*	*28*	1.31	1.22	1.27
South Africa	+	2342	2108	2117	2109	*28*	*27*	*27*	*27*	1.11	1.11	1.11
Malaysia		1990	1410	1527	1472	29	29	29	29	1.41	1.30	1.35
Mexico		1872	1318	1497	1436	30	30	30	30	1.42	1.25	1.30

Italics values represent the varied rankings in the clusters

Note. The plus sign (+) indicates rank rise from Method A to other methods, and the minus sign (−) indicates rank drop

Statistical tests further assist us to understand the influences of different counting methods. As seen in Table 3, Pearson's correlation analyses show that patent numbers using the four counting methods were all completely correlated at the 0.01 significance

Table 3 Correlation analysis of patent numbers, country ranks resulted from the four counting methods

	Counting methods	A	B	C
Patent numbers (Pearson)	B	1.000**	–	–
	C	1.000**	1.000**	–
	D	1.000**	1.000**	1.000**
Country rank (Spearman)	B	0.997**	–	–
	C	0.999**	0.999**	–
	D	0.999**	0.999**	1.000**

** Significantly different at the $p < 0.01$ level

level, since the correlation coefficient values were 1.000. Meanwhile, Spearman's test of the country rankings shows that the four methods' ranking results are highly correlated (>0.997 at the 0.01 significance level), indicating that the selection of counting methods have little effect on country rankings. In addition, Method A is slightly less correlated with the others, while Methods C and D were all completely correlated with the correlation coefficient values at 1.000. This is consistent with the phenomena discussed above.

Counting inflation in patent counts

As seen in Table 2, the ratio of counting inflation was obtained by dividing the patent count from Method A (whole counting) by those from Methods B to D, respectively. The counting inflation ranged as low as 1.01 (Japan in Method C and D) to as high as 1.50 (Russian Federation in Method B) for the top 30 countries/regions.

In paper count, Asian countries/regions showed markedly lower counting inflation (Huang et al. 2011). However, the situation varied for each country in patent count herein. One can see that the inflation ratios of the Top 5 countries/regions (the United States, Japan, Germany, Taiwan and South Korea) were evidently lower than those of the other 25 countries/regions. Among them, the United States, Japan, Taiwan and South Korea had the lowest inflation compared to the other countries/regions, all of which were lower than 1.05. Germany exhibits a relatively higher inflation compared to the four countries/regions above, though its inflation remained lower than 1.10. The low inflation suggests that these countries have not been as involved as the other countries in international collaboration.

The countries/regions ranked 6–30 showed higher inflation. The Russian Federation, Ireland, Malaysia, and Belgium showed the highest inflation compared with other countries/regions. Higher inflation suggests that those countries/regions serve supporting or facilitating roles more often than as the first inventor when participating in international collaboration.

Citation count

Country rank changes

As Table 4 shows, the top 30 countries/regions have maintained their places in the rankings regardless of counting method, though there is a slight variation in their relative positions. No countries/regions have dropped out of the top 30, nor have any new countries emerged to become one of the top 30 countries/regions regardless of the method applied. Furthermore, more than twenty countries/regions' rankings remained the same when

Table 4 Citation counts and country/region rankings by different counting methods

		1992-2011Citation counts by different counting methods				Country rank by citation count				Ratio of counting inflation		
		A	B	C	D	A	B	C	D	A/B	A/C	A/D
United States		17313687	17057198	16864625	16934824	1	1	1	1	1.02	1.03	1.02
Japan		4133559	4013834	4050685	4044302	2	2	2	2	1.03	1.02	1.02
Germany		1014629	906284	922675	918090	3	3	3	3	1.12	1.10	1.11
Canada		603597	519046	535318	527805	4	4	4	4	1.16	1.13	1.14
United Kingdom		596485	485716	505913	496055	5	5	5	5	1.23	1.18	1.20
France	-	466284	400801	414172	407469	*6*	*7*	*7*	*7*	1.16	1.13	1.14
Taiwan	+	465760	441829	449071	447800	*7*	*6*	*6*	*6*	1.05	1.04	1.04
South Korea		359861	342326	348137	346738	8	8	8	8	1.05	1.03	1.04
Israel		203523	173784	179061	176291	9	9	9	9	1.17	1.14	1.15
Switzerland	-	197927	148422	157431	154209	*10*	*12*	*12*	*12*	1.33	1.26	1.28
Netherlands		194230	149709	159014	154570	11	11	11	11	1.30	1.22	1.26
Sweden	+	190192	169866	171889	171619	*12*	*10*	*10*	*10*	1.12	1.11	1.11
Italy		152996	134482	137862	136230	13	13	13	13	1.14	1.11	1.12
Australia		138148	121559	124369	122733	14	14	14	14	1.14	1.11	1.13
Finland		103103	91508	94316	94350	15	15	15	15	1.13	1.09	1.09
Belgium		89071	63920	67317	64470	16	16	16	16	1.39	1.32	1.38
Denmark		56626	47568	48289	48299	17	17	17	17	1.19	1.17	1.17
Austria		48667	38815	40297	39404	18	18	18	18	1.25	1.21	1.24
Singapore		46545	36104	37881	37380	19	19	19	19	1.29	1.23	1.25
China P.Rep.		38216	26469	29083	28285	20	20	20	20	1.44	1.31	1.35
Ireland	-	31458	21643	23520	22797	*21*	*22*	*23*	*22*	1.45	1.34	1.38
Spain	-	31206	20981	23811	22578	*22*	*23*	*22*	*23*	1.49	1.31	1.38
Norway	+	29145	23621	24432	23919	*23*	*21*	*21*	*21*	1.23	1.19	1.22
Russian Federation		27776	17170	19307	19173	24	24	24	24	1.62	1.44	1.45
India		26231	14804	18482	16976	25	25	25	25	1.77	1.42	1.55
South Africa		15043	13631	13634	13549	26	26	26	26	1.10	1.10	1.11
New Zealand		14397	11593	12335	12159	27	27	27	27	1.24	1.17	1.18
Brazil		11652	8465	9317	8861	28	28	28	28	1.38	1.25	1.31
Mexico	-	11124	6751	8391	7594	*29*	*30*	*29*	*30*	1.65	1.33	1.46
Argentina	+	9466	8309	7847	7595	*30*	*29*	*30*	*29*	1.14	1.21	1.25

Italics values represent the varied rankings in the clusters

The plus sign (+) indicates rank rise from Method A to other methods, and the minus sign (−) indicates rank drop

different methods were employed, especially the top five countries/regions, such as the United States (1), Japan (2), Germany (3), Canada (4) and United Kingdom (5). To summarize, the distributions of country/region rankings based on citation count are rather

Table 5 Correlation analysis of citation counts, country ranks resulted from the four counting methods

	Counting methods	A	B	C
Citation counts (Pearson)	B	1.000**	–	–
	C	1.000**	1.000**	–
	D	1.000**	1.000**	1.000**
Country rank (Spearman)	B	0.996**	–	–
	C	0.996**	0.999**	–
	D	0.996**	1.000**	0.999**

** Significantly different at the $p < 0.01$ level

similar using each of the four counting methods, which is similar to the results based on patent count discussed above.

Detailed studies of the countries with different rankings also reveal cluster phenomena as mentioned above. There were four clusters of countries with adjacent rankings based on citation counts. Within each cluster, country ranks vary by method, but ranks are interchangeable within the same cluster (e.g., the cluster of France and Taiwan) and the differences in ranking did not exceed 2. This indicates that in citation count, country rankings are not so influenced by counting methods, which is the same as in patent count. Correlation analysis also demonstrates this phenomenon. As exhibited in Table 5, the citation counts for the four counting methods are all completely correlated at the 0.01 significance level in Pearson's analysis. Spearman's test on the country rankings revealed that the four methods' ranking results were highly correlated (>0.996 at the 0.01 significance level). This indicates that the selection of counting methods did not impact country rankings much.

In patent counts, it can be found that Methods C and D result in the same country/region rankings. In other words, fractional counting methods obtain the same results on country/region ranks in patent counts, whether whole-normalized counting or complete-normalized counting. But in citation counts, the study shows that Method A (whole counting) results in rankings that are different than other methods. In contrast, Methods B to D produce similar ranks. Furthermore, Method B (straight counting) and Method D (complete-normalized counting) result in the same rankings. The differences among these four methods can also be reflected in correlation analysis. As shown in Table 5, Method A is slightly less correlated with the others, since the coefficient value were 0.996. Method B, C and D are highly correlated compare to the Method A. Additionally, Methods B and D are all completely correlated, thus Methods B and D resulted in the same ranks.

It is worth mentioning that United States, Japan and Germany are invariably the top 3 countries by patent and patent citation count by any counting method. This finding has also been mentioned in earlier studies based on paper counts (Huang et al. 2011). Huang et al. investigated the country rank changes based on paper counts as well as paper citation counts. They found that United States, Japan and Germany were invariably the top three using different counting methods. This reflects that United States, Japan and Germany are obviously more superior than the other countries/regions in terms of Science and Technology (S&T) output and impact.

Counting inflation in citation counts

Citation count generated from whole counting (Method A) was again used as the basis for calculating the counting inflation ratio. As seen in Table 4, the counting inflation ranged between 1.02 (United States in Method B and D, Japan in Method C and D) and 1.77 (India in Method B). Only four countries/regions (United States, Japan, Taiwan and South Korea) show inflation ratios lower than 1.06 for the top 30 countries/regions.

In patent count, the top 5 countries/regions showed lower inflation than the other countries/regions. But the distribution of the lower and higher inflation ratio values among the top 30 countries/regions was relatively irregular in citation count. For example, in the top 5 countries/regions, although the United States had lower inflation (e.g., <1.04), the United Kingdom had an inflation ratio higher than 1.17. On the other hand, although most of the other 25 countries/regions showed relatively higher inflation, some showed comparatively lower inflation (e.g., <1.15), such as Taiwan, South Korea, Sweden, Italy, Australia, and South Africa. This reflects that counting methods somewhat influence patent and citation counts.

In addition, note that the Russian Federation and India showed particularly unfavorable citation counts in A/B (e.g., >1.60). This suggests that a larger portion of their cited patents are collaborative works of several countries/regions. On the contrary, some countries/regions showed rather low inflation, such as the United States, Japan, Taiwan and South Korea. It indicates that these countries/regions are not as involved as other countries in international collaboration in highly cited works.

Ratio of CP count

Country rank changes

Citation count is one way to evaluate research impact. Citation count divided by patent count (CP ratio) is another method that produces normalized assessment. However, evaluation using CP ratio may have problems. A country with small patent and citation counts may turn out to have a much higher CP ratio than another country with high numbers of both patent and citation counts. Therefore, the first country does not necessarily show more influence than the second country. The comparison of CP ratio should be reasonably confined to countries/regions with relatively high numbers of patents and citations. Herein, the CP ratios are limited to the top 25 countries/regions, which belong to top 25 in both the patent and citation counts as seen in Table 4.

Similar to patent and citation counts, the distributions of country/region ranking are similar across all four counting methods, and a few clusters are also found in CP ratio count, as seen in Table 6. Within each cluster, rankings are interchangeable and the differences in ranking do not exceed 2. In previous studies on paper counts, ranking fluctuates due to various counting methods employed for some countries. For example, Singapore rose from 29th by whole counting to 21st by straight counting using corresponding author (Huang et al. 2011). In contrast, this phenomenon is not observed in CP ratio counts; the country rankings in CP ratio counts are not greatly influenced by different counting methods. As shown in Table 7, the CP ratio counts for the four counting methods were highly correlated at the 0.01 significance level in Pearson's analysis. Spearman's test on the country rankings revealed that the four methods' ranking results were relatively highly correlated (>0.994 at the 0.01 significance level), too. As a result, different counting methods do not exert great influence on country rankings.

The number of countries/regions within these clusters (exhibiting different ranks by using different counting methods) are 12 of the top 25 countries/regions, which is greater than those in patent and citation counts, which show only 9 of the top 30 countries/regions. Additionally, whole-normalized counting and complete-normalized counting (Methods C

Table 6 CP ratio and country/region rankings by different counting methods

		1992-2011CP ratio by different counting methods				Country rank by CP ratio				Ratio of counting inflation		
		A	B	C	D	A	B	C	D	A/B	A/C	A/D
United States		10.91	10.99	10.97	10.98	1	1	1	1	0.99	0.99	0.99
Israel		9.70	9.36	9.52	9.41	2	2	2	2	1.04	1.02	1.03
Ireland	-	8.50	8.06	8.28	8.22	*3*	*4*	*4*	*4*	1.05	1.03	1.03
Canada	+	8.36	8.19	8.31	8.26	*4*	*3*	*3*	*3*	1.02	1.01	1.01
United Kingdom		7.63	7.42	7.52	7.48	5	5	5	5	1.03	1.01	1.02
Sweden		7.23	7.16	7.19	7.20	6	6	6	6	1.01	1.01	1.00
Finland	-	6.85	6.61	6.77	6.75	*7*	*8*	*7*	*7*	1.04	1.01	1.02
Australia	+	6.79	6.70	6.74	6.72	*8*	*7*	*8*	*8*	1.01	1.01	1.01
Netherlands	-	6.70	6.31	6.49	6.39	*9*	*11*	*9*	*11*	1.06	1.03	1.05
Japan	+/-	6.46	6.38	6.42	6.41	*10*	*9*	*11*	*10*	1.01	1.01	1.01
Singapore	+	6.44	6.34	6.45	6.44	*11*	*10*	*10*	*9*	1.02	1.00	1.00
Switzerland	-	6.17	5.88	6.09	6.02	*12*	*13*	*12*	*13*	1.05	1.01	1.02
Denmark	+	6.13	6.05	6.03	6.03	*13*	*12*	*13*	*12*	1.01	1.02	1.02
France		5.99	5.82	5.92	5.88	14	14	14	14	1.03	1.01	1.02
Russian Federation	-	5.84	5.41	5.58	5.46	*15*	*16*	*15*	*16*	1.08	1.05	1.07
Belgium	+	5.70	5.53	5.57	5.48	*16*	*15*	*16*	*15*	1.03	1.02	1.04
Norway		5.60	5.28	5.40	5.34	17	17	17	17	1.06	1.04	1.05
Germany		5.03	4.89	4.96	4.93	18	18	18	18	1.03	1.02	1.02
Taiwan	+	4.96	4.88	4.94	4.93	19	19	19	18	1.01	1.00	1.01
Italy		4.72	4.58	4.62	4.59	20	20	20	20	1.03	1.02	1.03
Spain		4.66	4.08	4.31	4.20	21	21	21	21	1.14	1.08	1.11
Austria		4.22	4.05	4.12	4.08	22	22	22	22	1.04	1.03	1.04
South Korea		3.93	3.82	3.87	3.86	23	23	23	23	1.03	1.01	1.02
India		2.85	2.20	2.55	2.42	24	24	24	24	1.29	1.12	1.18
China P.Rep.		2.17	1.96	2.04	2.00	25	25	25	25	1.11	1.06	1.08

Italics values represent the varied rankings in the clusters

The plus sign (+) indicates rank rise from Method A to other methods, and the minus sign (−) indicates rank drop

and D) obtained same rankings in patent counts; straight counting and complete-normalized counting (Methods B and D) show identical rankings in citation counts, while none of the four counting methods exhibits the same country/region ranks in CP counts. This suggests that counting methods may exert bigger influence on CP ratio counts than it does on patent and citation counts. That is to say different counting methods may result in slightly differed country rankings in CP ratio counts than it does in patent and citation counts. Statistical analysis also confirms this point of view. As shown in Table 7, the four methods are less correlated to each other in CP ratio counts than they are in patent and citation counts, since the correlation coefficient in CP ratio counts were less than that in patent and citation counts. In the Spearman's tests on country rankings of CP ratios, the four counting methods are less correlated than they were in country rankings by patents

Table 7 Correlation analysis of CP ratio, country ranks resulted from the four counting methods

	Counting methods	A	B	C
CP ratio (Pearson)	B	0.997**	–	–
	C	0.999**	0.999**	–
	D	0.998**	1.000**	1.000**
Country rank (Spearman)	B	0.995**	–	–
	C	0.998**	0.995**	–
	D	0.994**	0.998**	0.996**

** Significantly different at the $p < 0.01$ level

and citations, as also revealed by correlation coefficient comparison. In addition, unlike patent and citation counts, there were no counting methods that provided the same country rankings in CP ratios. This answer can also be found in correlation analysis. In the country rankings of patent and citation counts, there are methods that are completely correlated (coefficients were 1.000). But in the CP ratio country rankings, there are no methods that are completely correlated.

Comparing CP ratio with citation counts, we can see that the United States has dominated the first place throughout the period of interest. Canada and the United Kingdom have maintained leading positions too, ranking 4th and 5th respectively. Both showed no change in ranking in citation counts and CP ratio. Switzerland, the Netherlands, Belgium, Spain and India showed little change. Additionally, 10 countries/regions showed a rise in rank from citation count to CP ratio, namely Israel, Sweden, Australia, the Netherlands, Denmark, Austria, Singapore, Norway, the Russian Federation and Ireland. Among these countries, Ireland exhibited a dramatic rise in ranking from the 21st place in citation count to the 3rd in CP ratio. These countries/regions proportionally produced more highly cited patents, making their CP ratio counts significantly higher than that of other countries/regions.

On the other hand, seven countries/regions suffered a huge drop in ranking from citation counts to CP counts: Japan, Germany, France, Taiwan, South Korea, Italy and China. Among them, Germany and South Korea dropped dramatically in ranking from citation count to CP ratio counts, occupying the 3rd and 8th places respectively in citation count, but falling to 18th and 23rd places in CP ratio. It is worth noting that most Asian countries/regions except Singapore have shown a drop in ranking from citation to CP ratio counts, reflecting that these countries/regions proportionally produced less highly cited patents.

Counting inflation in CP ratio

Different from patent and citation counts, the inflations are lower in CP ratio counts. The inflation ratios for most of the countries/regions are lower than 1.10, except for Spain, India and China. The highest inflation ratio is India in A/B (1.29). This is also the first time to have inflation ratio lower than 1.00. The United States experienced “counting deflation” in A/B, A/C and A/D, indicating that the whole counting method (Method A) has underrated their research impact per patent. This may be due to the fact that United States has produced proportionally more influential patents as the first inventor.

Conclusion

This study examined how counting methods have influenced country rankings and inflation in patent, citation and CP ratio counts, employing patent and citation data issued by USPTO during the period from 1992 to 2001. In light of our findings, we draw the following conclusions:

> Country rankings are not significantly influenced by different counting methods. All four counting methods can yield reliable country-level evaluations of technology innovation capability and impact.

In patent counts, the distributions of country/region rankings are rather similar across the four counting methods. In spite of slight variation in their relative order, the top 30 countries/regions remained in the rankings throughout. Furthermore, more than twenty countries/regions' rankings remain identical when different methods were used. Detailed studies of those countries of varied ranks reveal clusters of countries with adjacent rankings. Ranks are interchangeable only within the same cluster and the differences in ranking do not exceed 2.

Although the number of countries/regions that exhibit different rankings are greater in CP ratio count than those in patent and citation counts, the differences in ranking are rather small and do not exceed 2. This study shows that counting methods have minor effects on country rankings in technology innovation and its impact. Statistical analysis also confirms that all the counting methods are highly correlated with each other.

> There has shown no evidence that different counting methods may favor certain types of country/regions in patent, citation or CP ratio counts. However, the influence of counting methods was not exactly the same for these evaluation measures.

Previous studies show that paper counts, whole counting tends to favor Western countries while straight counting and fractional counting better represent the East Asian and other emerging countries (Huang et al. 2011). This tendency, however, is not noticed in patent, citation or CP ratio counts herein.

Comparing the results of different methods, it can be seen that whole-normalized counting and complete-normalized counting have obtained the same rankings in patent counts, and straight counting and complete-normalized counting have provided the same ranks in citation counts, while none of the four counting methods exhibit the same country/region ranks in CP counts. This suggests that counting methods may exert greater influence on CP ratio counts than on patent and citation counts, as shown in correlation analysis.

> The distributions of higher and lower inflation by the four counting methods were different in patent, citation and CP ratio counts.

In patent counts, the inflation ratios of the top five countries/regions (the United States, Japan, Germany, Taiwan and South Korea) are obviously lower than those of the other 25 countries/regions. But the distribution of the lower and higher inflation ratio values is more irregular in citation counts. For example, in the top five countries/regions, although the United States shows lower inflation (e.g., <1.04), the United Kingdom has an inflation ratio higher than 1.17.

Unlike patent and citation counts, inflation is noticeably lower in CP ratio counts. The inflation ratios for most of the countries/regions are lower than 1.10, except for Spain, India and China. An inflation ratio lower than 1.00 is first observed in CP ratio. This indicates that the whole counting method (Method A) underrates research impact per patent.

The influences of different counting methods on country ranks and inflation in patent, citation and CP ratio counts have been explored. This study provides an objective statistical reference regarding the country-level evaluation of technological innovation and its impact. However, whether the findings hold true in institution-level evaluation requires further study. The counting methods may exert different influences in different technology areas, hence further investigation is needed. Additionally, a fixed citation window would be more precise for the evaluation of patent citations, especially for countries whose patents come late in the period, which will be added in future studies. Finally, this study focused "inventor country patents"—"assignee country patents" would probably provide distinctly different results, which also need further study. These statement in above will be added in the future studies.

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