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# A Comparative Study on Scientometric Indicators in Papers and Patents: A Case Study on Graphene[1]

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## Introduction

Scientometric indicators have been used for decades to evaluate research performance and establish R&D policies in many countries. There have been reports dealing with bibliometric and patent indicators. Although some approach based on the combination of publication and patent data are reported (e.g. A.F.J. van Raan, 2017; A.F.J. van Raan and J.J.Winnink, 2018), there are not many direct comparative studies on papers and patent indicators. In this study, we intend to perform a comparative study of paper and patent indicators focusing on graphene research which has been widely studied not only in the basic science but also in industrial applications in recent 15 years. By using the 'Insightful Integrated Indicators Metrics(i*Metrics)' system developed by Korea Institute of Science and Technology Information(KISTI), scientometric indicators are calculated to identify research activities, impact, collaboration and technological convergence by country. The mapping and clustering based on the similarity of the computed indicators is carried out to characterize the country profiles on graphene research.

## Data and methods

The dataset for analysing graphene research was constructed using search queries made of keywords with '*graphene*' for papers and patents in publication year from 2000 to 2016. As a paper resource, we used the SCOPUS DB constructed by KISTI using the SCOPUS XML Custom Data provided by Elsevier. Also, patents granted in USPTO of PATSTAT DB provided by European Patent Office were used to analyse patents. The i*Metrics system was used to calculate scientometric indicators and the VOSviewer 1.6.7 of CWTS was used for mapping and clustering. The eight common indicators shown in Table 1, were selected to investigate the R&D performance of graphene research by country.

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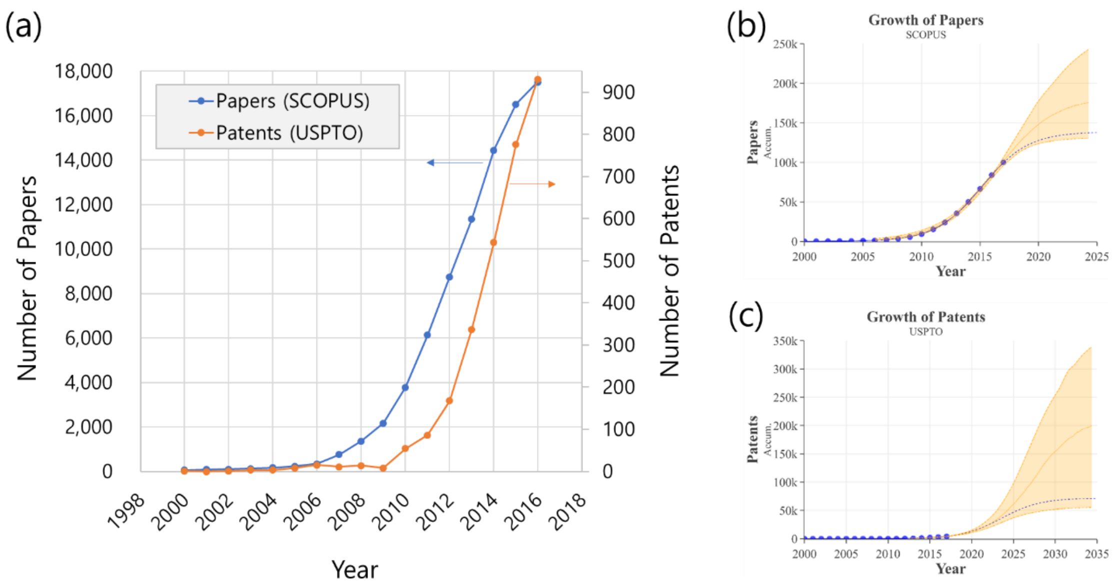
Table 1. The used scientometric indicators for comparative analysis in papers and patents.

| Category | Productivity | Influence & Excellence | Networking & Collaboration | Technology Convergence & Diffusion |
|---|---|---|---|---|
| Indicator | • Number of Papers/Patents(NP) | • Mean Normalized Citation Score(MNCS) | • International Collaboration Rate(ICR) | • Absorption Rate from Other Fields(ARO) |
| | • CAGR | • Excellence Paper/Patent Rate(EPR) | • Incremental Citation Impact(ICI) | • Diffusion Rate to Other Fields(DRO) |

## Results & Discussion

Figure 1 shows the growth of research on graphene through the number of publications of papers and patents by year. The total number of documents published from 2000 to 2016 are 99,987 and 4,066 for patents. The number of papers are increasing rapidly since 2004 when A. K. Geim and K. S. Novoselov, the winner of 2010 Nobel Prize in physics, extracted a single-atom-thick crystallite from bulk graphites(Geim and Novoselov, 2004). Meanwhile, the increase in patents starts a little later due to the time lag between the fundamental researches and industrial applications. The inflection point of the predicted growth curve of papers and patents is 2015 and 2024, respectively(figure 1(b) and (c)). From these growth pattern, we can expect that the development of research on graphene is at a leaping stage now and the possibility of commercialization is growing.

Figure 1: (a) Number of publications by year for papers and patents, (b) cumulative number of papers with prediction value(blue dashed line) until PY=2025 (99% confidence interval), and (c) cumulative number of patents with prediction value(blue dashed line) until PY=2035 (99% confidence interval) by publication year for Graphene.




The research papers on graphene have been published in 110 countries and the USPTO application countries are 48 countries. From the distribution of number of publications by countries, China has the largest number of papers, followed by the United States, South Korea, and Japan. However, the United States has more than 50% share in patents, followed by South Korea and Japan (Figure 2).

We selected the ‘Mean Normalized Citation Score(MNCS; Waltman *et al.*, 2011)’ and ‘Excellence Paper/Patent Rate(EPR; Bornmann *et al.*, 2013)’ as the ‘influence and excellence’ indicators. Figure 3(a) shows the MNCS value of papers(x-axis) and patents(y-axis) of the top-15 countries by the number of papers. The United States, United Kingdom(UK) and Germany are in the first quadrant; the quadrant base line was formed by the median values of 15 countries. The UK is the country of A. Geim who received the Nobel Prize as mentioned, the UK’s MNCS value of the paper is 5.7, which is very high, but the UK’s MNCS value of the patent is not relatively high. The United States, Japan, and South Korea which has many patents, the MNCS value of the patent was also high. The positions of countries on EPR were almost similar with those of MNCS.

Figure 2: Distribution of number of publications by countries.

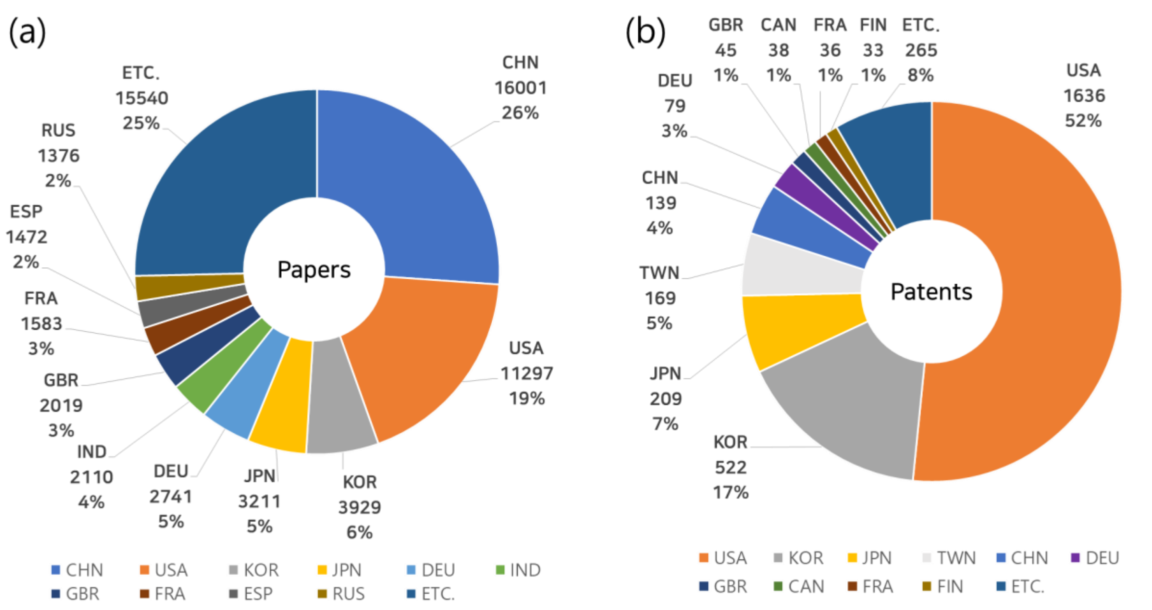
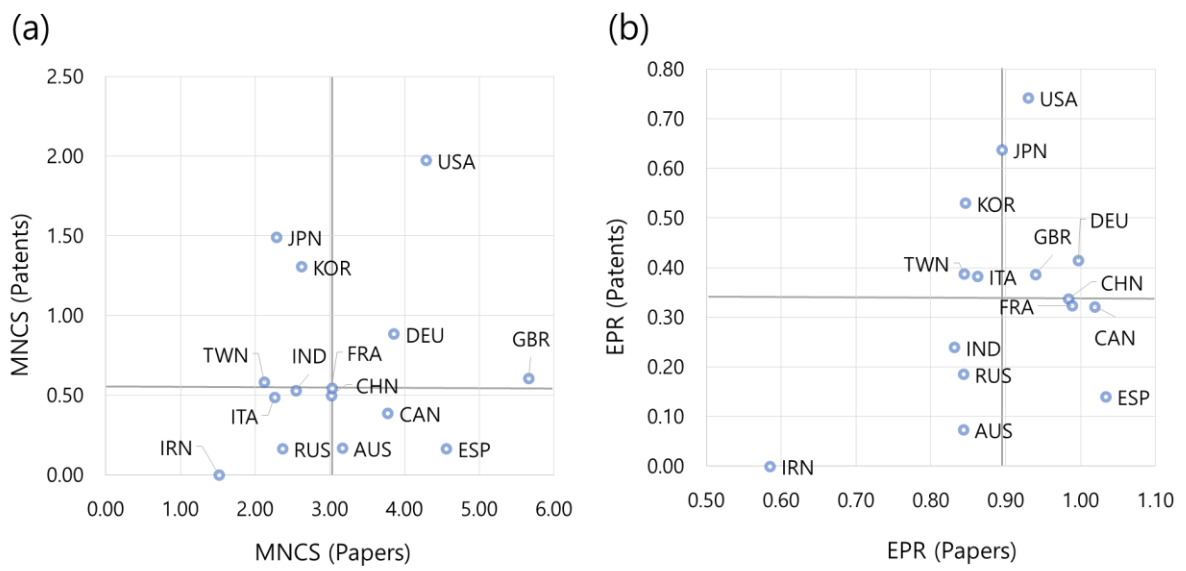



Figure 3: Influence & excellence indicators, (a)MNCS and (b) EPR.



The ‘networking and collaboration’ analysis was carried out with ‘International Collaboration Rate(ICR)’ and ‘Incremental Citation Impact(ICI)’ indicators(Inzelt *et al.*, 2009). The productivity of Canada and Russia is relatively low in both of papers and patents, but the international collaboration rate is high. Taiwan and South Korea have a considerable citation increase as shown in the ICI indicator for papers. Also, Russia shows the high cooperative effect with the United Kingdom. This can be considered the effect of Novoselov from Russia, who won the Nobel prize with Geim. In the case of patents, South Korea and the United States cooperate well together, and United Kingdom gains the benefit by cooperation with Korea and Germany.

Figure 4: Networking & collaboration indicators, (a) ICR and (b) ICI for papers and (c) ICI for patents.

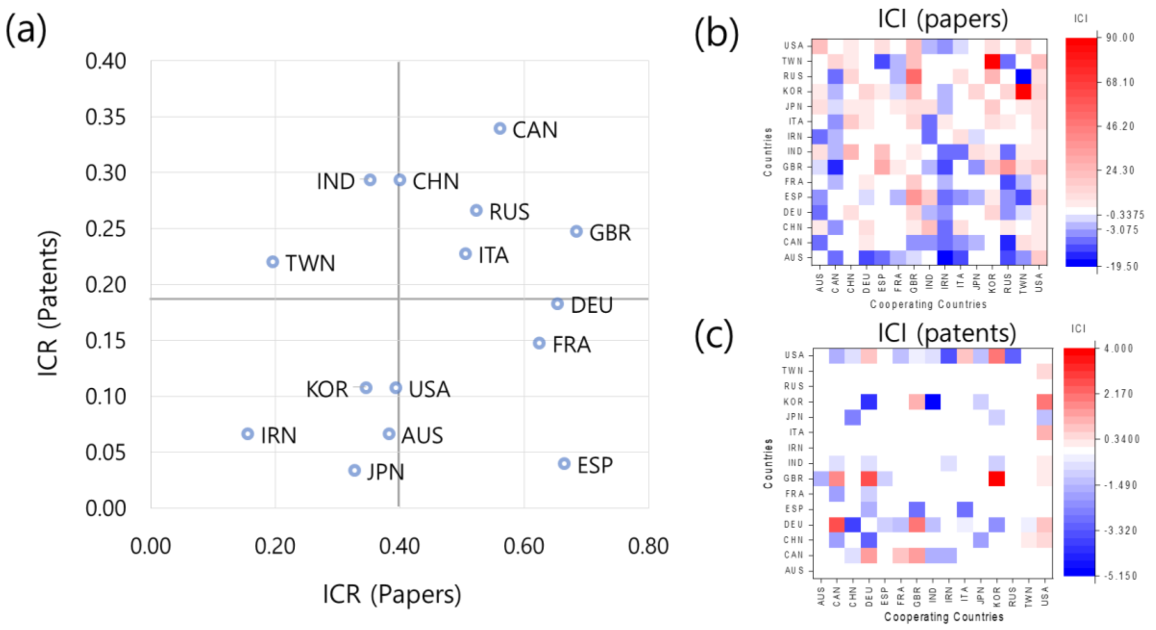
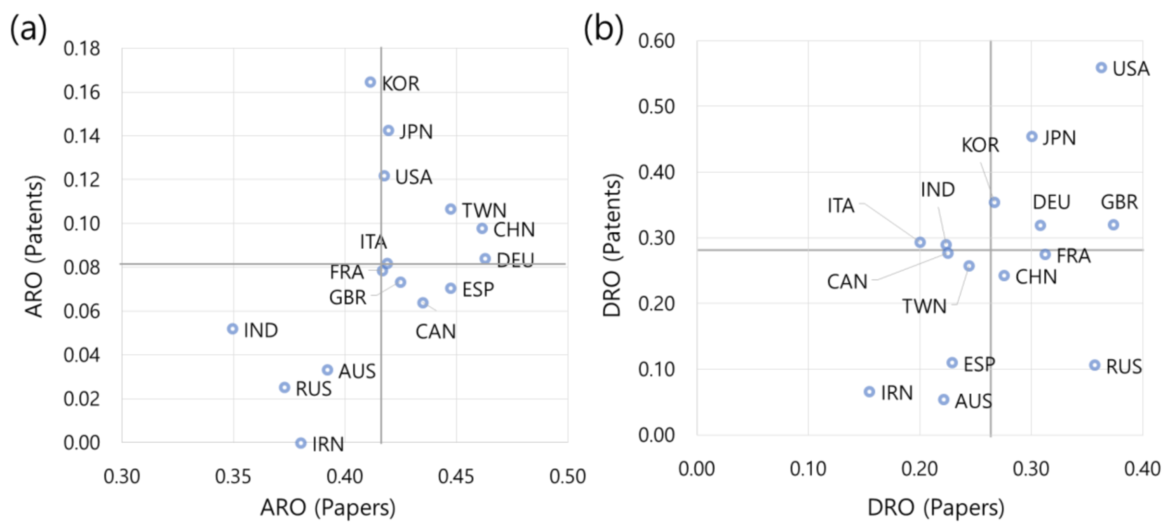


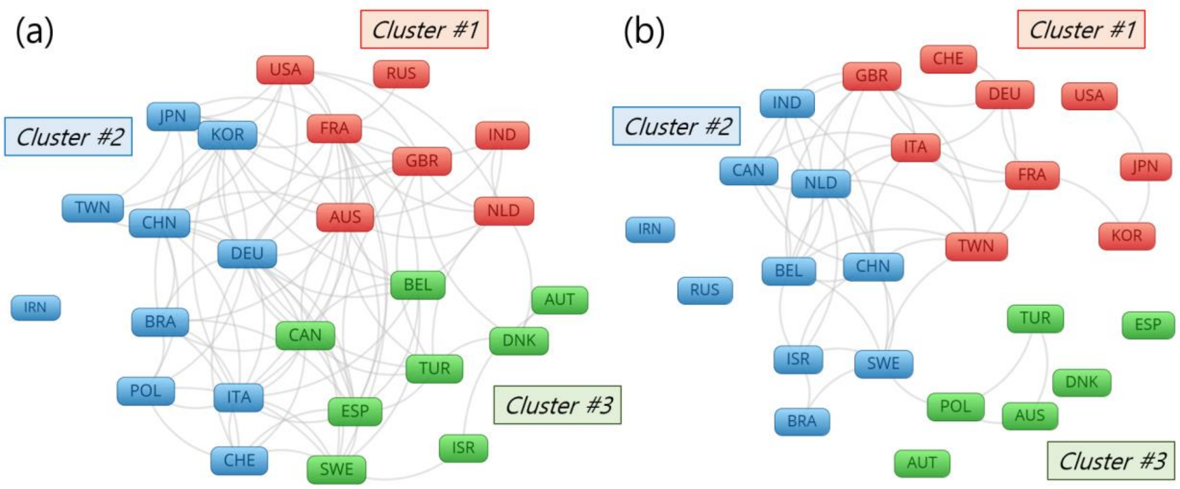

Figure 5: Technology progress & diffusion indicators, (a) ARO and (b) DRO.



We selected the 'Absorption Rate from Other Fields(ARO)' and 'Diffusion Rate to Other Fields(DRO)' as indicators of 'technology convergence and diffusion'. The ARO and DRO are defined as the ratio of other fields in cited references and citing publications, respectively. This indicators are similar with the approach to measure researcher interdisciplinarity reported by Porter *et al.*(2007). China, and Taiwan showed relatively high ARO values in the papers and patents, and India and Russia were located in the fourth quadrant where both of ARO and DRO are low value. In the case of the DRO, the DRO of countries with high productivity and influence, such as the United States, Japan, and the United Kingdom, were all high in papers and patents. This means that leading countries in graphene technology are leading the diffusion of knowledge in both the basics and application areas. On the other hand, latecomers such as Korea and China show that they actively absorb knowledge in both basic and applied areas.

Finally, we try to derive national characteristics through mapping and clustering using the indicators in papers and patents. For this purpose, mapping and clustering were performed on the top-25 countries based on the similarity of the profile vector composed of five indicators(MNCS, EPR, ICR, ARO and DRO) of each country. In both the papers and patents, all 25 countries are classified into 3 clusters. Cluster #1 is a leading group which contains United States and United Kingdom in both cases of papers and patents. South Korea, Japan and Taiwan are clustered in a same group, which are belonging in cluster #2 for papers and cluster #1 for patents. This implies that they are leading in industrial applications although they are latecomers in basic research on graphene research area.

Figure 6: Mapping and clustering of top-25 countries in (a) papers and (b) patents based on indicators of *Graphene.*

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