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PERSPECTIVES

Corporate engagement with nanotechnology through research publications

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Abstract Assessing corporate engagement with an emerging technology is essential for understanding the development of research and innovation systems. Corporate publishing is used as a system-level knowledge transfer indicator, but prior literature suggests that publishing can run counter to private sector needs for management of dissemination to ensure appropriability of research benefits. We examine the extent of corporate authorship and collaboration in nanotechnology publications from 2000 to 2019. The analysis identified 53,200 corporate nanotechnology publications. Despite the potential for limits on collaboration with corporate authors, this paper finds that eight out of 10 nanotechnology corporate publications involved authors from multiple organizations and nearly one-third from multiple countries and that these percentages were higher in recent years. The USA is the leading nation in corporate nanotechnology publishing, followed by Japan and Germany, with China ranking fourth, albeit with the greatest publication growth rate. US corporate publishing is more highly cited and less cross-nationally collaborative. Asian countries also have fewer collaborative authorship ties outside of their home countries. European countries had more corporate collaborations with authors affiliated with organizations outside of their home countries. The paper concludes that distinguishing corporate publications, while difficult due to challenges in identifying small- and medium-sized corporations and grouping variations in corporate names, can be beneficial to examining national systems of research and development.

Keywords Nanotechnology · Private sector · Corporate engagement · Tracking research publications

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Introduction

The US National Nanotechnology Initiative put forward in 2000 is its four key goals: advancing R&D, fostering new technologies for commercial and public benefit, developing a skilled workforce, and supporting responsible development. Reviews of the National Nanotechnology Initiative find progress toward these goals, highlighting efforts such as The Signature Initiatives, which foster collaboration among academic and industrial sectors in particular areas of national importance, as well as challenges, including at the intersection of research and commercial activity (National Academies of Sciences, Engineering, and Medicine 2020). This paper, while not a formal evaluation of these four goals, informs

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assessment of the first two of these goals by examining the extent of, and linkages around, corporate publishing.

Corporate publishing concerns research appearing in scholarly sources that has at least one author with a corporate (i.e. business or company) affiliation. Although most publications are produced by authors based in universities or research institutes, scientists and engineers in corporations do produce scholarly publications. The ability to generate scholarly publications is particularly noteworthy in science-driven domains such as nanotechnology. However, corporate publishing is not much studied in comparison with the scholarly attention attracted by corporate patenting. Corporate publishing can be viewed as a signal of corporate interest in a topical area, research directions, relationships with other organizations, development of human capital, and value in knowledge transfer (Hicks 1995; Stern 2004; Li et al. 2015). There can be strategic reasons why corporations publish (or do not publish), including, for example, to disclose results that can make it difficult for competitors to appropriate benefits. In short, corporate publishing is an underused signal of private sector exploration and development in an emerging technological area.

This paper examines corporate nanotechnology publication attributes in a comparative global context to understand the extent of corporate publishing in top nanotechnology publishing countries. It depicts the size and growth of corporate nanotechnology publications among the top publishing countries as well as their citation prevalence. A particular focus is on the extent of international collaboration involving corporate authors among different countries' nanotechnology research systems. The paper shows that European corporate nanotechnology publications have a higher proportion of international collaborating works than those involving US and Asian corporate publications.

Background

Studies of nanotechnology corporate activity have focused on patenting as well as gross counts of publications alongside patent measures. Huang and colleagues profiled the growth of nanotechnology-related patenting based on US Patent and Trademark Office data from 1976 to 2002 by country and topical area (Huang et al. 2003; Huang et al. 2004). The top countries in this analysis were OECD nations led by the USA; China was not among them in this timeframe. This analysis was updated to include the year 2003, with a similar listing of top countries by patent counts which diverged somewhat depending on whether the keyword search was applied to the full text of the patent or to the titles and claims (Huang et al. 2004), suggesting that differences in methodological approaches can affect inter-country patent count differences. Roco reported growth in US Patent and Trademark Office nanotechnology patent applications and Web of Science Science Citation Index nanotechnology publication counts as two of six indicators to understand nanotechnology global developments 10 years after the creation of the National Nanotechnology Initiative (Roco 2011). He found a 35% annual growth rate in patent documents from 2000 to 2008 and a 23% annual growth rate in nanotechnology publications over the same period. This work was subsequently updated (Chen et al. 2013; Zhu et al. 2017). The 2017 update highlighted China's and South Korea's rapid World Intellectual Property Office patent document growth. That paper also reported growth by China and South Korea in overall nanotechnology publication counts but noted US prominence in publications in the most highly cited journals—Science, Nature, and Proceedings of the National Academy of Sciences.

Hullmann provided a geographically extended perspective by using European Patent Office data and cross-class tags. Patents were broken down regionally into Europe, Asia, and the Americas over the 1995 to 2003 period (Hullmann 2007). Hullmann's country breakdowns were broadly consistent with those of Huang and colleagues while noting the significance of China in the rise in Asian patents toward the end of the timeframe. Hullmann also reported other statistics from the consulting firm Lux Research, such as private funding and venture capital, as well as total Web of Science nanotechnology publications.

Miyazaki and Islam presented nanotechnology patent (and overall publishing) results by country and sector (Miyazaki and Islam 2007). The aim of this work was to understand differences in national nanotechnology innovation systems. The paper reported the fast growth of publications from China and other Asian nations, as well as the impact of USA and Asian companies on nanotechnology publication output.

Our own group measured nanotechnology publishing and patenting based on the development of a complex Boolean search strategy. The strategy was comprised of keywords obtained from text analyses and expert interviews along with nanospecific classifications for identifying nanotechnology publications and patents in a first stage. A second exclusion stage was applied to the keyword search results to remove out-of-domain documents that reference size or nonengineered matter only (Porter et al. 2008). This search strategy was updated in two additional efforts to capture changes in the field, such as emerging two-dimensional materials (Arora et al. 2013; Wang et al. 2019). The latter two search results demonstrated the growth of Chinese publications, which surpassed US counts by 2010.

The above studies presented publications and patents without much segmentation of corporate and noncorporate sectoral sources. This lack of segmentation in assessing nanotechnology's development is less of an issue for patents in that corporate patenting is dominant (although see Shapira and Wang 2009 for a contrary perspective showing patenting from noncorporate entities in China in the initial decade of the 2000s). One of the first studies to apply a segmented approach to analysis of research publications is Shapira and colleagues (Shapira et al. 2011). The authors distinguished nanotechnology publications with a corporate author affiliation. They then compared corporate publishing and patenting, finding a shift in the ratio of corporate patenting to publishing in the early 2000s. They introduced the concept of corporate entry into nanotechnology based on a corporation's being involved with a minimum threshold of nanotechnology patents or publications. They used this concept to understand national differences in corporate (mostly patenting) activity and the country-level factors underlying these differences. The results highlighted the importance of specialization and early entry at the country level. The authors further found that national innovation measures were more significant than international measures in predicting corporate patenting.

Our present work updates and extends this earlier research on corporate publishing. Given recent changes in the nanotechnology global research system, such as the rise of Chinese nanotechnology publication authorship (National Academies of Sciences, Engineering, and Medicine 2020) and patent document counts (Hu et al. 2017), we wonder how corporate publishing is affected by these changes. Such an analysis contributes towards understanding national research and development system features as they relate to the nanotechnology domain.

This work on nanotechnology publication activity also contributes to research into corporate publishing. Science and Engineering Indicators put forth corporate publishing as an indicator of knowledge transfer (National Science Board, National Science Foundation 2020). The report found that corporate publications as a percentage of all publications from the Scopus database were 2% in 2018, a decline from the 3% figure reported for 2008, with overall counts of corporate coauthored publications 8% lower in 2018 than in 2008. Much of the literature on corporate publishing view it less as a straightforward measure of knowledge transfer, because corporate publishing would seem to run counter to the ability of corporations to appropriate benefits from intellectual property that has been disclosed, and instead focuses on the motivation for this activity. Hicks explains that corporate publishing is particularly significant for reputational enhancement through strategic management of information dissemination of large firm research and development efforts and in sectors requiring regulatory approval (Hicks 1995). Internal capacity development is highlighted in the work of Stern about the motivations of industrial researchers that are allowed to publish as a perk to support their "taste for science," (Stern 2004) even as Roach and Sauermann found that this motivation may be less strong in the private sector than in academia (Roach and Sauermann 2010). In the nanotechnology domain, Li and colleagues observed an association between publishing by small- and medium-sized nanotechnology enterprises and involvement in public science and in more established research areas (Li et al. 2015).

This paper's objective is to examine global comparisons in corporate publishing rather than exploring the reasons underlying corporate publishing. The paper will examines the size and growth of corporate publications over time and their citation characteristics. We then move to looking at the characteristics of global corporate research systems. Different companies may cooperate or outsource research to organizations in other countries (Leitner et al. 2020). Our paper will consider the role of globalization in nanotechnology research by investigating how international collaboration in papers with corporate authors differs among leading countries.

Methodology

There are no comprehensive global lists of corporations engaged in nanotechnology. We infer corporate publishing in nanotechnology by tabulating corporate affiliations of publication authors or coauthors from Clarivate

Web of Science for publications in the nanotechnology domain. Identification of corporate organizations is based on the author affiliation. Publication databases are typically not set up to identify which author affiliations are corporations. While publication databases have improved their standardization of organizational names, we still have difficulty identifying which organizations should be considered to be corporations. Large corporations can be readily identified from global lists such as the European Union R&D Investment Scoreboard [https://iri.jrc.ec.europa.eu/scoreboard] or the Forbes Global 2000 [https://www.forbes.com/global2000/#47a6c2ef335d], but small- and medium-sized firms are less well-known. Industry classifications, such as the North American Industrial Classification System, are of limited use because emerging technologies are, for the most part, not incorporated into their categorization system (Hicks 2011). We used VantagePoint version 2020 software [www.theVantagePoint.com] to separate out corporations from academic organizations or government agencies and to combine variations of corporate names such as IBM and International Business Machines. There is also a gray area of research service corporations that primarily do not produce tangible products (associated with industrial or consumer applications). We excluded these research service corporations (such as SRI International, RTI International, and Battelle Memorial Institute in the USA) from top lists of corporations but included them in global and in-country counts. Some of the corporations we list in one period were subsequently acquired (such as Rohm & Haas, which was acquired by Dow Chemical in 2009), but we report them as they appear in the datasets at the time of publication.

Nanotechnology publication information is obtained from 2000 to April 2020 from Clarivate Web of Science (WoS). The starting year of 2000 marks the establishment of the National Nanotechnology Initiative. Abstract records from WoS were gathered based on the nanotechnology search strategy developed by Wang and colleagues (Wang et al. 2019). This search strategy is based on a first step of including publication records with titles and abstracts that relate to complex Boolean search terms. A second step excludes publication records that fall outside the domain because they only mention size, naturally occurring phenomena, or other noise (e.g., chemical formulas such as $NaNO_2$), as initially detailed in Porter and colleagues (Porter et al. 2008) and updated in Arora and colleagues (Arora et al. 2013) prior to the more recent update by Wang and colleagues. The initial search developed by Porter and colleagues was included in an assessment of six nanotechnology search strategies by Huang and colleagues. This showed that the search strategy of Porter and colleagues fell in the middle of the six strategies in size and distribution, providing corroboration of the results of the approach (Huang et al. 2011).

This analysis makes global comparisons at the country level for top publishing countries. We assign publications to countries based on the author affiliation address. We use full (i.e., not fractional) counting of author affiliations; so, country totals do not sum to global figures. The results are shown for the 2000–2019 and 2015–2019 periods. The reason for these analyses is to compare recent results since 2015 with results since the proposal of the National Nanotechnology Initiative. As we extracted the data in April 2020, the results reported for 2019 may be incomplete.

Results

Corporate publication size and growth

Our analysis begins with counts of nanotechnology publications by corporate organizations in top publishing countries. As previously indicated, a corporate publication is defined as a publication with at least one author or coauthor affiliated with a corporation. The total number of corporate publications for the 2000 to 2019 period was 53,200. This figure comprised 2.3% of all nanotechnology publications during that period. This percentage was slightly higher (3%) in the first decade of the 2000s but trended somewhat downward to 2% in the second decade, as the total number of nanotechnology publications grew faster than corporate publications. These corporate publishing percentages are comparable to the overall figures of 2% for 2008 and 3% for 2018 presented in Science and Engineering Indicators (National Science Board, National Science Foundation 2020). Global corporate publications grew by 17% on average per year from 2000 to 2019, and by just under 4% per year, on average, from 2015 to 2019 (Table 1). These same figures for all nanotechnology publications were 34% and 5%, respectively.

Figure 1 presents Web of Science corporate nanotechnology publications by year and country affiliation using full counting of author affiliations for the world

Table 1 Growth rates in nanotechnology corporate publications

	Total corporate publications 2000–2019	Average annual growth 2000–2019	Average annual growth 2015–2019
All	53,200	17.3%	1.2%
USA	20,332	14.2%	1.1%
Japan	13,762	4.0%	−1.0%
Germany	6413	18.8%	−0.2%
China	3680	416.9%	23.1%
South Korea	3419	12.2%	0.7%

Source: 53,200 global nanotechnology corporate publications extracted from Clarivate Web of Science in April 2020. Nanotechnology search terms based on Wang, et al. (2019)

and for the USA, China, Japan, Germany, and South Korea. The USA had by far the largest number of corporate publications over the 2000 to 2019 period at more than 20,000, followed by Japan at nearly 13,800, Germany at 6400, China at just under 3700, and South Korea at over 3400. The average annual growth in corporate publications over the full 2000 to 2019 period was 14% for the USA, 4% for Japan, 19% for Germany, 12% for South Korean, and more than 400% for China (Table 1). China's corporate publication counts—though well below counts for the USA, Japan, and Germany—had the greatest growth starting in the middle of the second decade of the 21st century. China's corporate publication average annual growth rate from 2015 to 2019 was 23%. In comparison, the average annual growth rate from 2015 to 2019 was 2% for US

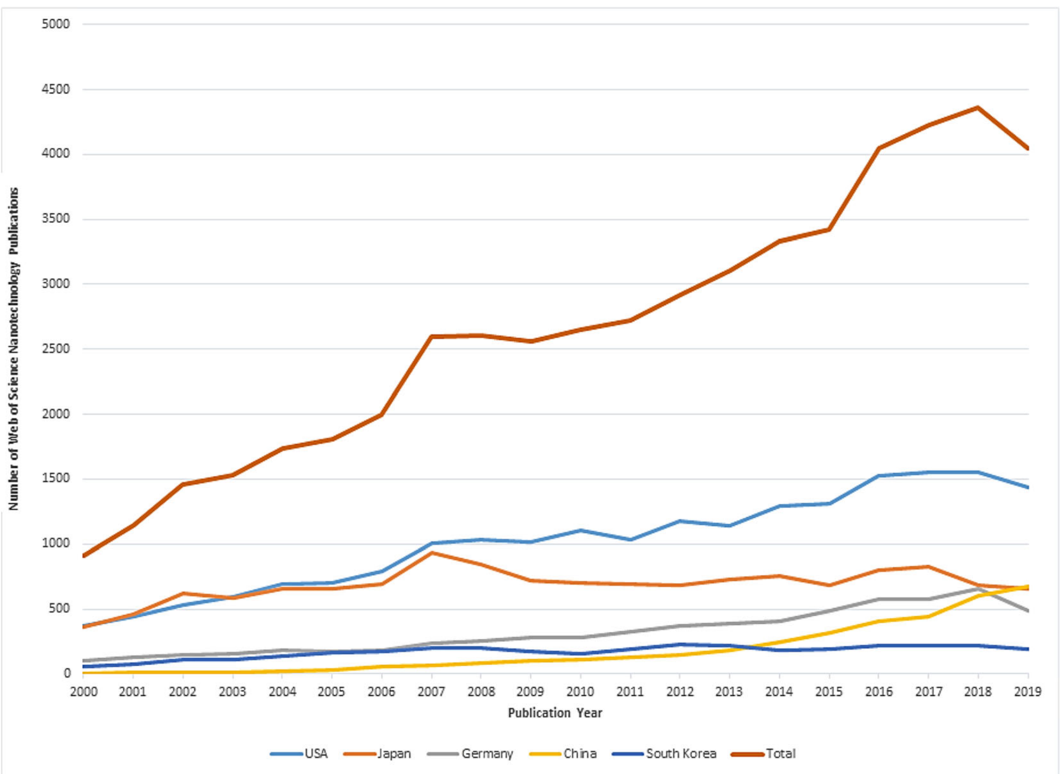

Fig. 1 Number of corporate nanotechnology Web of Science publications by year. Source: 53,200 global nanotechnology corporate publications extracted from Clarivate Web of Science in April 2020; 2019 results are not final. Nanotechnology search terms based on Wang, et al. (2019)

corporate publications and just under 1% for Korean publications. The average annual growth rate from 2015 to 2019 for Japanese and German corporate publications declined by 1% and 0.2%, respectively.

The top 10 global corporations based on publication counts are presented in Table 2. We exclude research service corporations from this list, although they are included in the aggregated global counts (as shown in the figures). The top 10 list includes four Japanese-headquartered corporations (NTT, Hitachi, Toshiba, and NEC), three US-headquartered corporations (IBM, Intel, and Texas Instruments), and two corporations headquartered in Europe (STMicroelectronics in Switzerland and Infineon in Germany). Five corporations have coauthors on more than 1000 publications in the 2000 to 2019 period: IBM, Samsung, NTT, Intel, and Hitachi. No Chinese corporation appears among the top 10 author-affiliated corporations based on nanotechnology publication output. PetroChina ranks 25th in nanotechnology output with 226 nanotechnology publications in the 2000 to 2019 period.

Hicks' work noted the importance of large corporate publishing (Hicks 1995), such as we present in Table 2. Large corporations are prominent in the list of corporate publishers, particularly among the most prolific publishers. However, we find more than 800 corporations with more than 10 nanotechnology publications, some of which are not large.

Table 2 Top 10 corporations based on nanotechnology publication counts: 2000–2019

Corporation	Publication count 2000–2019	Global headquarters
IBM Corp.	2425	USA
Samsung	1707	South Korea
NTT Corp.	1645	USA
Intel Corp.	1362	Japan
Hitachi Ltd.	1061	Japan
STMicroelectronics	810	Switzerland
Toshiba Co. Ltd.	784	Japan
NEC Corp. Ltd.	782	Japan
Texas Instruments Inc.	408	USA
Infineon Technologies AG	407	Germany

Source: 53,200 global nanotechnology corporate publications extracted from Clarivate Web of Science in April 2020. Nanotechnology search terms based on Wang, et al. (2019). Notes: primarily research service organizations not listed

Reviewing this list of corporations with around 20 nanotechnology publications, we found several small- and medium-sized author-affiliated organizations. Nion Company, a microscopy instrumentation corporation, in Kirkland Washington, published 22 articles from 2002 to 2018 on aberration correction and spectroscopy. Nineteen of their 22 articles received at least one Web of Science citation, for a total of 1200 Web of Science citations. Three of these articles received more than 150 citations, including one article about dark-field electron microscopy cited 370 times in the Web of Science (Krivanek et al. 2010). The latter article had 12 authors affiliated with institutions in the USA and UK (Nion, Vanderbilt University, Oak Ridge National Laboratory, Oxford). aBeam Technologies Inc. in Hayward, California, published 25 nanotechnology works from 2008 to 2018 on nanofabrication, microscopy, and simulation. Nineteen of their publications attracted more than 70 citations, including one paper on scanning electron microscopy cited 16 times (Abe et al. 2009); this article had seven authors affiliated with organizations in the USA and Japan (aBeam Technologies and Toshiba). Agiltron Inc. in Woburn Massachusetts published 19 articles from 2006 to 2018 on nanocomposites, nanowires, and chemical vapor deposition. All but two of their articles received at least one Web of Science citation, for a total of 325 citations. One article on nanowire detectors was cited more than 50 times (Zhang et al. 2008); this article had six authors, all of whom were affiliated with US organizations (Agiltron and the University of California at San Diego). After we selected these corporations, we looked them up in SBIR awards database [sbir.gov]. These three corporations each were found to have US Small Business Innovation Research (SBIR) awards, which is consistent with the conclusion of Li and colleagues about the role of public funding as a factor in corporate publishing, as least for these three purposively selected corporations (Li et al. 2015).

Citations

The previous paragraph mentioned relatively highly cited works of several small- and medium-sized corporate authors. This section looks broadly at the citations of these publications with at least one corporate-affiliated author. To enhance analytical variation, we expand this part of the analysis to the top 10 countries in terms of corporate publishing. In addition to the USA, Japan, Germany, China, and South Korea, we add the UK, France, Switzerland, the Netherlands, and Sweden, because they are the next largest countries in terms of corporate publication counts.

Figure 2 shows a citation chart with the primary *Y*-axis presenting total citations for each of the 10 countries and the secondary *Y*-axis presenting average citations per corporate nanotechnology publication for the 2000 to 2019 period. US corporate-authored papers have the most total citations on the primary *Y* axis, with nearly half a million total citations. Japan-authored papers comprise more than 200,000 total citations, followed by Germany with more than 100,000. US papers also have the most average citations per publication on the secondary *Y*-axis at 24.3 average citations. The only other country with more than 20 average citations per publication is Switzerland. Publications with authors based in South Korea and the UK have the next largest number of average citations per publication at 19.8 and 19.2, respectively. The lowest average citations per corporate nanotechnology publication are for corporate publications with authors in China (12.0), followed by France (14.6) and Japan (15.3). Thirty-two corporate publications have 1000 or more citations. All 32 publications with 1000 or more citations have a US-affiliated author. The next most common countries of coauthors for these highly cited corporate nanotechnology publications are from Germany, Japan, and the UK (four highly cited corporate nanotechnology publications each).

The top two most highly cited articles with corporate authors involve graphene-related research. Ten authors affiliated with institutions in South Korea (including three authors affiliated with Samsung) and the USA published "large-scale pattern growth of graphene films for stretchable transparent electrodes" in Nature in 2009; this article attracted more than 4500 citations (Kim et al. 2009). The second most cited article with a corporate-affiliated author is the 13-author article (including one author from Texas Instruments) "large-area synthesis of high-quality and uniform graphene films on copper foils" appearing in Science in 2009 (Li et al. 2009). This article was cited by nearly 4500 other works. In addition to these works, the third and fourth most highly cited articles with corporate-affiliated authors include the IBM-affiliated "monodisperse FePt nanoparticles and ferromagnetic FePt nanocrystal superlattices" (Sun et al. 2000) and "organic thin film transistors for large area electronics" (Dimitrakopoulos and Malenfant 2002). Each of these two works garnered more than 4000 citations.

The nature of corporate publishing in nanotechnology

Prior work on corporate publishing, discussed earlier in section two of this paper, highlighted the promotion of corporate publishing as an indicator of knowledge transfer through sharing and dissemination of research results. It also raised the rationale for avoiding corporate scholarly publishing of findings, that disclosing research results may limit the potential of corporate appropriation of

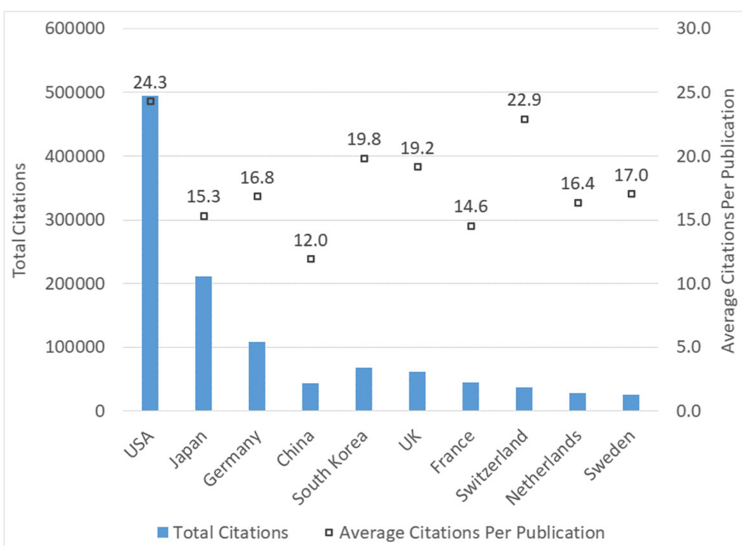

Fig. 2 Number of corporate Web of Science publication citations 2000–2019 by top 10 countries. Source: 53,200 global nanotechnology corporate publications extracted from Clarivate Web of Science in April 2020. Nanotechnology search terms based on Wang, et al. (2019)

the benefits of research and development. This section probes the nature of corporate publishing inherent in these two viewpoints by examining the extent of collaboration with other organizations on corporate-authored nanotechnology publications. One might infer that corporations would be less likely to collaborate with other corporations on research publications, because of their interest in limiting dissemination to potential competitors, and, by logical extension, more likely to collaborate with universities. We might expect this percentage to differ by country based on differences in the composition of the research enterprise. We investigate these differences by delving into organizational affiliation, cross-national co-authorship, and lead authorship characteristics.

Multi-organizational authorship in corporate nanotechnology publications

We begin our examination of the nature of corporate collaboration by counting the number of corporate nanotechnology publications with more than one authoring organization. Eighty percent of the 53,200 publications with a corporate author publish with authors in other organizations (Table 3). This percentage is comparable to the Science and Engineering Indicators coauthorship figures of 76% for 2008 and 84% for 2018 (National Science Board, 2020). The 80% figure suggests that most corporate authors of nanotechnology publications do collaborate outside their company employer. This percentage varies by country. Collaborative publishing with authors from other organizations was the most common as a percentage of nanotechnology publications affiliated in Sweden and China (96% and 95%, respectively). Also with a high percentage of multi-organizational coauthoring were the UK (94%), the Netherlands (94%), and France (93%). The next group of countries—Germany, Switzerland, and South Korea—had 90% of corporate nanotechnology publications involving multi-organizational coauthorship. Japanese and US corporations were least likely to publish nanotechnology works with another organization (74% and 79%, respectively). We also examined the percentage of multi-organizational coauthored corporate publications over the 2015–2019 to understand if these collaborations were rising or declining in recent years. Table 3 shows that the percentage of multi-organizational corporate nanotechnology publications increased to 90% in the 2015–2019 period.

Globalization in corporate nanotechnology publications

Globalization in coauthorship is a further dimension of corporate research collaboration and knowledge dissemination. We consider country differences in these

Table 3 Percentage of corporate nanotechnology publications by top countries with author affiliations involving two or more countries

Country affiliation of at least one author	Percentage with at least two organizational affiliations		Percentage with at least two country affiliations	
	Publication year 2000 to 2019	Publication year 2015 to 2019	Publication year 2000 to 2019	Publication year 2015 to 2019
All corporate publications	79.8%	90.0%	31.8%	41.3%
USA	79.3%	89.8%	40.8%	51.6%
Japan	73.7%	85.6%	23.5%	33.4%
Germany	89.7%	96.6%	64.4%	71.7%
China	95.5%	96.8%	58.1%	53.8%
South Korea	89.5%	97.0%	36.8%	79.8%
UK	94.4%	97.3%	72.7%	74.2%
France	93.2%	94.4%	64.6%	48.1%
Netherlands	94.3%	97.9%	78.0%	85.3%
Switzerland	89.7%	95.5%	81.6%	88.3%
Sweden	95.8%	96.8%	70.9%	77.4%

Source: 53,200 global nanotechnology corporate publications extracted from Clarivate Web of Science in April 2020. Nanotechnology search terms based on Wang, et al. (2019)

measures of collaborative corporate nanotechnology publishing for the top 10 corporate nanotechnology publishing countries. Previous work (Shapira et al., 2011) indicated that national innovation system measures were significantly associated with corporate patenting to a greater extent than international measures, though that paper did not specifically look at associations with corporate publishing.

Overall, more than 30% of corporate nanotechnology publications from 2000 to 2019 had more than one country in the author affiliations field (Table 3). This percentage rose to more than 40% when considering publications in the more recent 2015 to 2019 period. The National Science Board reported that 37% of US corporate publications were coauthored with a foreign institution in 2018, suggesting that our figures are within range of what has been reported elsewhere.

Corporate publications with a European author were most likely to involve another country. The percentage of nanotechnology corporate publications with two or more countries, including a European country author, ranged from 64% for Germany to 82% for Switzerland, for the 2000 to 2019 period. These percentages were even higher for the 2015 to 2019 period. Japanese and US corporate nanotechnology publications, in contrast, were much less likely to have two or more author-affiliated countries. Corporate publications with a Japanese author were the least likely to involve another country; only 24% had corporate publications with authors from different countries. South Korean corporate publications were the next least likely to involve another country, with 37% having two or more authors from different countries. Among corporate publications with a US author, 41% had two or more countries represented in their author affiliations. China had the highest share of corporate nanotechnology publications with two or more author-affiliated countries at 58%. On the other hand, China's percentage of corporate nanotechnology publications with two or more author-affiliated countries did not increase in the 2015 to 2019 period, while the percentages for the USA, Japan, and South Korea did go up.

Collaborative coauthorship with universities and other corporations

An examination of first author organizations can provide a sense of the extent to which corporations lead the research in collaborative nanotechnology publications. We extracted the first author organizations and applied (with some manual reclassification overrides) a VantagePoint thesaurus that groups academic, corporate, government, and individual organizations. We were able to classify 78% of the first author organizations in this manner. Chinese Academy of Science is classified in the "other" group comprised of public research institutes, government agencies, and hospitals. For the purpose of this analysis, we focus on the academic and corporate sectors.

The results show that 40% of nanotechnology publications with a corporate author had a corporate organization as the first author affiliation. While this is a substantial number, it is lower than universities appearing as the first author affiliation. Fifty-five percent of the corporate nanotechnology publications had a university first author affiliation (Table 4).

National differences are evidenced in contrasting academic versus corporate first authorships in nanotechnology publications aggregated to the country level. The UK and Switzerland had the highest percentage of corporate nanotechnology publications led by academic authors, each with 77% of corporate nanotechnology publications having an academic first author. China ranked second at 74%, followed by South Korea and

Table 4 Percentage of corporate nanotechnology publications with corporate or academic first authors

Country affiliation of at least one author	Percentage with academic lead author	Percentage with corporate lead author
All corporate publications	55.2%	40.2%
UK	77.2%	19.0%
Netherlands	76.6%	20.2%
China	74.3%	13.1%
South Korea	71.1%	10.8%
Sweden	70.7%	24.3%
France	68.4%	26.0%
Germany	57.2%	38.8%
Switzerland	57.1%	40.1%
USA	54.0%	39.3%
Japan	41.9%	51.4%

Notes: the remainder includes public research institutes, government agencies, hospitals, and individuals. Results are arrayed in order of the percentage of corporate nanotechnology publications with an academic lead author. Source: 41,375 global nanotechnology corporate publications extracted from Clarivate Web of Science in April 2020. Nanotechnology search terms based on Wang, et al. (2019)

Sweden, each with 71% of corporate nanotechnology publications with an academic first author.

Corporate lead authors were most frequent as a percentage of nanotechnology publications in Japan. Fifty-one percent of Japanese corporate nanotechnology publications had a lead author from the business sector. Switzerland, Germany, and the USA followed with around 40% of corporate first authored nanotechnology publications.

In summary, the nature of corporate publishing in nanotechnology has been observed to be collaborative, with eight out of 10 publications involving authors from multiple organizations. Cross-national collaborative research was also apparent in 30% of the corporate nanotechnology publications. Multi-organizational and multinational corporate nanotechnology publishing was increasing over time and varied across the top publishing countries. In addition, corporations did not appear to be publishing in a secondary role in all these collaborations, serving as the lead author in 40% of corporate nanotechnology works.

Conclusions

This study has depicted corporate entry into nanotechnology publishing. It provided a methodology to extract information about corporations from affiliations of authors of nanotechnology publications. A peer-reviewed search strategy was used to identify publications in the nanotechnology domain. This search strategy has been updated twice since its initial publication in 2008 to keep up with changes in the field. Corporate information is extracted from these publications, and counts of these documents were presented overall and by country.

This research was guided by studies showing low rates of corporate publishing, potentially due to concerns about the ability to appropriate benefits from disclosed results. This study identified more than 53,000 nanotechnology publications with a corporate author which, although accounting for only 2% of all nanotechnology publications in the Web of Science, is still a significant number that grew by 17% per year on average. The results showed that the USA was the leading nation in corporate publishing from 2000 to 2019, followed by Japan and Germany. China's corporate publishing activity placed the country in the fourth position following these top three most prominent corporate publishing nations, but with the fastest growth of all the leading corporate publishing countries since the middle of the 2010s. It is unclear whether this growth rate will change China's position in nanotechnology corporate publishing the way it has in overall science and engineering publishing, but for now, the leading countries' positions seem relatively stable.

The extent to which corporate publishing serves as a knowledge transfer indicator was further explored by examining cross-organizational and cross-national publishing. Most corporate publications involved authors from multiple organizations and nearly one-third from multiple countries. National research systems for nanotechnology could be broadly viewed according to distinctive corporate publishing characteristics. US corporate publishing tends to be more highly cited, but less collaborative with organizations outside of the USA. Asian countries are observed to have fewer collaborative ties outside of their home countries. In contrast, European countries have more corporate collaborations with authors affiliated with organizations outside of their home countries. Chinese corporate nanotechnology publications had a higher percentage of multi-organizational authors than did the USA or other Asian countries but a lower percentage of international authorships than did European countries. The UK, Switzerland, and China were most apt to have academic first authors, while Japan was most apt to have corporate first authors.

Our literature review indicated that studies of national nanotechnology systems of research and development primarily have characterized national differences based on gross counts of nanotechnology publications and patents. We suggest that distinguishing corporate publications can be beneficial to examining national systems of research and development. While it can be argued that publications with a corporate affiliate only comprise a small percentage of overall publications, we suggest that it is useful to distinguish corporate publications to understand the research, development, and knowledge transfer disposition of national innovation systems. Our results showed that corporate nanotechnology publication results do differ from overall nanotechnology publication counts. This kind of parsing of publication information is important for understanding corporate involvement in the nanotechnology research enterprise, inasmuch as national policies and programs, such as the US National Nanotechnology Initiative, often include efforts targeted toward collaborative corporate research, such as the US Signature Initiatives. We did not examine the effects of government, private sector, and other funding programs on collaborative corporate research in this paper. Future research studies should extend from our work to investigate the effects of sponsored research programs, including sponsored programs from two or more countries.

The analysis is subject to limitations. The publication index we used for the analysis was set up primarily to standardize information for research searching purposes, not for counting corporate activity. Although the standardization of organizational affiliations has improved, we found that variations of corporate names continue to exist. Some of the records we worked with had incomplete geographic information. These factors resulted in many variations of names of organizations and geographic areas. We applied thesauri and several rounds of manual checking of corporate organization names and geographic affiliations to address these errors, but variations persist.

The lack of a comprehensive global list of small- and medium-sized and large corporate organizations involved in nanotechnology makes measuring and understanding private sector activity in this cross-cutting domain difficult. We suggest that this paper provides an alternate approach that can be used to address this gap in research system assessment of emerging technological areas.

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Data Availability This article is based on bibliometric and text analyses of sets of nanotechnology-related research publication abstracts from Web of Science. We provide information on the search routines used to locate, and then download, those records. These instructions allow an interested party with suitable license to those databases to regenerate comparable datasets.

Code availability Routines employed in the analyses are available via the analytic software used—VantagePoint [www.theVantagePoint.com] and MS Excel.

Declarations

Conflict of interest Alan Porter and Nils Newman are employees of Search Technology, Inc., which develops and markets analytical software (VantagePoint) used in these analyses. There are no other conflicts of interest.

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Consent to participate Not applicable

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