Journal of Informetrics 17 (2023) 101369

Contents lists available at ScienceDirect

Journal of Informetrics

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

A New Look at National Diversity of Inventor Teams within Organizations

Chun-Chieh Wang [a,d], Jia-Tian Lin [b], Dar-Zen Chen [b,d], Szu-Chia Lo [c,d,*]

[a] Department of Bio-Industry Communication and Development, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Taipei, Taiwan (R.O.C)
[b] Department of Mechanical Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Taipei, Taiwan (R.O.C)
[c] Department of Library and Information Science, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Taipei, Taiwan (R.O.C)
[d] Center for Research in Econometric Theory and Applications, National Taiwan University, No. 1, Sec. 4, Roosevelt Rd., Taipei, Taiwan (R.O.C)

A R T I C L E I N F O

Keywords:
Mobile talent
National diversity
Inventive-collaboration
Inventor team

A B S T R A C T

Mobile talent brings different expertise, perspectives, knowledge, and experience into an organization. With a diversity of views, organizations can obtain new ideas that help improve research and development. National diversity can be deemed to represent the mobile talent within an organization, which might increase innovation. Organizations with national diversity are more innovative. Performance is generally based on collaboration between domestic and international talent, which provides the opportunity to capture benefits from the knowledge transfer effect. Most studies on national diversity generally take a headcount of countries on an organizational basis to calculate the National Diversity Index; however, this approach fails to reveal the contribution of knowledge transfer between domestic/international inventor team collaborations. In this study, the authors propose an index, which includes two parts, in which values are assigned based on domestic/international collaboration and international/international collaboration. The index can determine the level of national diversity. The authors further provided a mechanism for visualizing the diversity of inventor teams. An empirical analysis that focuses on the pharmaceutical industry was conducted to test the proposed model.

1. Introduction

In the age of mass global migration, the increased mobility of skilled individuals has facilitated the effective global transfer of knowledge and technology (Hatton & Williamson, 2005). Organizations, through joint ownership or strategic alliances, spend considerable effort to optimize the efficiency of the exchange of global resources, which in turn enhances knowledge exchange. Having a global linkage for industrial development is essential because it can “unlock” an evolutionary path (Martin and Sanely, 2006) by merging knowledge, technology, and capital from around the world (Davenport, 2005). Talented individuals, such as scientists, engineers, and technicians, are all carriers of knowledge and technology. Importing international talent may be beneficial (Kerr, 2010). Appelt et al. (2015) found that mobile talent induces international knowledge flows and that mobile inventors are positively associated with research and development (R&D) productivity. With different cultural backgrounds, mobile talent and locals bring diverse abilities and knowledge into an organization. These diversities are not only irreplaceable but also complementary to skills and talents (Niebuhr, 2010). Bergek and Bruzelius (2010) contended that patents with inventors from different countries are a good indicator of international R&D collaboration. Aman (2018) found that knowledge transfer is more prevalent among internationally mobile scientists than among non-internationally mobile scientists. In this study, inventors from countries other than the assignee’s

* Corresponding author.
E-mail address: szuchialo@ntu.edu.tw (S.-C. Lo).

https://doi.org/10.1016/j.joi.2022.101369
Received 5 May 2022; Received in revised form 30 November 2022; Accepted 8 December 2022

were regarded as mobile talent working for a foreign company. Mobile talents usually contribute more to a company's R&D efforts compared with domestic talent.

Mobile talent is correlated with the quality of inventions (Ferrucci and Lissoni, 2019) and is beneficial not only to the organization they work for but also to the region in which they work. In academia, research productivity is reflected by scholarly papers, whereas in industry, R&D productivity is represented by patents. Inventors of a patent can be considered as an inventor team (Orsatti, Quatraro, & Pezzoni, 2020). If the members are from different countries, the team can be regarded as an international inventor team. At the team level, Bergek and Bruzelius (2010) analyzed international R&D collaboration in ABB corporation by assessing patents with inventors from different countries and found that less than half the teams met the definition to be considered international inventor team as defined in previous studies. Orsatti et al. (2020) classified inventor team ability as "recombinant creation" and "recombinant reuse" and found that green technologies are generated by teams that creatively recombine previous knowledge.

Previous studies have found that international collaboration among inventors results in greater innovation. Shapira et al. (2011) focused on the effect of international collaboration on productivity. In their study, the authors examined US patents filed by enterprises from non-US countries that included at least one US inventor and patents filed by US-based enterprises that included at least one non-US-based inventor. The authors measured the extent to which countries have international inventor-based linkages, and their results indicated that cross-border international invention linkages have positive and significant effects on national innovation systems. A later study by De Prato and Nepelski (2014) reached similar conclusions. Two authors reviewed international co-invented patents issued by the European Patent Office and found a positive correlation between cross-border inventor collaboration and innovation performance; geographic closeness was a driving force for collaboration. Studies on academic research communities have also made similar observations regarding the positive effect of geographical diversity on research performance (Abbasi & Jaafari, 2013; Baji, Mostafavi, Parsaei-Mohammadi, & Sabaghinejad, 2021). The aforementioned studies jointly indicate that higher national diversity enriches industrial technology and R&D. From a research methodology point of view, the studies used the addresses of inventors to determine their nationalities. Associations of the national diversity of inventors with R&D innovation were investigated. However, most studies measured national diversity solely at an organizational level, did not consider different collaboration types, such as domestic/international and international/international, and did not investigate the effect of collaboration type on knowledge transfer and research performance (Abbasi & Jaafari, 2013; Aman, 2018; Ba, Mao, Ma, & Liang, 2021; Baji, Mostafavi, Parsaei-Mohammadi, & Sabaghinejad, 2021; Bašić & Vlajčić, 2021; Bergek & Bruzelius 2010; Bruzelius, 2010; Chinchilla-Rodríguez, Sugimoto, & Larivière, 2019; Lei, et, al., 2013; Gautam, 2017; Jiang, Jefferson, Zucker, & Li, 2019; Jiang, Zhu, Yang, Xu, and Jun, 2018; Lazear, 1999; Liao, 2011; De Prato & Nepelski, 2014; Shapira, Youtie, & Kay, 2011; Wang, Ren, Zhang, Zhu, Qiu, & Huang, 2014; Zhu, Liu, & Yang, 2021). Accordingly, this study proposed a method of measuring national diversity to investigate patterns of inventive collaboration, particularly among domestic/international and international/international inventor teams. Inventor nationality was determined according to inventor addresses recorded on patent documents. Patents are widely analyzed for research on national competitiveness and cross-country collaboration in R&D (Sung, Wang, Chen, and Huang, 2014). The United States Patent and Trademark Office (USPTO) does not restrict applications by inventor nationality, and it reports the names and addresses of all inventors for each patent application (Jiang, Jefferson, Zucker, & Li, 2019).

This paper proceeds as follows. Section 2 is a literature review that includes three parts: national and international collaboration in R&D activities, introduction of diversity indexes, and national diversity analysis in Patentometrics. In Section 3, we propose an algorithm for measuring national diversity in inventor teams and at the assignee level. Section 4 consists of a case study in the pharmaceutical field and a discussion on the results. Section 5 is the conclusion.

2. Literature Review

To have a comprehensive understanding of the related issues and the research design, the authors examined scholarly literature on several topics, including national and international collaboration, diversity indexes, and national diversity in Patentometrics.

2.1. National collaboration and international collaboration

R&D involves collaboration and the sharing of ideas and knowledge. The creation and transfer of knowledge requires diversity (Berliant and Fujita, 2008). Lazear (1999) argued that multinational teams were devised to overcome skill shortages. Wuchty et al. (2007) and Jones (2009) have argued that for an individual to make advancements in a field, they must master all of the aspects of that field, which is difficult due to the increasing complexity of scientific and technical innovation. Therefore, the need to bring diversity into research teams is crucial. Complementarity of disciplines and techniques among team members is important for a team to appropriately function. Recruitment of members from diverse backgrounds provides opportunities for Interdisciplinary and cross-sector cooperation (Alesina et al., 2016; Kemeny, 2017), which enhances the innovative potential through the diffusion of scientific and technical knowledge (Ferrucci and Lissoni, 2019; Lissoni, 2018). A previous study showed that nationality, political views, cultural background, and socioeconomic status influence an inventor's work performance (Jiang, Zhu, Yang, Xu, and Jun, 2018). Moreover, the size of a collaborative team affects its performance (Zhu, Liu, & Yang, 2021).

In bibliometric analysis, national collaboration usually refers to collaboration between institutions or researchers from the same country or region and international collaboration refers to collaboration between institutions or researchers from at least two different countries or regions. International collaboration has been the main force of scientific and technological development. In general, research on author collaboration and publication effects has been based on coauthor networks; publication effects have been associated with the number of external collaborations (Abbasi & Jaafari, 2013; Liao, 2011; Gautam, 2017). Based on the coauthor network, collaboration intensity and member diversity can predict research quality (Baji, Mostafavi, Parsaei-Mohammadi, & Sabaghinejad, 2021). Rafols and Meyer (2010) analyzed diversity and network coherence to evaluate knowledge integration. They used diversity indicators (variety of disciplines, the Shannon Index, the Simpson Index, and the Stirling Index (Stirling, 1998; 2007)) to measure disciplinary diversity and found that disciplinary diversity is indicative of the breadth of the knowledge base of publications and that network coherence reflects the novelty of its knowledge integration. Abramo et al. (2018) followed Stirling (2007)'s diversity indexes (Variety, Balance, and Disparity) to investigate interdisciplinary research output according to the disciplinary diversity of authors and the disciplinary diversity of reference lists.

Chinchilla-Rodríguez et al. (2019) analyzed academic papers and categorized them as national or international according to the nationalities of the corresponding authors. International collaboration was positively correlated with the citation effect. Abramo et al. (2021) investigated the scientific effects of research by private and public institutions. They compared types of research collaboration and the effects of publication. In Italy, 70% of publications were the result of collaboration between private and public institutions, and these publications all showed greater scholarly effects than the others.

Through patentometric analysis, Lei et al. (2013) clearly defined that inventor collaboration and assignee collaboration represent two dimensions of geographical collaboration; the former reflects the collaboration of inventive activity, and the latter represents the economic collaboration produced by innovation. Wang et al. (2014) investigated inventor collaboration and assignee collaboration and analyzed patterns of international technological collaboration in China. Regarding assignee collaboration, China very often works with the United States and Taiwan; regarding inventor collaboration, various countries work with China, and different fields have their own preferred priority. Bašić and Vlajčić (2021) studied international R&D cooperation as a determinant of the technological specialization of a country. Data were obtained from the Organisation for Economic Co-operation and Development (OECD) database. The degree of international R&D cooperation was indicated by the number of patents that had foreign inventors. Ba et al. (2021) analyzed patent data from the USPTO to explore the effects of national and international collaboration on innovation at the city level. They found that city-level collaboration and knowledge networks have distinct structural characteristics and affect innovation in different ways.

In summary, R&D collaboration at the organizational and individual levels is discussed frequently in bibliometric and patentometric analyses. However, substantive knowledge flow interactions also exist at the individual level. This study mainly focused on patterns of national diversity from the perspective of inventor teams to assess the differences in talent allocation among organizations.

2.2. Diversity indexes

Previous studies have investigated international collaboration from, among other perspectives, country, organizational, individual, and disciplinary levels. Inventor nationality can be identified by the address listed on the patent application. Previous studies have used indicators such as the International Collaboration Range (Wang, Huang, Wang, Lei, Zhu, Ren, & Jabeen, 2014), which is defined as the number of partner countries involved in a collaboration and reflects the breadth of a country or region's international collaboration from a macro perspective. The Country Diversity Index (Huang, Ma, Porter, Kwon, & Zhu, 2015) is based on the number of country in articles and is used to show collaboration distribution among and collaboration instances between countries. In previous studies, factors of diversity included "variety," the number of distinctive categories, "balance," the evenness of the distribution of categories, and "disparity or similarity," the degree to which the categories are different or similar (Stirling, 1998). Glänzel and Delange (1997) developed the Multilateral Collaboration Index to measure the extent of multilateral coauthorship links in a country or region. They calculated the share of international publications and the number of international collaboration links. Wang et al. (2014) proposed the International Collaboration Activity Index, which includes subindicators regarding the proportion of the participation of each country. Using the International Collaboration Activity index, they measured the Average Number of Collaborating Countries per Paper (the number of times the paper's first country has cooperated with other countries or regions), the Paper Collaboration Ratio (how much a country or region's multinational papers accounted for the country or region's total number of papers), the International Collaboration Range (how many partner countries or regions have been involved in collaborations), and the Publishing Paper Ratio (the extent to which the total number of papers that a country or region has published account for the total number of papers). Chen et al. (2019) studied the main research trajectories and intellectual communities of the International Research Collaboration (IRC). They conducted a qualitative review on the three dimensions of author, coauthorship, and citation network and presented the features in different IRC research phases. However, the aforementioned indexes all focus on the proportion of international collaboration rather than on the strength of national diversity in international collaboration.

Previous empirical studies have adopted indexes that measure levels of diversity. For example, Shannon's Index, also known as the Shannon–Wiener Index, is popular in ecological studies (Spellerberg and Fedor, 2003). Aydinoglu et al. (2016) adopted Shannon's Index to measure the disciplinary diversity of a research team. Their results indicated that intended team diversity was achieved. Aman (2018) also adopted Shannon's Index as a diversity measure to analyze the knowledge base of scientists during the mobility phase. Simpson's Index (Simpson, 1949) and the Brillouin Index (Brillouin, 1956) are measurements of biodiversity. Stirling (2007) proposed a revised index based on Simpson's Index and named it the Stirling Index, which weights distance/similarity (Rafols, & Meyer, 2010) and was later used to measure team disciplinary diversity (Feng & Kirkley, 2020). In economics, the Herfindahl–Hirschman Index (HHI) is used to measure the size of companies that are competitive. The HHI is used in patent analysis to measure international R&D cooperation and to reveal the effects of international cooperation among OECD countries from the viewpoint of technological specialization (Bašić & Vlajčić, 2021). Blau's Index (Blau, 1977) has been applied in human resources management for the measurement of talent diversity, including national, educational background, age, and skill diversity. Fagan et al. (2018) measured the diversity of articles published over time by adopting Blau's Index to understand whether changes in coauthorship networks are reflected in the diversity of articles published by research members from different research programs. Although these indexes were developed by scholars from a variety of fields, they only have slight differences in their formulations.

Blau's Index considers the shares of group members and is calculated as follows:

$$Blau's\ Index = 1 - \sum_{m=1}^{M} S_m^2 \tag{1}$$

where M is the number of groups and S_m refers to the share of group m. In Blau's Index, higher values correspond to more diversity in the group. Simpson's Index and the HHI are similar to Blau's Index. The three indexes all range from 0 to 1; however, in Simpson's Index and the HHI, higher values correspond to less diversity in the group. The formula for Simpson's Index and the HHI is

$$Simpson's\ Index,\ HHI = \sum_{m=1}^{M} S_m^2 \tag{2}$$

Shannon's Index is similar to the previous diversity indexes and calculates the share of each group in population S_m. The difference between Shannon's Index and the previous indexes is that the previous indexes calculate the square of each group's share as (S_m^2), whereas Shannon's Index calculates each group's share plus its natural logarithm as ($S_m \times \ln S_m$). The formula for Shannon's Index is

$$Shannon's\ Index = -\sum_{m=1}^{M} S_m \ln S_m \tag{3}$$

Although similar to Shannon's Index, the Brillouin Index is based on the actual number in each group rather than the proportions. The formula for the Brillouin Index is

$$Brillouin\ Index = \frac{\ln(N!) - \sum_{m=1}^{M} \ln(n_m!)}{N} \tag{4}$$

N refers to the total number of the population, and n_m is the number of members in group m. In general, the Brillouin Index is suitable for estimation based on random sampling that cannot be guaranteed (Magurran, 1988).

Blau (1977) proposed Blau's Index to measure national diversity in the social context. In addition to national diversity (Dahlin, Weingart, and Hinds, 2005; Díaz-Fernández, González-Rodríguez, and Simonetti, 2020; Ferrucci and Lissoni, 2019; van Veelen and Ufkes, 2019), the index has also been applied to measure educational diversity (Dahlin, Weingart, and Hinds, 2005; Díaz-Fernández, González-Rodríguez, and Simonetti, 2020; Garcia Martinez, Zouaghi, and Garcia Marco, 2017), age diversity (Díaz-Fernández, González-Rodríguez, and Simonetti, 2020), and skill diversity (Díaz-Fernández, González-Rodríguez, and Simonetti, 2020; Garcia Martinez, Zouaghi, and Garcia Marco, 2017). Blau's Index can also be applied to measure the national diversity of assignees in a patent document. However, the use of Blau's Index should not be restricted by organization level. We argue that domestic cooperation with foreigners and pure foreigner collaboration on an inventor team should both be taken as parts of the national diversity measured by Blau's Index.

2.3. National diversity in Patentometrics

A Patent grants exclusive rights to an invention. An invention could be a product or a process that provides a new way of doing something or that offers a new technical solution to a problem. Patent applicants must disclose technical information to the public via the application document (World Intellectual Property Organization, 2021). Compared to other carriers that support the dissemination of research results, patent literature contains detailed technical information and may be the only material that carries such information. Patent bibliometrics is the systematic analysis of patents using mathematical methods that has been developed within the field of Informetrics. This type of analysis is also seen in economics research and policy making and is labeled as patent statistics or patent metrics (Narin, 1995). Patent bibliometrics in this study reflects the applications of methods and indicators developed in the field of Informetrics. Patents are granted for new and valuable technological inventions (Meyer and Persson, 1998). Information contained in a patent document can be beneficial for science and technology, policy making, identifying business opportunities, and evaluating the R&D landscape of a country or organization. Patent data are used not only to trace the development of technology (Basberg, 1987) but also to identify the technology life cycle (Lin, Liu, Guo, and Meyer, 2021), to characterize assignees in the technology evolution trajectory (Kuan, Lin, and Chen, 2021), and to measure the linkage between science and technology (Ba and Liang, 2021).

Anderson et al. (2005) suggested that creativity was more prevalent in regions with more diversity in employment. Breitzman and Thomas (2015) observed by using patent bibliometrics that patents with many inventors were more likely to detail high-quality innovations. Hunt and Gauthier-Loiselle (2010) investigated the effect of foreign skilled talent on innovation and found that more patents were granted to foreign inventors than to local inventors, possibly because skilled immigrants have an above-average share of degrees in science and engineering. Kerr and Lincoln (2010) showed in their study that increases in invention are positively correlated with levels of immigration, and immigration contributes to cultural diversity in the workforce. Such results were mainly due to cultural diversity in the entrepreneurship labor force (Audretsch, Dohse, and Niebuhr, 2010). Overall, inventor mobility is associated with higher quality patents via increased diversity at the inventor team level, the company level, and the local level. This positive correlation with diversity remains after adjusting for the presence of migrants in the team, which suggests not only functional but also cultural diversity (Ferrucci and Lissoni, 2019).

Table 1
Examples of national diversity calculation in inventor team level.

Patent No (Assignee Country)	Inventor Country	DPI	NDI	Types
US 8377955 (US)	US, US, US	1.00	0	Domestic Inventor Team
US 7872039 (DE)	DE, DE, DE, DE, DE, DE	1.00	0	
US 8791142 (CH)	CH, CH, FR	0.67	0.44	Domestic/International Inventor Team
US 7935724 (US)	IT, US, US	0.67	0.44	
US 8008302 (CH)	CH, CH, FR, FR, FR, FR	0.33	0.44	
US 9695163 (US)	CN, CN, CN, US, US, US	0.50	0.50	
US 8614215 (CH)	CH, DE, FR, FR, FR, FR	0.17	0.50	
US 8058289 (CH)	CH, CH, FR, FR, FR, US	0.33	0.61	
US 8362075 (US)	GB, IE, US	0.33	0.67	
US 9567320 (DE)	BE, BE, FR, FR, IN, IN	0	0.67	International Inventor Teams

3. Algorithm

Patents represent the R&D achievements of organizations. Patents are crucial for protecting intellectual property. The data presented in patents indicate embedded technologies and show the talent behind the inventions. In this study, addresses of inventors were used to measure the degree of national diversity of inventor teams. A patent document contains two sets of information related to nationality: country of assignee and country of inventor. The assignee is the owner of the intellectual property, and the inventor is the individual or individuals who contributed to the invention (Sung, Wang, Chen, and Huang, 2014). This study used the addresses of inventors to determine nationality. To measure the national diversity of inventor teams, this study proposed two instruments: the Domestic Proportion Index (DPI) and the National Diversity Index (NDI). The DPI measures the level of domestic collaboration according to how many assignees and inventors are affiliated with the same country. The NDI measures the extent of national diversity among inventors by using Blau's Index.

3.1. National diversity, a view from the inventor team

The first index introduced in this study is the DPI, which shows the contribution of inventors who are from the same country as the assignee. For example, the share of domestic inventors in Patent P with assignee country a is calculated as follows:

$$DPI\ (P_a) = \frac{N_a}{N} \tag{5}$$

where $\frac{N_a}{N}$ refers to the share of inventors in Patent P, a refers to the inventor's country, and N refers to the number of inventors in Patent P. The NDI used in this study is based on Blau's Index (Blau, 1977). The national diversity of the inventor team in Patent P is calculated as follows:

$$NDI(P) = 1 - \sum_{m=1}^{M} S_m^2 \tag{6}$$

where S_m is the share of inventors in Country m of Patent P. The national diversity of the inventor team in Patent P is shown as follows:

$$[DPI\ (P), NDI\ (P)]$$

Taking both the assignee's country and the inventor's country into consideration, this study identified three types of inventor teams: domestic, in which the inventors are from the same country as the assignee, domestic/international, in which the members of the inventor team are from both the assignee's country and other countries, and international, in which the inventors are not from the assignees' country. Examples of the three inventor team types are given in Table 1. US 8377955 and US 7872039 have domestic inventor teams. These two patents have an index value of (1,0), which corresponds to a DPI of 1 and an NDI of 0, because the assignee and inventors are from the same country. US 8791142 and US 8362075 have domestic/international inventor teams. At least one inventor is from a country other than that of the assignee. The index values are (0.67, 0.44) and (0.33, 0.67) for US 8791142 and US 8362075, respectively. US 9567320 has a typical International inventor team. None of the inventors are from the assignee's country. The DPI value is 0 and the NDI value is 0.67. With the DPI and NDI, one gets a chance to observe the characteristics of the national diversity of inventor teams in detail. US 8008302, US 8058289, and US 8362075 have the same DPI value (0.33), and US 8362075 has the highest NDI value.

Two more examples are US 9695163 and US 8614215. If we follow the previous studies and measure US 9695163 and US 8614215 by using the NDI only, we would obtain an index value of 0.5 for both patents. This suggests that the national diversity of these two inventor teams is the same. Yet, if we further measure the national diversity of the two inventor teams by using the DPI, we obtain DPI values of 0.5 and 0.17. Taking a close look, among the six inventors of US 9695163, three (50%) are local and three are foreign (CN). This patent is therefore a US–CN collaboration. However, among the six inventors of US 8614215, only one (17%) is local (CH); the other five are foreign (DE and FR). Accordingly, this patent is a CH–DE–FR collaboration. Although the NDI of the two inventor teams is the same, their levels of international collaboration differ when measured using the DPI. US 9695163 has a DPI value of (0.5), which is higher than that of US 8614215 (0.17) by using the DPI, we can differentiate types of international collaboration.

3.2. National diversity, a view from the assignee

The authors also used the indexes to analyze the national diversity of assignees (organizations). Averages of DPI values, NDI values of domestic/international inventor teams, and NDI values of International inventor teams were calculated for each assignee to determine the national diversity of assignees. The average DPI of assignee A is calculated as follows:

$$Average\ DPI\left(P^A\right) = \frac{\sum_{i=1}^{N} DPI(P_i^A)}{N} \tag{7}$$

where $DPI\ (P_i^A)$ is the share of Domestic inventors in Patent i owned by assignee A which holds N patents. The average NDI is calculated using Eq. (8) to obtain NDI values for domestic/international inventor teams and international inventor teams to show national diversity. The Average domestic/international inventor team NDI of assignee A is calculated as follows:

$$Average\ NDI\left(P^A\right) = \frac{\sum_{i=1}^{N} NDI(P_i^A)}{N}, \tag{8}$$

$$Average\ domestic/international - team\ NDI\left(P^A\right) = \frac{\sum_{j=1}^{N_{nf}} NDI_{nf}\ (P_j^A)}{N_{nf}}, \tag{9}$$

where $NDI_{nf}(P_j^A)$ is the NDI of domestic/international inventor team Patent j of assignee A, which owns N_{nf} domestic/international inventor team patents. A similar equation was designed to obtain the international inventor team NDI:

$$Average\ International - team\ NDI\left(P^A\right) = \frac{\sum_{k=1}^{N_f} NDI_f\ (P_k^A)}{N_f} \tag{10}$$

where $NDI_f\ (P_k^A)$ is the NDI of International inventor team Patent k for assignee A, which owns N_f International inventor team patents. With no International inventor team patents, the index for assignee A is zero. Finally, the national diversity of the inventor team of assignee A is presented as follows:

$$\left[Average\ DPI(P^A), Average\ domestic/international - team\ NDI(P^A), Average\ International - team\ NDI(P^A)\right]$$

4. Empirical practice of National Diversity Indexes on inventions in pharmaceutical industry

The pharmaceutical industry is knowledge intensive in nature, and the demand for highly skilled immigrants to advance R&D is increasing (Kale, 2009; González, 2020). Pharmaceutical development is cross-disciplinary and involves collaboration between individuals from diverse backgrounds, which serves to bring valuable knowledge into the domain. The correlation of talent diversity with promising outcomes that improve innovation has been widely reported (Lee, Walsh, and Wang, 2015; Singh, 2005; Zhu et al., 2019). The pharmaceutical industry is a good target for this study to examine differences in national diversity in inventor teams.

4.1. Data collection

This section reports further observations of the application of the proposed measurement to the national diversity of inventor teams. Assignees that were granted more than 150 pharmaceutical patents in the United States from 2011 to 2020 were selected for enrollment. Classification numbers for pharmaceutical technologies in the International Patent Classification reported by the World Intellectual Property Organization (Schmoch, 2008) were used for patent retrieval. In total, 53 assignees were included for analysis. These assignees were granted 25,609 pharmaceutical patents, accounting for 25.9% of the total number of patents. To ensure the validity of the results, name authority control was performed during the data processing stage.

4.2. National diversity at Inventor-team level in organizations

Average DPI, average domestic/international inventor team NDI, and Average International inventor team NDI were calculated for the 53 assignees, and the statistical results are listed in Tables 2 and 3. The index positions were also visualized, as shown in Fig. 1.

4.2.1. National diversity vectors

Among the 53 assignees that were granted more than 150 pharmaceutical patents are 33 companies (C1–C33), 14 universities (U1–U14), 5 research institutes and hospitals (I1–I5), and 1 government agency (G1). In Table 2, the statistical results for the 33 companies are listed, and Table 3 provides the information about the universities, research institutes, and other types of assignees.

The differences between the NDI (Blau's Index) and the NDIs with Domestic Proportion values are examined first in this paper. Take Merck, Janssen, and Baxter Pharma as examples. The NDI (Blau's Index) values for Merck, Janssen, and Baxter Pharma (0.58, 0.58, and 0.55, respectively) are similar, but after including the domestic inventors in the equation, they show very different diversity levels: Merck (0.78, 0.41, 0.11), Janssen (0.35, 0.43, 0.10), and Baxter Pharma (0.06, 0.48, 0.07). The indexes present very different

Table 2
National Diversity Indexes-companies.

Company	Inventor Teams	NDI (Blau's Index)	National Diversity Indexes		
			Average DPI	Average Domestics/International NDI	Average International NDI
C1. Merck	1,430	0.58	0.78	0.41	0.11
C2. Novartis	1,364	0.71	0.23	0.50	0.11
C3. Janssen (J&J)	1025	0.58	0.35	0.43	0.10
C4. Bristol-Myers Squibb	1011	0.15	0.94	0.40	0.17
C5. Roche	874	0.79	0.27	0.51	0.34
C6. Pfizer	860	0.23	0.90	0.37	0.02
C7. Sanofi	854	0.69	0.60	0.42	0.05
C8. Allergan	805	0.19	0.91	0.43	0.03
C9. GlaxoSmithKline	804	0.78	0.51	0.44	0.08
C10. Boehringer Ingelheim	729	0.64	0.61	0.43	0.07
C11. Genentech	678	0.27	0.88	0.40	0.24
C12. AstraZeneca	622	0.69	0.48	0.42	0.08
C13. Bayer	620	0.25	0.88	0.30	0.00
C14. AbbVie	594	0.42	0.78	0.33	0.16
C15. Takeda	538	0.59	0.71	0.36	0.04
C16. Amgen	480	0.25	0.92	0.35	0.07
C17. Vertex Pharma	459	0.42	0.75	0.30	0.00
C18. Gilead	444	0.15	0.93	0.43	0.08
C19. Abbott EPD	357	0.47	0.88	0.34	0.26
C20. Purdue Pharma	350	0.21	0.88	0.46	0.08
C21. General Hospital Corp.	304	0.14	0.93	0.42	0.17
C22. Eli Lilly	301	0.24	0.86	0.43	0.00
C23. Novo Nordisk	253	0.26	0.75	0.41	0.05
C24. 3M	249	0.37	0.79	0.35	0.01
C25. Regeneron	233	0.08	0.96	0.43	-1.00
C26. Incyte	228	0.01	0.99	0.23	0.00
C27. Otsuka	220	0.19	0.85	0.41	0.05
C28. Daiichi Sankyo	211	0.18	0.95	0.40	0.00
C29. Grünenthal	208	0.22	0.88	0.34	0.04
C30. UCB	206	0.56	0.34	0.49	0.06
C31. Immunomedics	201	0.04	0.98	0.41	0.00
C32. Biogen	199	0.26	0.94	0.42	0.00
C33. Baxter Pharma	155	0.55	0.06	0.48	0.07
Median	**459**	**0.26**	**0.86**	**0.41**	**0.06**

*Average International NDI= -1 means that there is no international team for the assignee

Table 3
National Diversity Indexes-assignees from the public sector.

University, Institute & Government	Inventor Teams	NDI (Blau's Index)	National Diversity Indexes		
			Average DPI	Average Domestics/International NDI	Average International NDI
U1. Univ. of California	1059	0.13	0.94	0.40	-1.00
G1. Dept. of HHS, US	915	0.16	0.92	0.43	-1.00
U2. Univ. of Texas System	683	0.11	0.95	0.41	0.44
U3. Univ. of Pennsylvania	469	0.10	0.96	0.40	-1.00
U4. Stanford Univ.	444	0.15	0.94	0.43	-1.00
I1. CNRS, FR	431	0.22	0.91	0.43	0.00
I2. INSERM	419	0.19	0.89	0.42	0.37
U5. Johns Hopkins Univ.	416	0.10	0.96	0.39	0.00
U6. Univ. of Wisconsin	312	0.12	0.95	0.43	-1.00
U7. Duke Univ.	269	0.04	0.97	0.47	0.00
U8. Univ. of Pittsburgh	268	0.05	0.97	0.42	-1.00
U9. MIT	261	0.16	0.92	0.38	-1.00
U10. Univ. of Michigan	251	0.08	0.96	0.39	-1.00
U11. Univ. of South Florida	247	0.13	0.97	0.37	-1.00
I3. Brigham & Women's Hosp.	233	0.17	0.92	0.36	-1.00
I4. Mayo Clinic	226	0.13	0.96	0.36	-1.00
U12. New York Univ.	226	0.15	0.94	0.42	0.21
I5. Dana-Farber Cancer Inst.	218	0.16	0.92	0.39	-1.00
U13. Harvard College	205	0.16	0.93	0.41	-1.00
U14. Northwestern Univ.	191	0.09	0.95	0.44	-1.00
Median	**268.5**	**0.13**	**0.95**	**0.41**	**-1.00**

*Average International NDI= -1 means there is no International-teams for the assignees

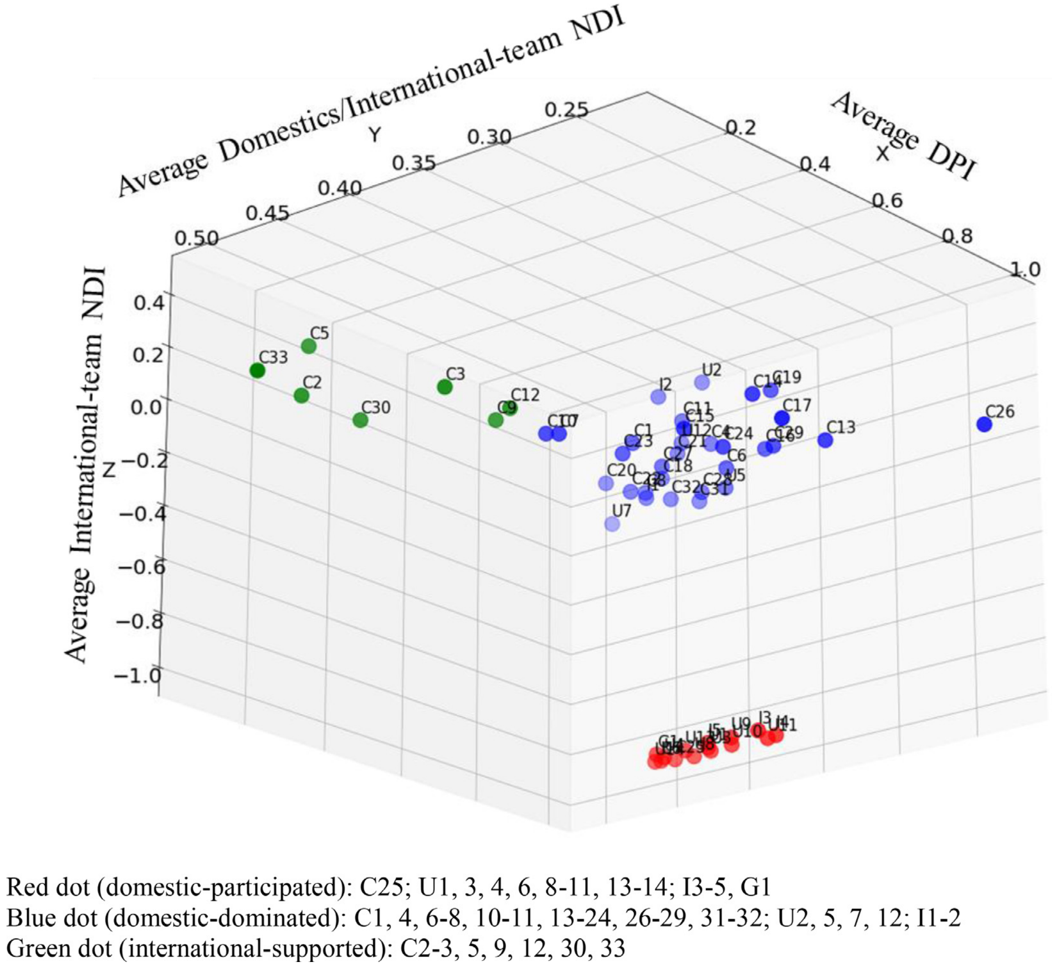

Fig. 1. Organizational positions in vector space.

indications for these three assignees, and this is be further discussed in the following section. With the DPI and the other two indexes, one can also observe whether the assignees rely more on domestic inventors or international inventors to advance the inventions. For example, Novartis (C2, 0.71, DPI-0.23), Janssen (C3, 0.58, DPI-0.35), Roche (C5, 0.79, DPI-0.27), AstraZeneca (C12, 0.69, DPI-0.48), UCB (C30, 0.56, DPI-0.34), and Baxter Pharma (C33, 0.55, DPI-0.06) have lower average DPI values (the median is 0.86), which means that compared to other peer assignees, these companies depend more on international inventors or international collaboration to bolster the knowledge and skills fundamental to their inventions. International inventor teams are the major force driving their inventions. A very different type of team strategy is observed in the group of assignees with low NDI values. For example, Bayer (C13, 0.42, DPI-0.88, D/I-0.30), Vertex Pharma (C17, 0.42, DPI-0.75, D/I-0.30), Eli Lilly (C22, 0.24, DPI-0.86, D/I-0.43), Incyte (C26, 0.01, DPI-0.99, D/I-0.23), Daiichi Sankyo (C28, 0.18, DPI-0.95, D/I-0.40), Immunomedics (C31, 0.04, DPI-0.98, D/I-0.41), and Biogen (C32, 0.26, DPI-0.94, D/I-0.42) have high DPI values, but the domestic/international values indicate that the assignees maintain a certain level of international collaboration with inventors from select areas. Among these 33 assignees, Regeneron is the only one with patents contributed solely by international inventors. This implies that knowledge and skill outsourcing to inventors abroad might be one of the strategies taken to advance industrial technologies in the private sector.

Compared to the private sector, universities and entities in the public sector have a different strategy. Table 3 shows the statistical results for the 22 assignees that are not companies (public entities). Assignees from the public sector have a higher level of domestic contribution in their inventor teams. The median of the average DPI is 0.95, and the lowest value is 0.89, which is the value for Institut National de la Santé et de la Recherche Médicale (INSERM). However, aggregating domestic inventor teams was not the only strategy taken for these assignees. A large number of inventions had teams with members from both domestic and international backgrounds. The average domestic/international inventor team NDI value is 0.41, which is the same as that for the assignees from the private sector. Furthermore, 14 out of 20 assignees from the public sector have no inventions contributed solely by international teams. Even among inventions with international teams, the assignees only seem to import technologies from specific regions.

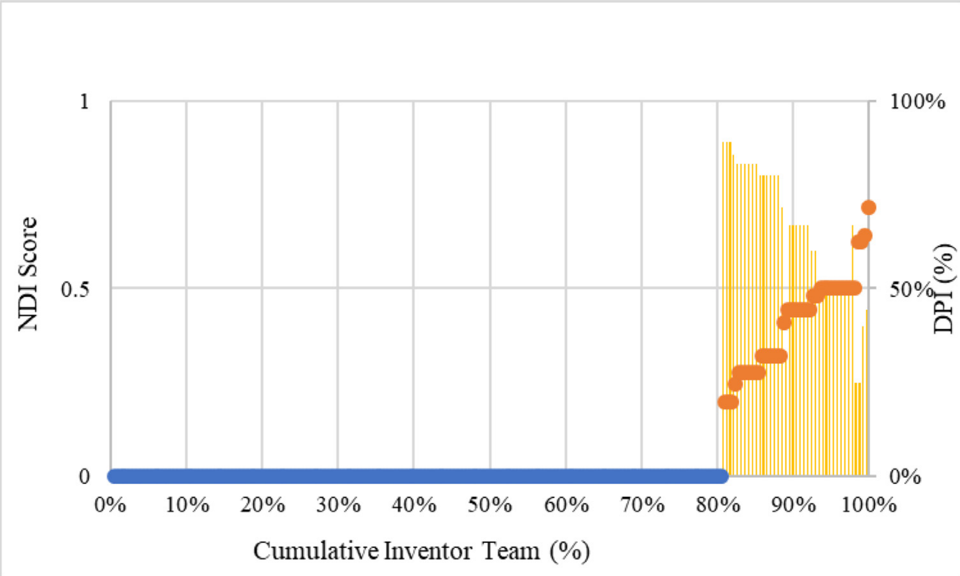

Fig. 2. National Diversity Spectrum of Harvard College's Inventor Team

4.2.2. *National diversity positions*

The authors further located the assignees in the three-dimensional vector space based on NDI values (Table 2 and Table 3). The results are presented in Fig. 1. The X-axis is the average DPI value, the Y-axis is the average domestic/international inventor team NDI value, and the Z-axis is the average International inventor team NDI value. From the positions in the vector space, the assignees can be classified into three clusters: domestic-dominated, in which the DPI value is greater than 0.6 with no international teams, domestic-participated, in which the DPI value is greater than 0.6 with international teams, and international-supported, in which the DPI value is less than 0.6 with international teams.

The results show that the largest cluster is the domestic-dominated cluster, which includes 31 assignees (marked blue in Fig. 1). The assignees in this cluster took the domestic team as the major force for technology development. For example, more than 96% of the inventors affiliated with The University of Texas, Johns Hopkins University, Duke University, and New York University were local, with an average domestic/international inventor team NDI value of 0.4. Similar results were observed for institutions based in Europe, such as Centre National de la Recherche Scientifique and INSERM, for which 90% of inventors were local and the sum of average domestic/international inventor team and International inventor team NDI values were greater than 0.5. Other assignees belonging to this cluster mainly worked with local inventors. An average of 85% of the inventors were from the same country, with an average NDI value of 0.4.

The second cluster is the domestic-participated cluster, which includes 15 assignees (marked in red in Fig. 1). Assignees in this cluster benefitted from domestic teams and elevated productivity, with contributions from research groups that included domestic and international inventors. Most of the assignees in this cluster are nonprofit organizations, such as educational and research institutions. The University of California, University of Pennsylvania, and Stanford University are members of this cluster.

The international-supported cluster is the smallest cluster and includes seven assignees. The average DPI value for the members of this cluster is less than 0.5, and more than 50% of the patents have at least one international inventor. The seven companies in this group are highly dependent on international talent for their R&D, except for GlaxoSmithKline, which has 51% domestic membership in their inventor teams. Another assignee, Baxter Pharma, has only 6% of domestic inventors in its inventor teams, which is the smallest proportion, and depends on international inventors for new drug development. Novartis, Janssen, Roche, AstraZeneca, and UCB are all supported by international talent in new drug development.

4.3. *National diversity spectrum in Organizations*

The national diversity spectrum can be further analyzed according to the NDI. National diversity can be represented by visualizing the inventor team. This study took one example from each cluster to visualize the inventor team. Harvard College represents the domestic-participated cluster (Fig. 2), Merck represents the domestic-dominated cluster (Fig. 3), and Novartis represents the international-supported cluster (Fig. 4). The X-axis presents the cumulative percentages of inventor teams. Blue dots represent domestic teams. Orange dots represent domestic/international teams. Grey dots represent international teams. Vertical bars reflect the domestic proportion of each inventor team.

Harvard College is a domestic-dominated assignee. Local inventors contribute more to their R&D than do foreign inventors. Its national diversity spectrum is shown in Fig. 2. The domestic-participated assignee in the national diversity spectrum is clearly

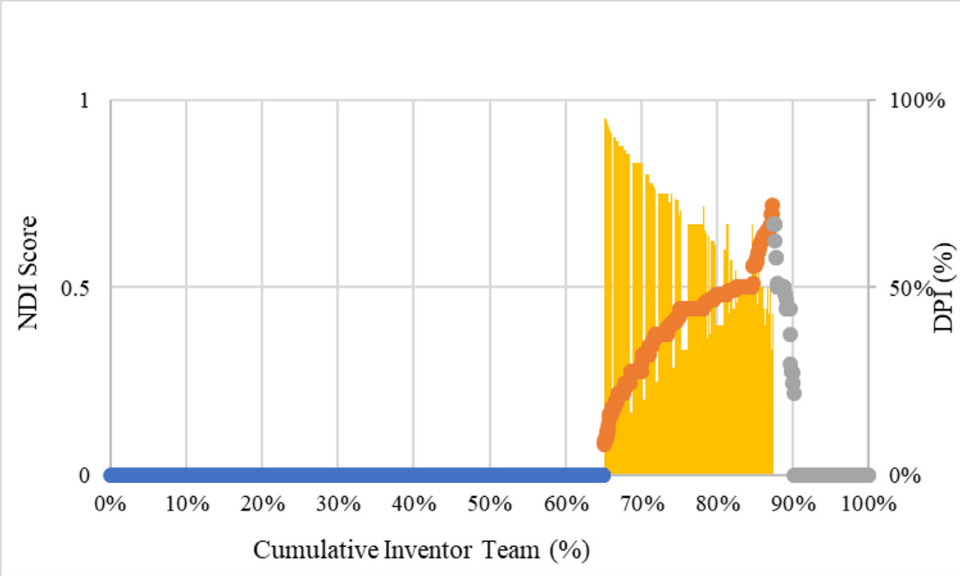

Fig. 3. National Diversity Spectrum of Merck's Inventor Team.

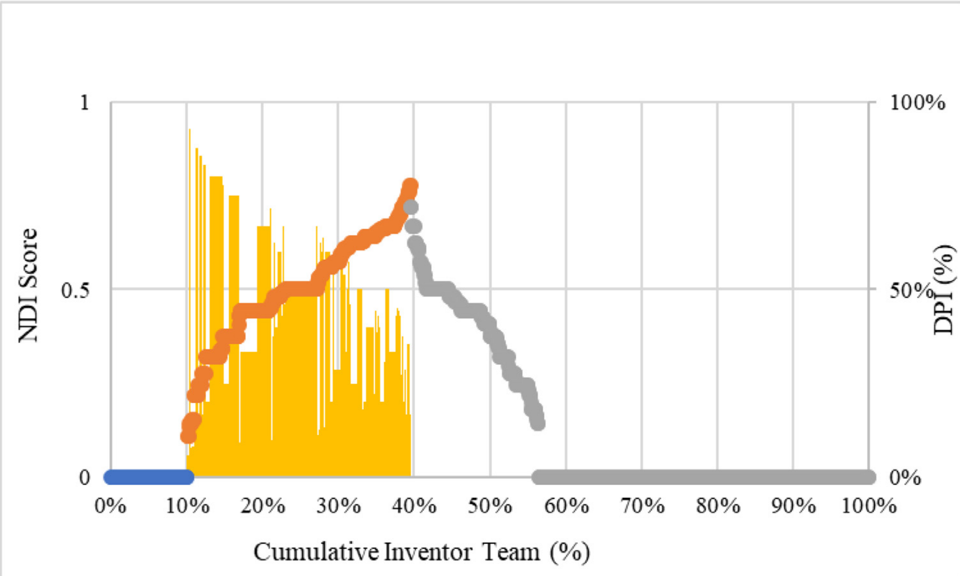

Fig. 4. National Diversity Spectrum of Novartis's Inventor Team.

characterized by the high proportion of domestic teams (80%) in blue, supportive domestic/international teams (20%) in orange, and zero international teams in grey. The NDI value of Harvard College's inventor team is less than 0.5, and the Domestic inventor proportion of Harvard College is more than 50%.

Merck is a domestic-participated assignee. Its national diversity spectrum is shown in Fig. 3. A characteristic of domestic-dominated assignees is that although the proportions of domestic teams and domestic/international teams are high, international teams play an important part in the strategic plan for R&D. For Merck, more than 30% of inventions were contributed by domestic/international inventor teams (orange) and more than 10% of inventions were contributed by international inventor teams (grey). Merck has a higher NDI value than Harvard College due to collaborating with mobile inventors. Merck demonstrates the most popular type of inventor team among pharmaceutical assignees, which is to have domestic inventor teams as the main driving force of R&D with support from domestic/international inventor teams and International inventor teams.

A few pharmaceutical assignees depend on international talent as major R&D contributors. Novartis is an international-supported assignee, and its national diversity spectrum is shown in Fig. 4. A characteristic of International inventor team assignees is that

International inventor teams make up the highest proportion of R&D output, and the sum of International inventor team and domestic/international inventor teams is more than 50%. Almost 90% of the inventor teams for Novartis were International or domestic/international. Furthermore, more than 40% of the members of International inventor teams were from the same country. Novartis has a higher level of national diversity than Merck and Harvard College.

5. Conclusion

With the increasing complexity of scientific and technical knowledge, it is difficult for a single researcher to master all the knowledge and skills required to make advances in technological development. Inventive collaboration has been regarded as an essential strategy for expanding knowledge and skills. Having immigrants in research teams is a potential solution. Previous studies have proposed indexes that show national diversity from the perspective of organizations, whereas this paper suggests a comprehensive method and multiple indexes to determine the level of national diversity and collaboration and identify various collaborative types. The aim of this study is to revisit the indexes that were applied in previous studies and suggest new approach, the necessary to identify the domestic/international and international/international collaborations and assign national diversity indexes separately, which could gain clearer picture of the talent allocation within the organization (Fig. 1) and show the National Diversity Spectrums (Figs. 2-4). An empirical analysis based on patents granted in the pharmaceutical industry was performed to measure national diversity. The results show that the proposed indexes and following visualization allow one to make in-depth observations about the inventor teams and to draw conclusions about different types of collaboration from the indexes.

5.1. Domestic Proportion in National Diversity Analysis

Previous research has mainly focused on measuring international collaboration within a country or region rather than investigating domestic collaboration. Previous studies used the Multilateral Collaboration Index proposed by Glänzel and Delange (1997). A study by Wang et al. (2014) proposed the Average Number of Collaborating Countries per Paper, the Paper Collaboration Ratio, and the International Collaboration Range. The present study differs from previous studies because it measured the contribution of domestic inventors to inventions. We suggest applying the DPI to show the level of participation of domestic inventors.

The DPI is used to measure the dominance or contribution of domestic inventors. If the average DPI value is more than 0.5, half of the inventors are from the same country as the assignee. R&D can then be considered to be led by domestic inventors. The present study, by using the average domestic/international inventor team NDI value and average International inventor team NDI value, aimed to evaluate the national diversity of organizations. In general, higher NDI values represent a higher level of national diversity. NDI values are positively correlated with R&D productivity (Appelt, van Beuzekom, Galindo-Rueda, and de Pinho, 2015) and invention quality (Chinchilla-Rodríguez, Sugimoto, and Larivière, 2019; Ferrucci and Lissoni, 2019; Jiang, Zhu, Yang, Xu, and Jun, 2018; Lissoni, 2018). Some organizations have both high NDI values and high average DPI values, indicating a high proportion of domestic inventors on their inventor teams. As shown In Table 2, Sanofi, GlaxoSmithKline, and Boehringer Ingelheim all have an NDI value of >0.6 and an Average DPI value of >0.5. According to Competitive Intelligence analysis, although these companies rely on domestic/international inventors for their R&D, their inventions are primarily led by domestic inventors.

5.2. Variety of Cross-National Inventor Team

The level of national diversity implies the potential knowledge and skills that come with mobile inventors. This might enrich the domestic labor force and enhance the overall productivity of organizations, which is crucial for R&D (Ottaviano and Peri, 2006). Cross-sector cooperation is associated with innovative capability. In previous studies, national diversity has been determined according only to the assignee, providing only a single dimension for observing national diversity.

Regarding the assignee country, cross-country collaboration in inventor teams can be classified into domestic/international collaborations and international collaborations. The authors of this study suggest using multiple indexes, namely the average domestic/international NDI and Average International NDI, to examine national diversity separately from inventor teams. After classifying the cross-country collaboration in inventor teams, the R&D characteristics of organizations in the pharmaceutical industry can then be categorized into three clusters, namely domestic-dominated, domestic-participated, and international-supported. The assignees in the domestic-dominated cluster depend on domestic inventors. The assignees in the domestic-participated cluster have not only more domestic inventor teams but also higher domestic participation in domestic/international inventor teams. Assignees in the international-supported cluster have less domestic participation in inventor teams, and a majority of them have at least one foreigner in their inventor teams. In summary, only by dividing cross-country inventor teams into domestic collaboration with foreigners and pure foreign collaboration can the differences in R&D characteristics within an organization be clarified.

5.3. Disclosing Talent Allocation by National Diversity Spectrum

Observing the talent allocation strategy of inventor teams through national diversity is essential for observing manpower inventory among assignees. However, it is hard to represent all aspects of talent allocation by adopting only a single index. Besides using multiple indexes, this study proposed a visual spectrum technique to show overall talent allocation; the NDI of each inventor team is visualized as a scatter plot, with DPI values as a bar chart for each inventor team, revealing details and different aspects of the talent allocation strategies of each assignee.

By having a clear picture of talent allocation in a company, one can understand the composition of an R&D team. Recruitment of domestic and international talent can therefore be adjusted according to the needs of inventor teams. By contrast, by observing competitors' talent allocation over time, one can evaluate competitors' R&D strategies for talent allocation. One can also evaluate their geographical strategic layout. In this study, the allocation of R&D talent at Harvard College, Merck, and Novartis are clearly shown in the spectrum. Through such a spectrum, we can observe the allocation of inventors to inventor teams by specific organizations. We can also observe the proportion of domestic inventors on each inventor team. Concerning follow-up monitoring of competitors' R&D talent allocation strategies, it is necessary to first observe the changes in the spectrum over time. We can subsequently observe the proportion of domestic and international talent on each of the competitors' inventor teams and changes in their roles. Each patent signifies an inventor team; therefore, when the allocation ratio of the three types of inventor teams changes, the corresponding change in patent quality can be inferred and serve as a reference for human resources management.

5.4. Limitations

The limitations in this study also mentioned by Bergek and Bruzelius (2010) that inventor addresses in the USPTO patent database are updated when the application is granted. Since the country of residence recorded in the USPTO record is where the inventor lives when the patent is granted, not when the patent was filed. This might result in "false" cross-country inventions due to the possible inconsistency. In this study the authors applied two indexes to distinguish domestic/international and international/international collaboration. However, the limitation of the indexes is that the indexes could not be used in investigating the level of contribution of each inventor, which was not the authors' intention to use the indexes originally.

Acknowledgment

This work was financially supported by the Center for Research in Econometric Theory and Applications (Grant no. 111L900204) which is under the Featured Areas Research Center Program by Higher Education Sprout Project of Ministry of Education (MOE) in Taiwan, the Universities and Colleges Humanities and Social Sciences Benchmarking Project (Grant no. 111L9A002), and the National Science and Technology Council (NSTC), Taiwan, with Grant No. 111-2634-F-002-018-.

References

Abbasi, A., & Jaafari, A. (2013). Research impact and scholars' geographical diversity. *Journal of Informetrics, 7*(3), 683–692.
Abramo, G., D'Angelo, C. A., & Di Costa, F. (2021). The scholarly impact of private sector research: A multivariate analysis. *Journal of Informetrics, 15*(3), Article 101191.
Abramo, G., D'Angelo, C. A., & Zhang, L (2018). A comparison of two approaches for measuring interdisciplinary research output: The disciplinary diversity of authors vs the disciplinary diversity of the reference list. *Journal of Informetrics, 12*(4), 1182–1193.
Alesina, A., Harnoss, J., & Rapoport, H. (2016). Birthplace diversity and economic prosperity. *Journal of Economic Growth, 21*(2), 101–138.
Aman, V. (2018). A new bibliometric approach to measure knowledge transfer of internationally mobile scientists. *Scientometrics, 117*(1), 227–247.
Andersson, R., Quigley, J. M., & Wilhelmsson, M. (2005). Agglomeration and the spatial distribution of creativity. *Papers in Regional Science, 84*(3), 445–464.
Appelt, S., van Beuzekom, B., Galindo-Rueda, F., & de Pinho, R. (2015). *Which factors influence the international mobility of research scientists?. In* Global mobility of research scientists (pp. 177–213). Academic Press.
Audretsch, D., Dohse, D., & Niebuhr, A. (2010). Cultural diversity and entrepreneurship: a regional analysis for Germany. *The Annals of Regional Science, 45*(1), 55–85.
Aydinoglu, A. U., Allard, S., & Mitchell, C. (2016). Measuring diversity in disciplinary collaboration in research teams: An ecological perspective. *Research Evaluation, 25*(1), 18–36.
Ba, Z., Mao, J., Ma, Y., & Liang, Z. (2021). Exploring the effect of city-level collaboration and knowledge networks on innovation: evidence from energy conservation field. *Journal of Informetrics, 15*(3), Article 101198.
Ba, Z., & Liang, Z. (2021). A novel approach to measuring science-technology linkage: From the perspective of knowledge network coupling. *Journal of Informetrics, 15*(3), Article 101167.
Baji, F., Mostafavi, I., Parsaei-Mohammadi, P., & Sabaghinejad, Z. (2021). Partnership ability and co-authorship network of information literacy field. *Scientometrics, 126*(9), 8205–8216.
Basberg, B. L. (1987). Patents and the measurement of technological change: a survey of the literature. *Research Policy, 16*(2-4), 131–141.
Bašić, M., & Vlajčić, D. (2021). Connecting international R&D cooperation and technology specialization in OECD countries. *Economy & Market Communication Review, 11*(1), 35–46.
Bergek, A., & Bruzelius, M. (2010). Are patents with multiple inventors from different countries a good indicator of international R&D collaboration? The case of ABB. *Research Policy, 39*(10), 1321–1334.
Berliant, M., & Fujita, M. (2008). Knowledge creation as a square dance on the Hilbert cube. *International Economic Review, 49*(4), 1251–1295.
Blau, P. M. (1977). *Inequality and heterogeneity: A primitive theory of social structure (Vol. 7)*. New York: Free Press.
Breitzman, A., & Thomas, P. (2015). Inventor team size as a predictor of the future citation impact of patents. *Scientometrics, 103*(2), 631–647.
Brillouin, L. (1956). *Science and information theory*. New York: Academic Press.
Chen, K., Zhang, Y., & Fu, X. (2019). International research collaboration: An emerging domain of innovation studies? *Research Policy, 48*(1), 149–168.
Chinchilla-Rodríguez, Z., Sugimoto, C. R., & Larivière, V. (2019). Follow the leader: On the relationship between leadership and scholarly impact in international collaborations. *PloS one, 14*(6), Article e0218309.
Dahlin, K. B., Weingart, L. R., & Hinds, P. J. (2005). Team diversity and information use. *Academy of Management Journal, 48*(6), 1107–1123.
Davenport, S. (2005). Exploring the role of proximity in SME knowledge-acquisition. *Research Policy, 34*, 683–702.
De Prato, G., & Nepelski, D. (2014). Global technological collaboration network: Network analysis of international co-inventions. *The Journal of Technology Transfer, 39*(3), 358–375.
Díaz-Fernández, M. C., González-Rodríguez, M. R., & Simonetti, B. (2020). Top management team diversity and high performance: An integrative approach based on upper echelons and complexity theory. *European Management Journal, 38*(1), 157–168.
Fagan, J., Eddens, K. S., Dolly, J., Vanderford, N. L., Weiss, H., & Levens, J. S. (2018). Assessing research collaboration through co-authorship network analysis. *The journal of research administration, 49*(1), 76–99.
Feng, S., & Kirkley, A. (2020). Mixing patterns in interdisciplinary co-authorship networks at multiple scales. *Scientific Reports, 10*(1), 1–11.
Ferrucci, E., & Lissoni, F. (2019). Foreign inventors in Europe and the United States: diversity and patent quality. *Research Policy, 48*(9), Article 103774.
Glänzel, W., & De Lange, C. (1997). Modelling and measuring multilateral co-authorship in international scientific collaboration. Part II. A comparative study on the extent and change of international scientific collaboration links. *Scientometrics, 40*(3), 605–626.

Garcia Martinez, M., Zouaghi, F., & Garcia Marco, T. (2017). Diversity is strategy: the effect of R&D team diversity on innovative performance. *R&D Management, 47*(2), 311–329.
Gautam, P. (2017). An overview of the Web of Science record of scientific publications (2004–2013) from Nepal: focus on disciplinary diversity and international collaboration. *Scientometrics, 113*(3), 1245–1267.
González, M. F. (2020). High skilled immigrants' pathways from risky to secure legality in the United States. *Ethnic and Racial Studies, 43*(15), 2807–2825.
Hatton, T. J., & Williamson, J. G. (2005). *Global migration and the world economy: Two centuries of policy and performance*. Cambridge: Cambridge University Press.
Huang, Y., Ma, J., Porter, A. L., Kwon, S., & Zhu, D. (2015). Analyzing collaboration networks and developmental patterns of nano-enabled drug delivery (NEDD) for brain cancer. *Beilstein Journal of Nanotechnology, 6*(1), 1666–1676.
Hunt, J., & Gauthier-Loiselle, M. (2010). How much does immigration boost innovation? *American Economic Journal: Macroeconomics, 2*(2), 31–56.
Jiang, L. A., Zhu, N., Yang, Z., Xu, S., & Jun, M. (2018). The relationships between distance factors and international collaborative research outcomes: A bibliometric examination. *Journal of Informetrics, 12*(3), 618–630.
Jiang, R., Jefferson, G. H., Zucker, S., & Li, L. (2019). The role of research and ownership collaboration in generating patent quality: China-US comparisons. *China economic review, 58*, Article 101336.
Jones, B. F. (2009). The burden of knowledge and the "death of the renaissance man": Is innovation getting harder? *The Review of Economic Studies, 76*(1), 283–317.
Kale, D. (2009). International migration, knowledge diffusion and innovation capacities in the Indian pharmaceutical industry. *New Technology, Work and Employment, 24*(3), 260–276.
Kemeny, T. (2017). Immigrant diversity and economic performance in cities. *International Regional Science Review, 40*(2), 164–208.
Kerr, W. R. (2010). Breakthrough inventions and migrating clusters of innovation. *Journal of Urban Economics, 67*(1), 46–60.
Kerr, W. R., & Lincoln, W. F. (2010). The supply side of innovation: H-1B visa reforms and US ethnic invention. *Journal of Labor Economics, 28*(3), 473–508.
Kuan, C. H., Lin, J. T., & Chen, D. Z. (2021). Characterizing patent assignees by their structural positions relative to a field's evolutionary trajectory. *Journal of Informetrics, 15*(4), Article 101187.
Lazear, E. P. (1999). Globalization and the market for team-mates. *The Economic Journal, 109*(454), 15–40.
Lee, Y. N., Walsh, J. P., & Wang, J. (2015). Creativity in scientific teams: Unpacking novelty and impact. *Research Policy, 44*(3), 684–697.
Lei, X. P., Zhao, Z. Y., Zhang, X., Chen, D. Z., Huang, M. H., Zheng, J., Liu, R. S., Zheng, J., & Zhao, Y. H. (2013). Technological collaboration patterns in solar cell industry based on patent inventors and assignees analysis. *Scientometrics, 96*(2), 427–441.
Liao, C. H. (2011). How to improve research quality? Examining the impacts of collaboration intensity and member diversity in collaboration networks. *Scientometrics, 86*(3), 747–761.
Lin, D., Liu, W., Guo, Y., & Meyer, M. (2021). Using technological entropy to identify technology life cycle. *Journal of Informetrics, 15*(2), Article 101137.
Lissoni, F. (2018). International migration and innovation diffusion: an eclectic survey. *Regional Studies, 52*(5), 702–714.
Martin, R., & Sunley, P. (2006). Path dependence and regional economic evolution. *Journal of Economic Geography, 6*, 395–437.
Magurran, A. E. (1988). *Ecological diversity and its measurement*. Princeton university press.
Meyer, M., & Persson, O. (1998). Nanotechnology-interdisciplinarity, patterns of collaboration and differences in application. *Scientometrics, 42*(2), 195–205.
Narin, F. (1995). Patents as indicators for the evaluation of industrial research output. *Scientometrics, 34*(3), 489–496.
Niebuhr, A. (2010). Migration and innovation: Does cultural diversity matter for regional R&D activity? *Papers in Regional Science, 89*(3), 563–585.
Orsatti, G., Quatraro, F., & Pezzoni, M. (2020). The antecedents of green technologies: The role of team-level recombinant capabilities. *Research Policy, 49*(3), Article 103919.
Ottaviano, G. I., & Peri, G. (2006). The economic value of cultural diversity: evidence from US cities. *Journal of Economic geography, 6*(1), 9–44.
Rafols, I., & Meyer, M. (2010). Diversity and network coherence as indicators of interdisciplinarity: case studies in bionanoscience. *Scientometrics, 82*(2), 263–287.
Schmoch, U. (2008). *Concept of a technology classification for country comparisons*. Final report to the World Intellectual Property Organization (WIPO).
Shapira, P., Youtie, J., & Kay, L. (2011). National innovation systems and the globalization of nanotechnology innovation. *The Journal of Technology Transfer, 36*(6), 587–604.
Singh, J. (2005). Collaborative networks as determinants of knowledge diffusion patterns. *Management Science, 51*(5), 756–770.
Simpson, E. H. (1949). Measurement of diversity. *nature, 163*(4148) 688-688.
Spellerberg, I. F., & Fedor, P. J. (2003). A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon–Wiener'Index. *Global ecology and biogeography, 12*(3), 177–179.
Stirling, A. (1998). On the economics and analysis of diversity. *Science Policy Research Unit (SPRU), Electronic Working Papers Series, Paper, 28*, 1–156.
Stirling, A. (2007). A general framework for analysing diversity in science, technology and society. *Journal of the Royal Society Interface, 4*(15), 707–719.
Sung, H. Y., Wang, C. C., Chen, D. Z., & Huang, M. H. (2014). A comparative study of patent counts by the inventor country and the assignee country. *Scientometrics, 100*(2), 577–593.
van Veelen, R., & Ufkes, E. G. (2019). Teaming up or down? A multisource study on the role of team identification and learning in the team diversity–performance link. *Group & Organization Management, 44*(1), 38–71.
Wang, X., Huang, M., Wang, H., Lei, M., Zhu, D., Ren, J., & Jabeen, M. (2014). International Collaboration Activity Index: Case study of dye-sensitized solar cells. *Journal of Informetrics, 8*(4), 854–862.
Wang, X., Ren, J., Zhang, Y., Zhu, D., Qiu, P., & Huang, M. (2014). China's patterns of international technological collaboration 1976–2010: a patent analysis study. *Technology Analysis & Strategic Management, 26*(5), 531–546.
World Intellectual Property Organization (2021). Patents: What is a patent?. Retrieved November 7, 2021, from https://www.wipo.int/patents/en/
Wuchty, S., Jones, B. F., & Uzzi, B. (2007). The increasing dominance of teams in production of knowledge. *Science, 316*(5827), 1036–1039.
Zhu, L., Zhu, D., Wang, X., Cunningham, S. W., & Wang, Z. (2019). An integrated solution for detecting rising technology stars in co-inventor networks. *Scientometrics, 121*(1), 137–172.
Zhu, N., Liu, C., & Yang, Z. (2021). Team Size, Research Variety, and Research Performance: Do Coauthors' Coauthors Matter? *Journal of Informetrics, 15*(4), Article 101205.