sustainability

MDPI

Article

Global Interdependence of Collaborative R&D-Typology and Association of International Co-Patenting

Hsin-Ning Su

Graduate Institute of Technology Management, National Chung Hsing University, No. 250, KuoKuang Rd., Taichung 402, Taiwan; ning@nchu.edu.tw

Academic Editor: Giuseppe Ioppolo
Received: 7 February 2017; Accepted: 30 March 2017; Published: 4 April 2017

Abstract: Economic globalization implies a growing interdependence of resources across countries. Technological R&D and cross-border collaboration are often identified as the primary driving forces in the process. This study aims to holistically analyze global landscape of international collaboration and identify influential countries and the interdependencies among countries. A total of 458,381 international patents granted by the United States Patent and Trademark Office (USPTO) from 1976 to 2013 are analyzed and the structure of international collaboration network is created. It is found that highly developed and small countries usually show a higher degree of internationalization. However, emerging countries such as China present high collaborative influences. The highly skewed collaboration distribution indicates significant inequality of internationalization, which is indeed a hurdle to a country's technological mobility. It can be observed that most pairs of interdependent countries are neighboring or even bordering countries because of their similar historical, linguistic and cultural heritages. Several contributions of this study are summarized as follows: (1) this study first proposes the II, IA, II-IA, IA-AA, and II-IA-AA system for classifying international patent; (2) all international patents (38-year time span) from USPTO are examined without sampling; (3) association rule mining is used to evaluate the interdependency of international collaboration; and (4) network structures illustrating 38 years international co-patenting are visually presented.

Keywords: international collaboration; global interdependence; co-patenting; association rule mining

1. Introduction

Collaboration facilitates sharing costs and risks, and allows partners to learn from each other and synergize complementary competences. Prior studies have investigated firm level innovation from strategic alliance [1–7]. It has been widely accepted that strategic collaboration allows firms to obtain strategic assets [8,9], complementary technology [4,10] and opportunity to learn from collaboration partner [11–13].

Multinational enterprise and foreign direct investment are two key factors accelerating economic globalization [14]. It is observed that global foreign direct investment has increased since the 1990s and become a key driver of international R&D collaboration. Collaborating with international partners has become an important strategy for firms to improve their efficiency and competitiveness in this globalized economic. International flow of technology, information, goods, capital, people, and services, have fostered a more efficient global supply chain and interdependence. A globalized economy and advanced living quality enhanced by reduced travel cost can be expected [15–17].

International R&D collaboration is one of common form of globalized business strategy comprising foreign direct investment, strategic alliances, join venture [18]. International R&D has been investigated to understand home and host innovation systems [19], opportunities and limitations [20], absorptive capacity and technology learning [21], collaborative R&D in developed countries [22,23], collaboration in developing countries [24], and collaboration between developing and developed countries [25]. Although it is widely accepted that international R&D collaboration is an important strategy in this globalized economy [15] and a growing trend of the international R&D over the 1990s has been observed [26–28], the degree of international R&D collaboration varies largely by regions. For example, East Asia is one of the most successful regional economies [29] with extensive R&D collaboration among Taiwan, Japan, Korea, and China [30]. The level and distribution of international R&D across the world has been increasingly complex.

Over the past few decades, it has been observed that cross-border networking has been extended to knowledge intensive R&D, initialized by early-adopter countries and increasingly involving latecomer countries, different countries are motivated to closely interact with one another for innovating R&D activities, giving rise to a global innovation network [31]. Multi-national enterprises intensively offshore knowledge activities and contribute to the formation of hub in global innovation network characterized by different forms of R&D interdependence among countries. To depict a comprehensive global innovation network as well as identify the hub, all countries (including early adopter and latecomers) need to be considered to obtain a complete picture of global R&D organization, e.g., international R&D structure, strength of interdependence, geographical dispersion of collaboration. On the other hand, international R&D is critical to the catch-up strategy of most emerging countries [32]. R&D policy has conventionally been largely national or regional but not global. The investigation of international R&D structure that span national borders allows the possibility of understanding how national innovation system relates to the global view of knowledge production.

However, it is complex to obtain a complete picture of global R&D organization. Since there is no direct approach, prior studies utilized indirect approaches which might be limited by incomplete data and thus lead the comparison among countries difficult. Those indirect approaches used in literature for measuring international R&D were, for example, foreign direct investments in R&D [33], foreign-affiliated R&D laboratories [34], foreign-owned R&D facilities [33], outsourced offshore R&D service [35], employees mobility [36,37], R&D and innovation surveys for obtaining up-to-date and detailed company-level data [23], patent citation [19], and international co-patenting [27,28,38,39]. In addition, the relationship between innovation and internationalization [40] was compared and a framework for analyzing different patterns of internationalization of R&D and innovation was proposed [41].

Based on prior literature, several research gaps can be identified. First, the number of countries and timespans considered in literature were limited and far from the "global" view. For example, Guellec and de la Potterie (2001) investigated internationalization of technology in the organization for economic co-operation and development (OECD) between 1993 and 1995 [38]. Ma and Lee (2008) and Ma et al. (2009) investigated eight most inventive OECD countries, Korea and Taiwan between 1980 and 2005 [27,39]. Picci (2010) investigated European countries for a timespan between 1990 and 2005 [28]. In addition, a global structure of international R&D for intuitively and visually understanding the landscape of global collaboration has never been explored by a large-scale approach. Second, the prior methods used for classifying international patents, e.g., the SHIA (Share of domestic inventions with foreign applicants), SHAI (share of domestic applications with foreign inventors), SHII (share of domestic inventions with at least one foreign inventor) system [38] and InvApp (Inventor-Applicant internationalization), InvInv (Inventor-Inventor internationalization), AppApp (Applicant-Applicant internationalization) system [28], need to be refined to meet the need of this rapidly globalized economy with increasingly complicated patterns of international collaboration. Third, the tendency of countries to collaborate with others, or how countries are associated together in collaborative work has never been studied.

Therefore, this study aims to heuristically analyze global interdependence of collaborative R&D by answering the following question: (1) What is the global landscape of international R&D? (2) How can international patents be precisely classified? (3) How can the tendency of a country to collaborate with others be measured?

This study examines the global interdependence of collaborative R&D and provides a way to visualize its structure. It contributes to literature in following aspects: First, the overview of international collaboration is investigated from the perspectives of cross-country and cross-industry comparisons. Second, the structure of international collaboration network is created to allow quantitatively and visually understanding on the role of each country in the international network. Third, a novel system of classifying international patent is provided to allow more detailed analysis and comparison on collaboration. Fourth, a global interdependency of collaborative R&D is quantitatively calculated to allow assessing how countries are associated together.

This paper is organized as follows. Theoretical Background is reviewed and discussed, and then data source and analytical methods are explained. Finally, research results are discussed and concluded. In addition, research limitation and future research are discussed.

2. Theoretical Background

2.1. International R&D as a Key Driver of Global Economy

Knowledge creation and knowledge flow are two determining factors motivating this modern knowledge-based economy. Knowledge flow is found to be more intense in the same countries than that of cross-country [42]. Geography boundary has been a physical constraint hindering knowledge flow [43,44], although geographical limitation has been largely avoided by the modern Information and communications technology. Previous studies analyzing international flow have address issues on Foreign Direct Investment [45,46], trade [47], and firm level innovation [48].

International R&D collaboration, which substantially strengthens knowledge creation and knowledge flow, integrates resources available in different countries and generates R&D results that can be applicable to wider preferences and contributory to countries involving the international R&D. Previous research concluded that international R&D generates more valuable results due to the fact that diverse knowledge and resources can be synergized from multiple countries [49,50]. Some studies argued that international R&D might cause higher coordination cost and communication difficulties, e.g., language, culture, and politics, and thus lead to less efficiency [51,52]. Although a consensus about the impact of international R&D on outcome quality has not been reached, a number of studies suggested international R&D generates patents of higher value. For example, Alnuaimi, Singh and George (2012) suggested international collaboration generates positive impact to patent value quantitatively evaluated by patent citation [53]. Branstetter, Li and Veloso (2014) found patents with foreign inventor are of higher value [54].

2.2. Social Network Theory for Understanding International R&D

The increasing interdependence of world indicates modern economic globalization. Firms may seek for foreign partner in order access complementary assets [9] as well as strategic technology [4,10]. Multiple firms work together on creating solutions through diverse type of interaction. The interactions allow all these firms to establish an interaction network which can be analyzed by social network analysis. Social network theory can be adopted on understanding what the relations are among all these firms [55,56].

Social network theory initially investigated in social research has been increasingly applied on analyzing interactions among investigated targets set in a research. Granovertter (1973) proposed the concept of "weak tie" after his social network research and suggested that social network is a way for understanding interconnection between microscopic and macroscopic analyses [57]. In the 1990s, social network research becomes more interdisciplinary as more researcher adopted social network theory in their own research fields. Watt and Strogatz published a book "Six Degrees: The Science of

A Connected Age" [58] and contributed significantly to the maturity of the "small-world" concepts from conventional neuro-science to human or social system that can be modeled by network.

A social network can be formed when firms interact, e.g., exchange resource or information. The social network based on firms' interaction can be created for understanding how firms exchange resource, how they are positioned in this network, and which resource exchange is important [59,60]. Each interaction or resource exchange can be depicted as a tie between paired firms in this network. The strength of the tie is dependent on the frequency of interaction between the paired firms [61].

It can be observed in literature that social network Analysis has been applied to investigate innovators' network, formal and informal knowledge network [56], international R&D organizations [62], knowledge and collaboration network [43,63]. To understand the structure of international R&D, the international collaboration network can be constructed and its network properties can be calculated not only to identify how each country collaborates with other, but also to help evaluate the feature of global landscape.

2.3. Patent for Investigating International Collaboration Network

The globalization of technology has been a subject of interest to policy makers since the 1990s. Patel and Pavitt (1991) investigated the patenting activities of 686 the world's largest manufacturing firms and concluded the technological activities of these large firms were concentrated in their home counties. The production of technology of these large firms remained far from globalized [64]. However, international R&D has been increasingly adopted by firms since the 1990s in order to synergize home country advantages and host country strengths. Patel and Pavitt's opinion has therefore been challenged by later researchers investigating R&D internationalization in different fields. Patel and Vega (1999) investigated US patenting activities of 220 of the most internationalized firms in terms of their technological activities outside their home countries in the 1990s. They found firms tend to locate technology abroad in firms' core areas where they are strong at home [65]. Le Bas and Sierra (2002) investigated the 345 multi-national firms with the greatest patenting activity in Europe and found that multi-national firms locate their activities abroad in technological areas or fields where they are strong at home [66].

Internationalization of R&D in selected industrial sectors was also studied. For example, Almeida (1996) investigated patent citations of international firms in US semiconductor industry and found the knowledge used in innovation by foreign subsidiaries in US regions is predominantly local [67]. Penner-Hahn and Shaver (2005) examined the international R&D expansion activities, research capabilities, and patent output of 65 Japanese pharmaceutical firms from 1980 to 1991, and found that firms benefit from international R&D only when they possess existing research capabilities in the underlying technologies [68]. Di Minin and Bianchi (2011) conducted US patent statistics on the international R&D for wireless telecom industry and illustrated the growing trend of the internationalization over the 1990s [26].

In addition to the above studies targeting selected firms or industrial sectors, overall analyses based on paten have also been conducted to obtain the overview of international collaboration. For example, Dominique Guellec and de la Potteris (2001) proposed three indicators, i.e., SHIA, SHAI, and SHII to measure degree of internationalization and found the degree of technological internationalization is higher for small countries and for countries with low technological intensity [38]. Ma and Lee (2008) utilized co-invention index and co-assignee index to examine the pattern of international collaboration for eight most inventive OECD countries and two Asian countries between 1980 and 2005, a pattern of increasing collaboration in patent across the world over the past two decades were observed [27], and China's international patent had begun to boom along its fast economic growth [39]. Picci (2010) proposed three indicators, InvInv, InvApp, and AppApp, to assess internationalization of European patent between 1990 and 2005, and observed that the level of internationalization, while being rather low, has steadily increased over time. Picci observed bilateral collaboration are affected by common language, common border, culture and distance [28].

3. Data and Method

3.1. United States Patent and Trademark Office (USPTO) Patent Data

Due to the fact that there is no direct measurement on international R&D, indirect methods have been used to understand internationalization of R&D [33–37]. However, this study aims to use patent as a proxy for measuring the global landscape of international R&D for the following reasons: (1) patent has been widely accepted in innovation study [69–73]; (2) patent document provides information of inventor and assignee countries which readily facilitate international comparison and internationalization study; and (3) the use of patent to measure internationalization has been confirmed by OECD [74,75]. Accordingly, patent was adapted in this study to understand internationalization of R&D.

This study utilized USPTO patent database as the data source because the US is the biggest market, and attracts global investments and collaborations based on which patent can be invented to generate largest value. This motivates international patent filing at USPTO and also increase both quality and quantity of information disclosed in USPTO patent document. In addition, USPTO database provides patent citation information which allows diverse patent analysis and therefore is regarded as an reliable data source for investigating global innovation pattern [73,76]. Further, US patent system is a well-established patent system and USPTO is a well-maintained database which encourages researchers to conduct researches in the field of technology, innovation, economics, etc.

3.2. Identifying and Classifying International Patents

International patents were identified by following the definition proposed by Lucio Picci (2010)—"at least one inventor/applicant is resident in a country different from the others" [28]. In addition, Picci (2010) proposed three indicators for measuring internationalization, i.e., a method for classifying international patents into three types: (1) Inventor-Applicant internationalization (InvApp); (2) Inventor internationalization (InvInv): and (3) Applicant internationalization (AppApp) [28]. After evaluating Picci's method, it is found that the three types of international patents significantly overlap each other and do not provide clear resolution on typology of international patents; for example: (1) a patent with two inventor countries, US and JP, and one assignee country, UK, is categorized into both InvInv and InvApp; and (2) an InvInv patent with or without assignee is an important indication for individual or firm's patent right ownership but is unable to be differentiated by this method. Therefore, this research intended to propose a revised classification system that can overcome the above limitations and be used to classify international patents into several types without overlapping each other.

3.3. Characterizing Patents

A number of studies suggested international R&D generates patents of higher value. For example, Alnuaimi, Singh and George (2012) suggested international collaboration generates positive impact to patent value quantitatively evaluated by patent citation [53]. Branstetter, Li and Veloso (2014) found patents with foreign inventor are of higher value [54]. By following this context, important characteristics of different types of international patents were analyzed and ANOVA was used to test if these types of international patents obtained by the newly proposed classification system can be distinguishable.

The patent characteristics considered in this study are number (No.) of Inventors, No. of Inventor Countries, No. of Assignees, No. of Assignee Countries, No. of Patent References, No. of Non-Patent References, No. of Foreign References, No. of Patent Citations Received, Degree Centrality, No. of International Patent Classifications (IPCs), No. of United States Patent Classifications (UPCs), and No. of Claims.

3.4. Depicting International Collaboration by Social Network Theory

International R&D collaboration network is created based on the international patents to allow the network structure to be visualized. International collaboration can be depicted by analyzing which countries involves in patenting activities. If two countries work together to co-invent, a linkage between the two countries can be created to illustrate the relation between the two countries. It is suggested in literature that the pattern of international collaboration can be reflected by co-invented patents which is based on created knowledge available to all countries [77,78].

In summary, countries that co-invent a patent are linked together to illustrate their international collaboration. For example, a patent co-invented by Germany, France and Belgium is presented as three network actors, i.e., Germany, France and Belgium, with three network ties between Germany and France, France and Belgium, and Belgium and Germany. In this study, all international patents are analyzed to obtain a global landscape of international collaboration.

After the completion of the international collaboration structure, network properties are calculated based on social network theory. The concept of "Centrality" in social network theory is to describe how central an actor is in the network or how easy an actor obtains or controls resource from the network.

(1) Degree Centrality:

The network property "Degree Centrality" proposed by Freeman (1978) was calculated to evaluate the role of each country in the created international collaboration structure [79].

$$d(i) = \sum_{j} m_{ij}$$

m_{ij} = 1 if country i collaborates with country j.

Degree Centrality: The number of times country i collaborates with other countries. The higher Degree Centrality, the more times country i collaborates internationally, indicating the higher tendency of international collaboration between country i and other countries j.

OutDegree Centrality: the number of times that country i influences other countries.

InDegree Centrality: the number of times that country i is influenced by other countries.

(2) Betweenness Centrality:

The concept of Betweenness is a measure of how often a country is located on the shortest path (geodesic) between other countries in the network. Those countries located on the shortest path between other countries are playing roles of intermediary that help any two countries without direct contact to reach each other indirectly. Countries with higher Betweenness Centrality are those located at the core of the network.

$$b(i) = \sum_{j \neq i \neq k} \frac{\sigma_{jk}(i)}{\sigma_{jk}}$$

$\sigma_{jk}(i)$: the shortest path between j and k that contains i.
σ_{jk}: the shortest path between j and k.

(3) Closeness Centrality:

The Closeness Centrality of a country is defined by the inverse of the average length of the shortest paths to/from all the other countries in the network. Higher Closeness Centrality indicates higher influence on other countries.

Closeness Centrality: The shortest path from other countries to country i, the higher Closeness Centrality, the higher influence of country i on other countries.

$$c(i) = \frac{1}{\sum_j d_{ji}}$$

d_{ji}: the shortest path from between j and i.

The higher centrality suggests higher association with the overall network. From the perspective of organizational behavior, Brass and Burkhardt (1992) argued that the higher centrality of an actor in a network, the more power the actor possesses [80]. This study utilized Degree Centrality, OutDegree Centrality, Betweenness Centrality, and Closeness Centrality as approaches to quantitatively estimate in what extent each country involves in the global collaboration network.

3.5. Mining Association Rule for Identifying Collaboration Interdependency

The concept of the association rule was first proposed by Agrawal, et al. in 1993 [81,82] and applied in Basket Data Analysis, Educational Data mining, Classification Clustering, etc. The association rule was initially utilized to handle transaction database to investigate the pattern among commodities purchased by the customers, in order to uncover which commodities are likely to be purchased simultaneously by customers. Association rules have been frequently used to find a pattern, association, or correlation in transaction database [83]. An association rule is derived from a series of item sets consisting of "items" purchased by customers in a transaction.

Items are the objects which association rule is to be identified. Each item is a product purchased by customer in the shop. A group of items is an item set: $I = \{i_1, i_2, i_3, \ldots, i_n\}$. Transactions are instances of groups of items co-occur together. Each transaction comprises an item set purchased by a customer: $t_n = \{i_i, i_j, \ldots, i_k\}$. An association rule takes the form LHS (Left-Hand Side) $\geq$ RHS (Right-Hand Side), RHS is likely to occur when LHS occurs, LHS and RHS are disjoint set of items: $\{i_1, i_2, \ldots\} \Rightarrow \{i_k\}$. Three measures: (1) support; (2) confidence; and (3) lift, are usually used to describe the patterns of transactions. (1) The "support" is the fraction of transactions that contain that item or item set, a rule with high support indicates the rule can be generalized to a large number of transactions [82]. (2) The "confidence" of a rule is the probability the rule has been found to be true, i.e., a transaction contains the items on LHS also contains items on the RHS [82]: $Confidene(i_m \Rightarrow i_n) = Support\ (i_m \bigcup i_n)/Support(i_m)$. (3) The "lift" value is the ratio of the support of the items of LHS co-occur with items of RHS divided by probability that LHS and RHS co-occur: $Lift(i_m \Rightarrow i_n) = Support\ (i_m \bigcup i_n)/(Support(i_m) * Support(i_n))$.

"Lift" value is used to measure the independence of LHS and RHS, "Lift" value larger than one suggests the items on the LHS has increased the probability that the items will be observed on the RHS. For "lift" value equal to one, this suggests that LHS and RHS are not dependent on the other. If "lift" value is less than one, this implies the items on the LHS decrease the probability that the items on the RHS to be found. "Lift" value larger than one allows understanding the positive association between LHS and RHS. The obtained association rules provide insights on how items associate with each other and how to identify influential items [84].

Association rule mining was utilized to analyze associations among co-patenting countries in this study. Similar to the original concept of association rule mining, i.e., handle transaction data to investigate the pattern among items purchased by the customers, each international patent is treated as a transaction and all assignee countries or inventor countries are regarded as items purchased by the customers. A priori algorithm [82], a classic algorithm for learning association rules in data mining, is utilized to discover the association rules among countries participating in international co-patenting activities. Low thresholds for both support and confidence (support = 0.001 and confidence = 0.005) were used to find all association rules for countries of different levels of international co-patenting, in order to depict a comprehensive global interdependence network.

4. Results and Discussion

4.1. Internationalization and Industry

All USPTO utility patents were differentiated into two groups, international and non-international patents by following the definition of international patent—"at least one inventor/applicant is resident in a country different from others" [28]. In the total of 4,969,491 utility patents granted by the USPTO between 1976 and 2013, there are 458,381 international patents and 4,511,110 non-international patents. International patents account for about 9.22% of the USPTO patents and non-international patents are about 90.78%. Figure 1 shows longitudinal analysis on the patent counts for both types of patents. The results show significant increase on the ratio of international patent in 1992. As the improvement in the early 1990s in information and communications technology which greatly advanced people's accessibility and exchange of information, productivity changes across industries can be observed in the early 1990 [85].

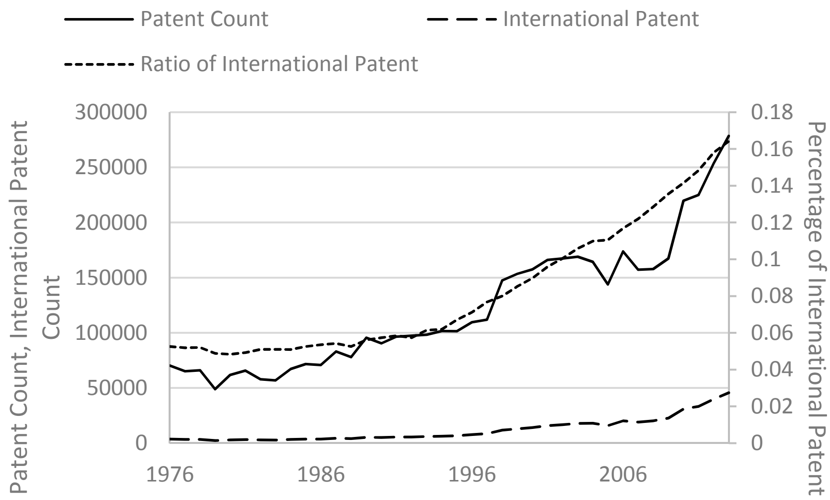

Figure 1. All patent counts and international patent counts in the US patent and trademark office (USPTO) database.

Considering different industries might have different degree of internationalization. This study classified international patents into five main industries, Chemistry, Electrical Engineering, Instrument, Mechanical Engineering, and Other fields, and the five main industries are further classified into 35 sub-industries based on the IPC to industries concordance proposed in prior study [86], to facilitate cross-industries comparison on the level of internationalization. The results are provided in Figure 2. The Top 10 industries with the largest portions of international patents indicate the highly internationalized industries are all related to Information and Communications Technology (ICT) and biochemistry. Since digital information and the Internet are borderless, the very high internationalization in ICT can be expected. Pharmaceutical industry, ranked as No. 1, is a capital-driven and knowledge driven industry where firms tend to locate foreign resources and knowledge to synergize home and foreign country advantages for enhancing the quality of R&D output. Several of the Top 10 industries directly related to pharmaceutical industry are biotechnology (No. 2), organic fine chemistry (No. 5) and food chemistry (No. 8). It can be observed in general that Chemistry and Electrical Engineering industries are more internationalized, Mechanical Engineering and Other fields are less internationalized, and Instrument industry is somewhere in the middle.

4.2. Cross-Country Analysis

Analyzing internationalization of each countries and creating the network of international collaborate rely on identifying which countries own a patent. Conventional concept of patent assignment, which is based on legal perspective, is the assignment of patent right so only patent assignee is considered. However, this study aims to understand how each country collaborates with others, from the perspective of international interaction, for creating patent as their technological knowledge output. The international interaction can be revealed in both inventor and assignee information so inventor country and assignee country are both considered and treated equally for cross-country analysis and creation of international collaboration network. A patent co-invented by multiple countries lead to difficulty in the identification of patent ownership. Several ways are used in prior researches to resolve this: (1) assign patent to the first inventor or first assignee [48,87]; (2) assign patent by the use of fractional counting so each owner shares a part of the patent [88,89]; or (3) assign patent by multiple counting so a patent belongs to all owners and is multiple-counted [77,90].

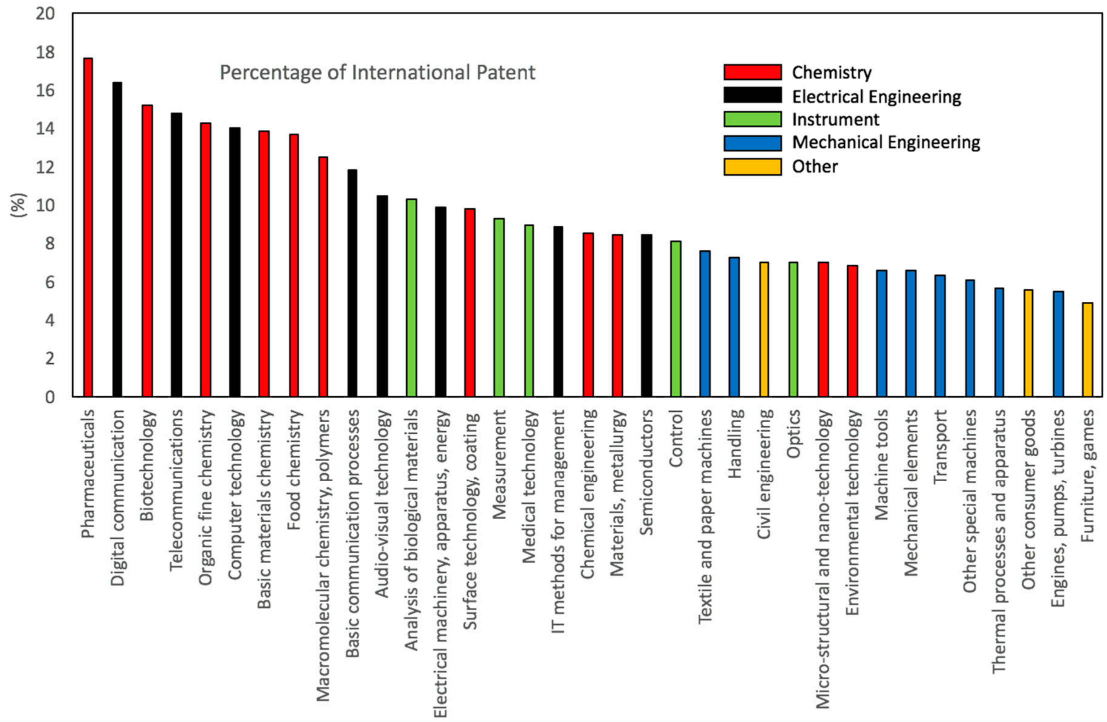

Figure 2. Internationalization of Industries.

International patents invented by multiple countries involve international knowledge sharing. The co-created knowledge is shared and available to all countries collaborating with each other. In this sense, multiple counting seems a more reasonable proxy for reflecting the national basis of patents [91]. It is also suggested in literature that multiple counting is used when cross-country patent are used as an indicator of international collaboration. [38,77,92]. The OECD report "OECD Patent Statistics Manual (Chapter 4, Page 64)" also suggested multiple counting is preferable on the measurement of the internationalization of technological activities [78].

Hence, multiple counting is used for cross-countries comparison. As shown in Figure 3 which compares the ratios of international patents for the Top 20 countries in terms of the total patents granted by USPTO. It can be observed that Nos. 1–3 are Singapore, Netherlands and China, with more than 50% international patents. Most countries with more than 30% international patents are small countries but China is an exception. Small countries rely more on trade and likely to adopt liberal trading policies, therefore small countries perform better than large countries in terms of trade facilitation [93] and therefore it can be expected that small countries are more international than large countries. However, China is a very large country but still ranked No. 3 in terms of the ratio of international patents. The spectacular rate of Chinese economic growth has been triggered by the expansion in foreign trade and foreign direct investment [94]. Therefore, unprecedented internationalization is observed in China.

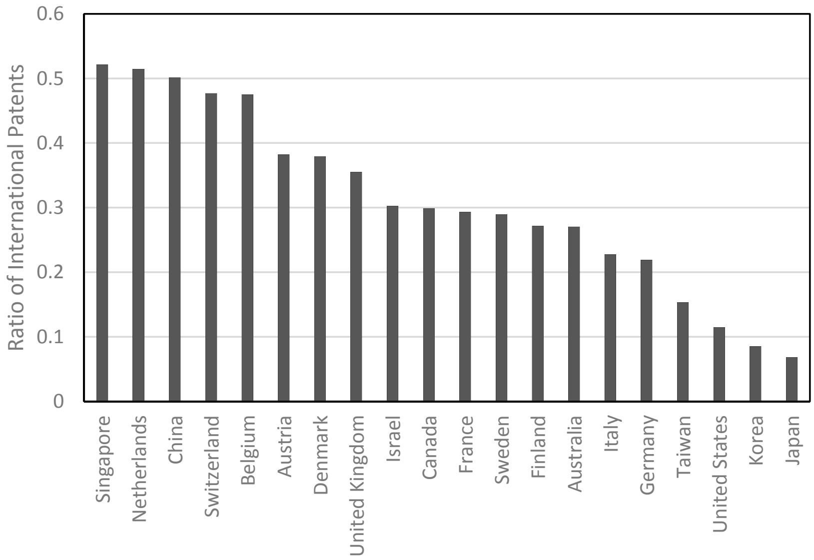

Figure 3. Ratio of International Patent for the Top 20 countries in USPTO from 1976 to 2013.

4.3. Creation of International Collaboration Network

The approach for creating international Collaboration Network is extended from the multiple counting method. An international patent co-invented by multiple countries reflects substantial interactions among multiple countries. Co-inventing countries are treated as network actors and their interactions can be depicted by multiple network ties. For instance, an international patent co-invented by Japan, Korea and Taiwan can be depicted as three network actors labeled as Japan, Korea, and Taiwan, and three network ties between Japan and Korea, Korea and Taiwan, and Japan and Taiwan. Since how resources are exchanged among all the three countries is not recorded in patent document, i.e., the directions of resource flows among the three countries is unknown, the network ties are non-directional.

The created international collaboration network is provided in Figure 4. The network contains 229 countries and 2413 network ties. Network Density is 0.092. The average Degree Centrality is 21.074 with maximum 200 and minimum 3. The Degree Centrality indicates the number of collaborative countries of a network actor. The size of each network actor is proportional to its Degree Centrality: the larger size of actor, the more international collaboration. The result shows a highly skewed distribution where there are 10 countries (with the highest degree centralities) collaborated with 85–200 countries and there are 120 countries (with the lowest degree centrality) that collaborated with fewer than 10 countries. It can be observed that most countries with higher centralities are in North America, Europe or East Asian countries, except Australia, Israel, Russia, and Saudi Arabia.

The thickness of network tie shown in Figure 4 is proportional to collaboration time. The thicker network tie indicates more collaborations (or interaction) between the two countries at the two ends of a network tie. Similarly, the distribution of collaboration is highly skewed. There are 492,125 collaborations between all of the 2413 pairs of countries.

To estimate how the distribution is skewed, the top pairs of collaborative countries and their collaboration times are analyzed. The maximum number of collaborations is the pair between US and Germany (40,759 collaborations), the second largest pair is between Japan and US (40,424), the third pair is between UK and US (40,250). The Top 10 pairs account for 250,816 collaborations (50.97%). Countries involved in the Top 10 pairs of collaborations are Germany, US, Japan, United Kingdom, Canada, Netherlands, France, Switzerland, Israel, and India. The Top 20 pairs account for 319,513 collaborations (64.93%), The Top 50 pairs of countries account for 395,806 collaborations (80.43% of the total collaboration). However, there are 1041 pairs of collaborative countries that only collaborated one or two times. The overall statistics is provided in Figure 5.

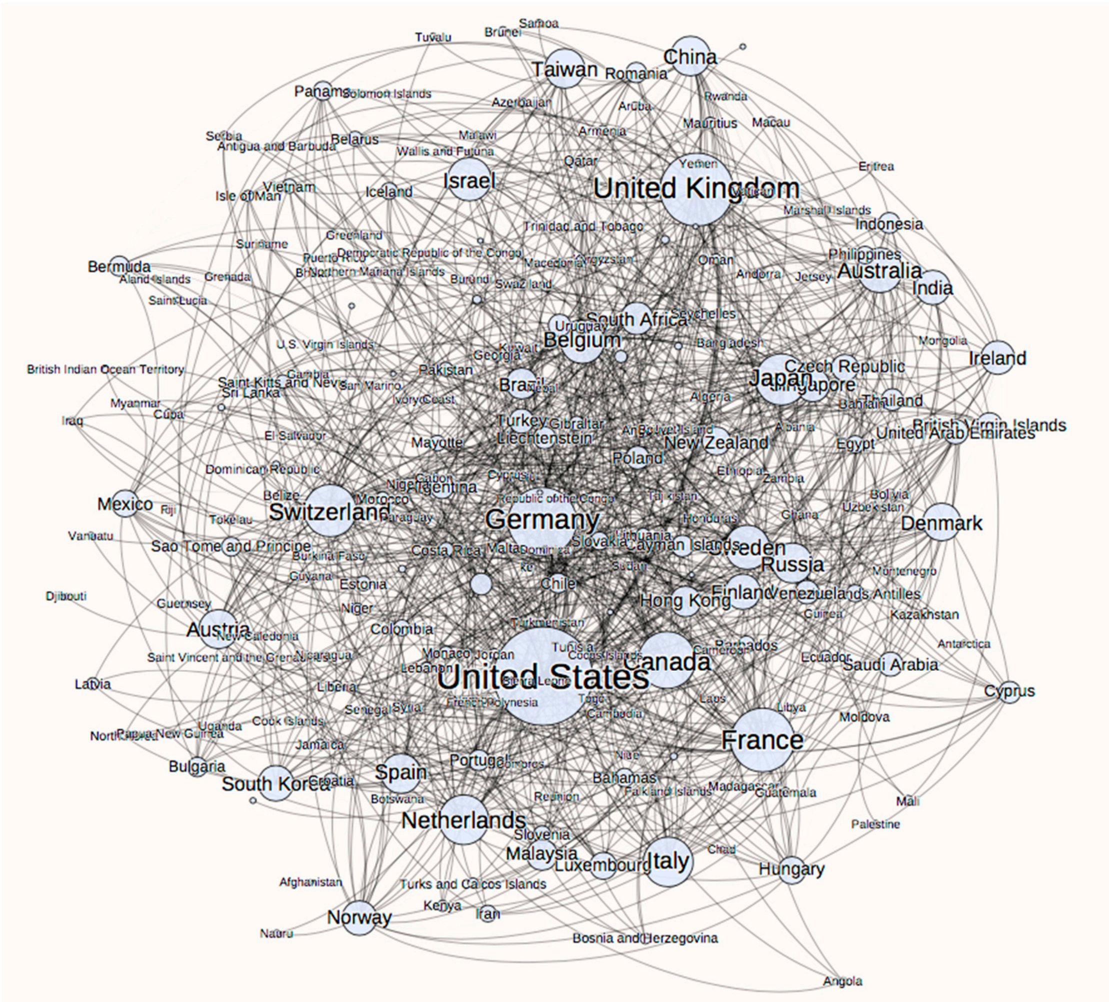

Figure 4. International Collaboration Network.

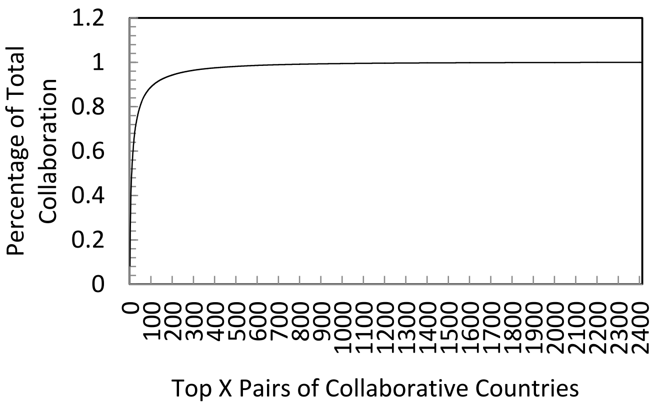

Figure 5. Distribution of Total Collaboration.

4.4. Typology of International Patents and Patent Characteristics

After evaluating Picci's method for classifying international patents [28], it is found that the three types of international patents proposed by Picci [28] significantly overlap each other and do not provide clear resolution on typology of international patents: (1) a patent with two inventor countries, US and JP, and one assignee country, UK, is simultaneously categorized into both InvInv and InvApp); and (2) an InvInv patent with or without assignee is an important indication for individual or firm's patent right ownership but is unable to be differentiated by Picci's method [28]. Therefore, this research intended to propose a method that can overcome the above limitations and be used to classify international patents into several types without overlapping each other.

Similar to what proposed by Picci [28], InvInv, InvApp, and AppApp are used as the infrastructure but their overlapping areas are further differentiated and assigned as new types. In this newly proposed method, "I" means inventor and "A" means assignee, and the five types of international patents are identified to ensure they do not overlap each other:

(1) II: A patent only contains inventors from different countries and has no assignee information.
(2) IA: A patent has (at least) one inventor and one assignee from different countries, and this patent is neither Inventor–Inventor international nor Assignee–Assignee international.
(3) II-IA: A patent meets two criteria. i.e., Inventor–Inventor and Inventor–Assignee internationalization (II-IA = InvInv ∩ InvAss).
(4) IA-AA: A patent meets two criteria, i.e., Inventor–Assignee and Assignee–Assignee internationalization (IA-AA = InvAss ∩ AssAss).
(5) II-IA-AA a patent meets three criteria, i.e., Inventor–Inventor, Inventor–Assignee and Assignee–Assignee internationalization (II-IA-AA = InvInv ∩ InvAss ∩ AssAss).

The above five types of patent are essential because of two reasons. First, as society is rapidly globalized, more detailed patent indicators for investigating more types of international patents help characterize innovation more precisely. The refined classification is able to measure five types of internationalization and provides a better resolution on how society has been internationalized. Second, prior method classifies international patents into three types. The three types of international patents mutually overlap each other. This leads to a collinearity problem when using the three types of patent as predictor variables in a multiple regression modeling, because the previous three indicators, i.e., InvInv, InvAss, and AssAss, based on the three types of international patents, are highly correlated to each other [38]. However, the five types of international patents proposed in this study do not overlap each other so the above collinearity problem can be avoided.

Table 1 presents illustrative example of patents concerned with the five types of international patents. This new classification system provides a better resolution for investigating internationalization of R&D because this system classifies all international patents into five types as shown in Figure 6. The patent counts for each type of international patents are: II: 6805 patents; IA: 255,168 patents; II-IA: 167,952 patents; IA-AA: 15,522 patents; and II-IA-AA: 12,934 patents. The longitudinal results of patent counts are provided in Figure 7. It can be observed that all five types of international patents have grown since the 1990s at different rates. The patent counts of IA and II-IA are much larger than those of the three other types of patents.

Table 1. Example of international patents.

Patent Number	Inventor Country	Assignee Country	Type of International Patent
8,263,590	France, Japan, Switzerland	-	II
8,492,351	US, Australia, Singapore	US, Australia, Singapore	II-IA-AA
7,273,848	Germany	France, Germany, Switzerland	IA-AA
5,281,710	UK, US, Austria, Germany, Hong Kong, Japan	US	II-IA
6,544,605	UK	Germany	IA

IA: Inventor-Assignee; II: Inventor-Inventor; AA: Assignee-Assignee.

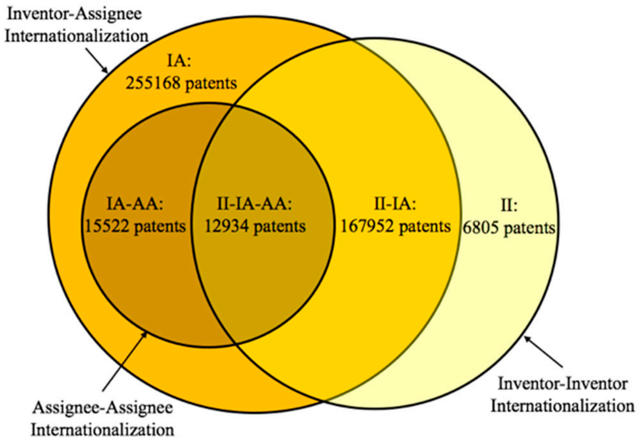

Figure 6. Classification of International Patents.

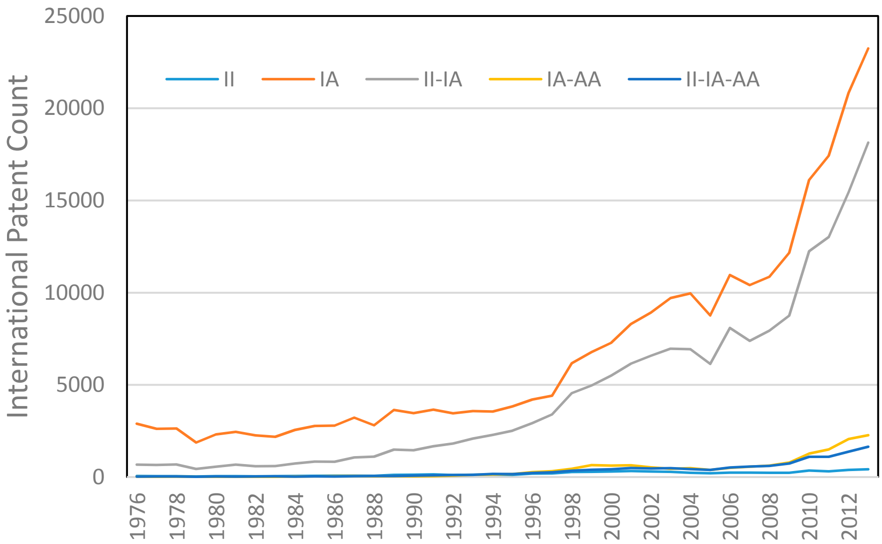

Figure 7. International Patent Counts from 1976 to 2013. IA: Inventor-Assignee; II: Inventor-Inventor; AA: Assignee-Assignee.

4.5. Characterizing International Patents

Patent characteristics of the five types of international patents are analyzed in Table 2. There are three objectives of analyzing patent characteristics for each types of international patents. First, the new classification system proposed in this study needs to be tested by ANOVA based on the patent characteristics. Second, the patent characteristics may uncover hidden implication correlated to the degree of internationalization. Third, large-scale characterizations on international patents granted between 1976 and 2013 have never been reported in the literature, and this study attempts to fill the gap.

In Table 2, the mean values of the 13 patent characteristics for the five types of international patents are listed. The five types of international patents are statistically analyzed by ANOVA based on these patent characteristics to test if the five types of patent can be distinguished, i.e., the quality of the new classification system. The ANOVA results show p-values are all smaller than 0.001 for all of the patent characteristics investigated in this study. The significant ANOVA results suggest the new method classifying international patents into five types are acceptable and meaningful. Subsequently, the 13 patent characteristics are discussed in following dimensions:

Table 2. Characteristics of International Patents.

Patent Characteristics	Mean Value						ANOVA Test	
	II (C)	**IA(B)**	**II-IA(D)**	**IA-AA(E)**	**II-IA-AA(G)**	**Non-International**	***F*-Value**	***p*-Value**
No. of Inventors	3.21 (1.76)	2.10 (1.41)	4.02 (2.24)	2.48 (1.71)	4.38 (2.41)	2.38 (1.65)	763,092	<0.000 ***
No. of Inventor Countries	2.05 (0.25)	1.00 (0.02)	2.08 (0.31)	1.00 (0.60)	2.10 (0.36)	1.00 (0.00)	1,198,710	<0.000 ***
No. of Assignee	0.00 (0.02)	1.00 (0.07)	1.02 (0.16)	2.06 (0.43)	2.10 (0.43)	1.02 (0.18)	154,946	<0.000 ***
No. of Assignee Countries	0.00 (0.02)	1.00 (0.05)	1.00 (0.00)	1.99 (0.16)	2.01 (0.19)	1.00 (0.00)	160,581	<0.000 ***
No. of Patent References	17.00 (51.03)	19.42 (54.22)	25.94 (77.07)	22.42 (55.49)	19.35 (40.80)	18.28 (46.96)	6123	<0.000 ***
No. of Non-Patent References	5.80 (23.96)	4.37 (20.53)	9.15 (33.46)	4.72 (33.69)	10.09 (38.81)	4.08 (21.81)	12,742	<0.000 ***
No. of Foreign References	2.67 (8.43)	3.56 (11.31)	5.05 (16.22)	3.78 (13.53)	4.86 (13.43)	3.19 (9.75)	10,710	<0.000 ***
No. of Patent Citations Received [10]	8.58 (15.80)	8.08 (14.69)	10.49 (18.70)	11.33 (18.18)	9.66 (16.72)	8.74 (15.70)	8190	<0.000 ***
Degree Centrality	28.08 (57.43)	27.52 (57.65)	34.76 (80.49)	29.69 (58.66)	26.15 (44.41)	29.01 (53.09)	14,015	<0.000 ***
Degree Centrality [10]	19.50 (23.84)	18.44 (21.75)	23.17 (28.67)	24.32 (32.18)	22.18 (27.94)	19.50 (23.92)	10,710	<0.000 ***
No. of IPCs	3.82 (3.31)	3.32 (2.91)	3.55 (3.56)	2.98 (2.75)	3.64 (4.61)	3.66 (3.01)	558.8	<0.000 ***
No. of UPCs	10.29 (8.07)	9.33 (8.17)	9.01 (8.51)	8.30 (8.90)	8.87 (9.05)	10.33 (8.05)	8190	<0.000 ***
No. of Claims	16.01 (12.55)	16.13 (12.16)	18.21 (14.03)	16.51 (11.94)	16.78 (12.74)	15.44 (12.41)	14,015	<0.000 ***

Standard deviations are in parentheses. *** indicates p-value < 0.001, [10] indicates a 10-year window is applied and the time span is 1976–2003. IPC (International Patent Classification); UPC (United States Patent Classification).

4.5.1. Inventor and Assignee

The analysis of No. of Inventors, No. of Inventor Countries, No. of Assignees, and No. of Assignee Countries shows the number of inventor per patent is always larger the number of assignee per patent. The maximum values can be found in II-IA-AA due to the nature of II-IA-AA which involves three types of internationalization (II, IA and AA). Non-international patents have all the four inventor and assignee related mean values equal to or smaller than those of the five types of international patents except: (1) No. of Assignees (0.00) and No. of Assignee Countries (0.00) in II patents; and (2) No. of Inventors (2.10) and No. of Assignees (1.00) in IA. The No. of Assignees and No. of Assignee Countries are originally set to be equal to zero for II because II is patent without assignee. However, the No. of Inventors and No. of Assignees in IA are both smaller than the counterparts of non-international patent suggest a larger portion of IA contains only one inventor and one assignee.

4.5.2. Backward Citation—Patent References, Non-Patent References and Foreign References

Three types of backward citations, i.e., No. of Patent References, No. of Non-Patent References and No. of Foreign References, are analyzed. The three backward citations represent a patent's linkage to the three types of prior knowledge. No. of Patent References, No. of Non-Patent References and No. of Foreign References are proxies for measuring a patent's linkages to prior USPTO technological knowledge, scientific knowledge and foreign technological knowledge, respectively. It can be observed that No. of Patent References of II-IA (25.94) and IA-AA (22.42) are much higher than others (17.00–19.42), No. of Non-Patent References of II-IA (9.15) and II-IA-AA (10.09) are much higher than other (4.08–5.80), No. of Foreign References of II-IA (5.05) and II-IA-AA (4.86) are much higher than the other (2.67–3.78). This suggests the stronger reliance on prior knowledge for II-IA, IA-AA and II-IA-AA. On the contrary, II has the lowest No. of Patent References (17.00) and No. of Foreign References (2.67), Non-International patent has the lowest No. of Non-Patent References (4.08). This may suggest the involvement of multiple countries and multiple assignees motivates a patent to cite more prior knowledge due to assignee's authoritative reasons required to be investigated by organizational behavior research.

4.5.3. Forward Citation—Patent Citations Received

The No. of Patent Citations Receive has been used as a proxy for evaluating patent value. Although it is far from a perfect indicator [95], it has been widely used for studying the value of patent [96–102]. However, a 10-year windows is imposed to avoid truncation problem [103]. In this case, every patent has exactly 10 years available to receive forward citations and the investigated patents are those with grant year from 1976 to 2003. The results of No. of Patent Citations Received suggests IA-AA (11.38) and II-IA (10.49) are the two most valuable types of international patents. Non-international patents (8.74) are more valuable than II (8.58) and IA (8.08).

4.5.4. Degree Centrality

In social network theory, Brass and Burkhardt (1992) argued that the higher centrality of an actor in a network, the more power the actor possesses [80]. Patent network can be constructed by considering a patent's backward patent references and forward patent references. The degree centrality of a patent in the patent network is directly proportional to the influence of a patent from the perspective of social network theory. Degree Centrality of each type of international patent is calculated as proxy for estimating the influence of international patent. The Degree Centrality results show II-IA and IA-AA are two most influential patents and the Degree Centrality imposed by 10-year windows shows IA-AA and II-IA are the most influential types.

4.5.5. IPC and UPC

Lerner (1994) suggested the higher number of patent classification, the broader scope [104]. Nos. of IPCs and UPCs are calculated in Table 2. All types of international patent as well as non-international patents do not differ too much in No. of IPCs (2.98–3.82) and No. of UPCs (8.30–10.33). Most of mean values of IPC and UPC for the five types of international are smaller than those of non-international patents. This indicates international collaborations, except II, lead to more focused patents which tend to solve more specific technological problems than non-international patents.

4.5.6. Claim

Claim determines the breadth of patent right. The structure of the patent fee is based on the number of claims in a patent, more claim indicates high patent fee. The number of claim reflects not only the breadth of a patent, but also its market value. The more claims in a patent, the higher patent value can be expected [105,106]. The results of No. of Claims show II-IA has the highest No. of claim and non-international patent has the lowest.

It is reasonable to assume international patent are more valuable because international collaboration can be equipped with legal contract, bilateral agreement, specialized coordination, and formal evaluation procedures and therefore enable collaboration partners to initiate larger-scale R&D project [107]. Considering those patent characteristics that are relevant to patent quality, e.g., value, influence, scope, II-IA is ranked as top for No. of Patent References, No. of Foreign References, Degree Centrality, No. of Claims. IA-AA is ranked as top for No. of Patent Citations Received^{10} and Degree Centrality^{10}. II-IA-AA is ranked as top for No. of Non-Patent References. It seems that II-IA, IA-AA, and II-IA-AA have higher forward citation, backward citation, degree centrality and claim, implying their higher values. However, IA patent has smaller forward citation and degree centrality than non-international. The assumption that international patents are more valuable is not always true because it is not necessary for non-international to be the least valuable patent. It may be explained that international collaboration generates positive value but the price paid is the increased cost for overcoming cross-country barrier such as geographic, linguistic or cultural issue. It is a trade-off between the collaboration impact and the cost paid to collaboration. Although it is still far from realizing how internationalization and firm's business strategy depicted by patent characteristics are correlated, and how possible they can be correlated. The results are reported in this study to contribute to researches investigating economic globalization with patent.

4.6. Global Interdependency of Collaboration R&D

To estimate how each country depends on each other, the algorithm for learning association rules in data mining proposed by Agrawal et al. in 1993 [82] was used to uncover the association rules among countries participating in international collaboration. Since this study aims to find all association rules, low thresholds for support and confidence (support = 0.001 and confidence = 0.005) are selected. The low thresholds used in this study allow obtaining all association rules. If we reduce the threshold values, the number of obtained association rule does not increase. If the "Lift" value is larger than one, it suggests that countries on the LHS has increased the probability that the country on the RHS can be observed. Alternately, country on the RHS is dependent on country on the LHS.

The numbers of association rules learned for the five types international patents are 298 (II), 198 (IA), 285 (II-IA), 173 (IA-AA), and 319 (II-IA-AA). The numbers of those learned association rules with Lift values larger than one are 92 (II), 39 (IA), 59 (II-IA), 82 (IA-AA), 104 (II-IA-AA). The association rules with Top 15 lift values are provided in Table A1 (Appendix A).

It can be observed in Table A1 that most associations show one country on the LHS and one country on the RHS because one-to-one interaction is most likely to happen in global collaboration (99.73% of international patents involves only two countries). The very small fraction of international patents involving more than three countries implies that those association rules with two countries on the LHS are very unusual. In IA-AA, KY (Cayman Islands) occurs six times in the Top 15. A possible explanation is that the Cayman Islands is a country without corporate tax. This encourages multinational enterprises to base subsidiary entities to shield some of their incomes from taxation. In this case, the patent is international because of taxation issue rather than R&D. This will lead to bias when using patent to understand the R&D output of international collaboration.

In most cases, the association rules show one country on the LHS and RHS and the interdependence of paired countries can be observed. Several examples selected from Table A1 are: (1) II: Thailand and Hong Kong, and Belarus and Russia; (2) IA: Malaysia and Singapore, Hong Kong and China, and China and Taiwan; (3) II-IA: Liechtenstein and Austria, and Malaysia and Singapore; (4) IA-AA: Cyprus and Hungary, and the Czech Republic and Belgium; and (5) II-IA-AA: Finland and Sweden, and the Czech Republic and Belgium. In addition, it can be observed that most pairs of interdependent countries are neighboring or even bordering countries because neighboring countries may share similar historical, linguistic and cultural heritage. In addition, the traveling cost is cheaper. This leads the communication between neighboring countries easier and more frequent. All these factors contribute to the significant interdependency between two neighboring countries observed in the results of learned association rules.

Similar to the method utilized for creating the international collaboration network (Figure 4), this study created a global interdependence network based on the association rules learned from the co-patenting activities. A total of 376 learned rules with lift values larger than one, i.e., 92 rules (II), 39 rules (IA), 59 rules (II-IA), 82 rules (IA-AA), 104 rules (II-IA-AA), are selected to designate positive tendencies for international collaborations. Countries on both the LHS and RHS of the total 376 rules were chosen as network actors, and the actor size is proportional to actor's OutDegree Centrality. The interdependence relationship between LHS country and RHS country are depicted by network tie, while the arrow of network tie is always pointing towards the country on the RHS means the occurrence of RHS country is dependent on the LHS country at the other side of the network tie. Finally, the thickness of network tie is proportional to the lift value of the 376 learned rules and different types of international patents are specified as different colors.

The obtained interdependence network is provided in Figure 8. There are 50 countries, 340 network ties, network density is 0.135, and averaged degree centrality is 13.60. Unlike the nondirectional network in Figure 4, the interdependence network is directional and the dependence of RHS on LHS, or the influence of LHS on RHS, can be presented by the direction of the arrow. It is observed that most of the paired countries mutually depend on each other, which suggests international collaboration first initialized by one country will eventually reach a bilateral relationship where the mutual influences between the two paired countries can be expected. The paired countries are often neighboring countries, e.g., China and Taiwan, Malaysia and Singapore, Finland and Sweden, and Germany and Switzerland, which share similar cultural and linguistic heritages. In addition, the US presents a very strong influence on its diverse collaboration partners so it is always the top country in all types of centrality measurements.

By following the concept using association rule mining for identifying influential actors, the LHS countries are identified as influential countries [84]. This suggests that, compared to other centrality measurements, OutDegree Centrality is a direct proxy for measuring countries' influence in international collaboration. Five network properties of global interdependence network, Figure 8, are calculated to allow cross-country comparison on different network property, the results ranked by OutDegree Centrality are shown in Table A2 (Appendix B). It can be observed that US, France, Switzerland, Germany, and Sweden are the Top 5 influential countries, and South Korea (No. 9), China (No. 10), Japan (No. 11), Taiwan (No. 15), Singapore (No. 17), Hong Kong (No. 18), and India (No. 19) are the seven Asian countries in the Top 20 influential countries. This confirms prior findings that East Asia is one of the most successful regional economies [29] and R&D collaboration among Taiwan, Japan, Korea, and China is extensive [30]. In addition, it indicates the possibility for emerging or developing countries to dominate international collaboration.

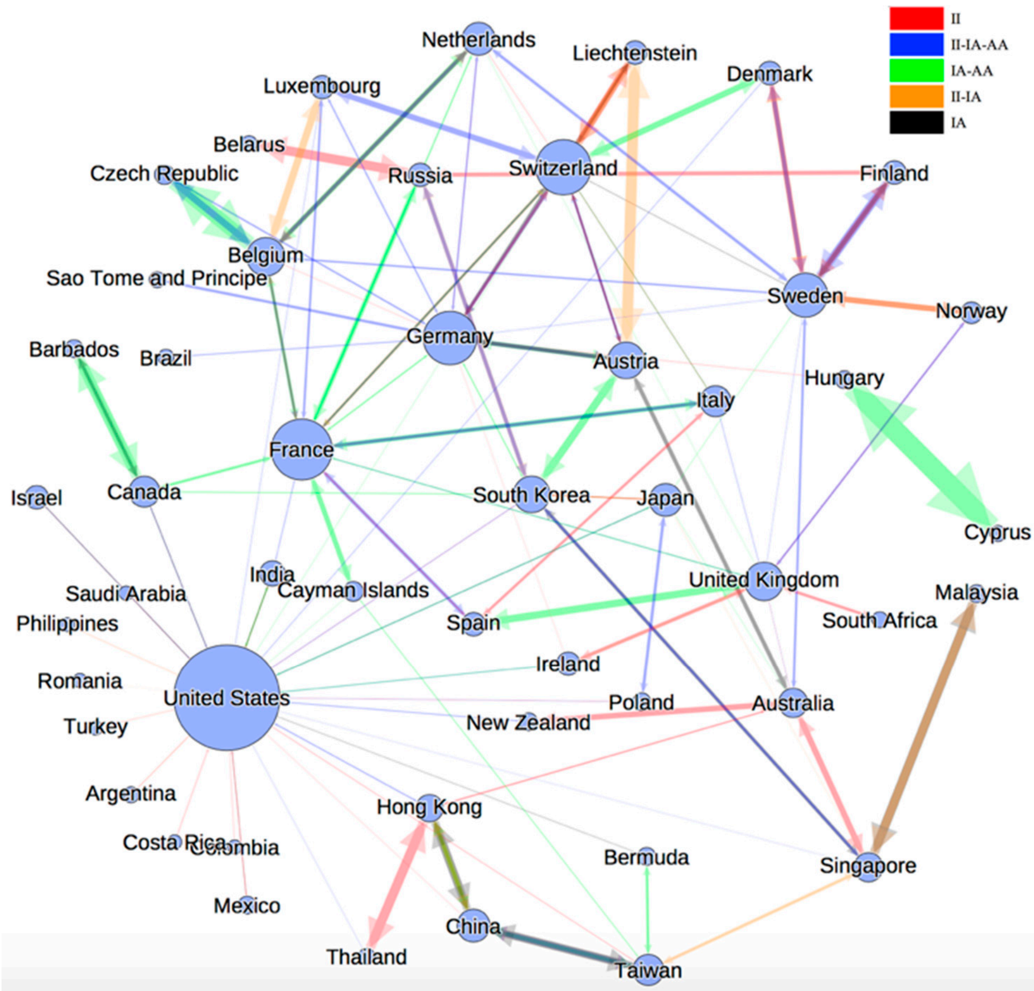

Figure 8. Global Interdependence Network.

5. Conclusions

Remarkable growth of international collaboration has been initialized in this rapidly globalized society since the 1990s. It is of importance to assess international R&D as well as depict the global landscape of international collaboration, which has never been investigated by a large-scale approach. Therefore, this study integrates social network theory, patent characterization and association rule mining to provide an overall assessment on the global landscape of international collaboration.

The internationalization of collaboration is holistically assessed and visually presented. It is found that international patent has increased significantly since 1992. Biochemistry and ICT related industries are most internationalized. Singapore, the Netherlands and China are the most internationalized in terms of the ratio of international patents.

The newly proposed system for classifying international patents provides better resolution without the overlap problem. The higher forward citation, backward citation, degree centrality and claim for II-IA, IA-AA, and II-IA-AA implies the possibility of higher patent value. International collaboration generates positive value but the price paid is the increased R&D cost for overcoming cross-country barrier such as geographic, coordination or language issues.

The created structure of global interdependence network provides evidences for understanding how countries are interdependent on each other. Most countries are paired together with their neighboring countries and mutually dependent on each other. The top influential countries are those with the highest OutDegree Centralities, i.e., US, France, Switzerland, and Sweden.

5.1. Management Implication

The investigation of international co-patenting provides an overview of global landscape of collaborative R&D. The increasing internationalization in collaborative patenting presents a highly skewed distribution from where it can be observed that the developing process of a country and its level of internationalization are strongly correlated. A highly developed country usually shows a higher degree of internationalization, and vice versa. Small countries such as Singapore, the Netherlands, Switzerland, Belgium, and Denmark have very high percentages of international patents (Figure 3) because seeking external resources is essential for small countries to overcome domestic constraints. Small countries have difficulties building up domestic human and financial resources but the difficulties can be avoided through international collaboration, therefore the international collaboration of small country is frequent [108]. Highly developed countries from Europe and North America appear to be those with high patent stock and therefore present strong influence on international collaboration (Figure 5). However, China and India are both large and developing countries but still present high portion of international patent (China is 3rd in Figure 3) or high influence of international collaboration (China is 10th and India is 19th in Table A2). Large and developing countries are potentially emerging and big markets, which attract foreign direct investments and technological know-how from around the world, a spectacular rate of internationalization and economic growth can thus be observed. However, the large number of influential Asian countries (Asian countries with top OutDegree Centrality in Table A2) implies that the dominance of international collaboration by western developed countries has gradually shifted towards Asia and has accelerated the catch-up of Asian countries towards Western level productivity [109]. The history of international competition shows that country capabilities are diffusing slowly cross national border [110]. Finally, the highly skewed global collaboration indicates an inhomogeneous or unequal levels of internationalization, where is indeed a hurdle to countries' technological mobility.

5.2. Management Implications of Five Types of International Patents

5.2.1. II Type

II patents indicate that multiple inventors from different countries are self-employed. II patents have lower No. of Patent References, No. of Foreign References, and lower No. of Claims, which implies II patents are less valuable than other types of international patents. Due to the lack of organizational support, inventors are not able to obtain guidance from assignee for how to increase patent quality. The strongest interdependences in II patents can be found in following groups of countries: (1) Thailand and Hong Kong; (2) Ukraine, Belarus and Russia; (3) Liechtenstein and Switzerland; (4) Singapore, Australia, and New Zealand; and (5) Norway and Sweden. Countries in the same group are neighboring to each other and share similar cultures.

5.2.2. IA Type

IA patents comprise inventor and assignee from different countries. The type of patents is the most usual international patents if a local assignee hires an inventor or a foreign assignee hires a local inventor. IA patents have higher No. of Patent References, No. of Foreign References, and No. of Claims than those of II patents. This suggests the positive role of assignee in seeking prior knowledge and expanding legal scope. The lower No. of IPCs and No. of UPCs compared to II patents indicate assignee tends to allocate resources on solving specific problems. The following groups of countries have the strongest interdependences: (1) Malaysia and Singapore; and (2) Hong Kong, China, and Taiwan. Assignee tends to hire inventors from neighboring countries with geographic proximity and same language.

5.2.3. II-IA Type

II-IA patents contain multiple inventor countries and at least one assignee. II-IA patents are more internationalized than IA patent as inventors from multiple countries are involved. II-IA patents have very high No. of Patent References, No. of Foreign References, and No. of Patent Citations Received. This indicates II-IA patents are of very high value. In addition, II-IA patents have the highest No. of Claim and Degree Centrality, which implies II-IA patents have high legal value and strong linkage to the development of technology. The following groups are countries involved in II-IA type of patent: (1) Liechtenstein, Austria, and Switzerland; (2) Malaysia and Singapore; and (3) Norway, Sweden, Denmark, and Finland. Similar to IA patents, assignee tends to hire inventors from neighboring countries with geographic proximity and same language, but the strong interdependencies in II-IA patent are dominated by European countries.

5.2.4. IA-AA Type

IA-AA patents meet both criteria of IA and AA. The highest No of Patent Citation Received and Degree Centrality within 10 years indicates IA-AA patents are the most valuable patents. Since assignees from multiple countries are involved, the inventing process is very likely based on international formal contract or agreement that strongly shapes multilateral R&D strategy and thus synergize each assignee to generate quality output. The lowest No. of IPCs and No. of UPCs indicates the engagement of multiple assignees countries leads to the development of very focused technologies agreed by all assignees from different countries. The strongest interdependency can be observed in following group: (1) Cyprus and Hungary; (2) France, Taiwan, and China; (3) Czech Republic and Belgium; (4) Austria and Korea; and (5) Spain and England. Assignees strategically collaborate to mutually advance competences beyond the consideration of geographic proximity or language.

5.2.5. II-IA-AA Type

II-IA-AA patents contain multiple inventor countries and multiple assignee countries and are therefore the most internationalized patents. This type of patents has the highest No. of Non-Patent References and No. of Foreign References, indicating the strong reliance on scientific knowledge and foreign patents. The unusually high degree of internationalization is positive for generating technological output emphasized more on scientific linkage. The strongest interdependency can be observed on (1) Switzerland, US, Luxembourg, Czech Republic, and Belgium; (2) China and Taiwan; (3) US, Japan, and Poland; (4) Finland, Sweden, and Denmark; and (5) Austria and Germany. Most groups contain countries with strong scientific background.

5.3. Contribution to Theory

This study contributes to literature by analyzing global landscape of international collaboration in a large-scale manner. The holistic scaled analysis through USPTO patent granted between 1976 and 2013 has never been investigated in literature. Contributions can be summarized as: (1) the overview of international collaboration is investigated from the perspectives of cross-country and cross-industry comparisons; (2) the structure of international collaboration network is created to allow quantitative and visual understanding of each country's role in the international network; (3) a novel method for classifying international patents is proposed, and different types of international patents are characterized to uncover hidden implication related to internationalization; and (4) association rule mining is used to understand how each country associate with others and identify influential collaborative country, also a structure illustrating global interdependency of collaboration is created.

However, this is still a long way from fully realizing how to correlate patent-based internationalization measure and firm's business strategy. This heuristic study tends to report the results to contribute to literature as well as stimulate more researches investigating globalized collaboration with patent.

5.4. Research Limitation

Collaborative patent granted by USPTO is used as a proxy for understanding the landscape of international collaboration. However, some limitations in this research are summarized as follows: (1) The US is the biggest market and the USPTO patent database is regarded as the most reliable data source for innovation study [73,76]. However, the results based on only USPTO does not fully reflect a global view. (2) Co-occurrence of countries in a patent is assumed as collaborative partners but this is not always true. For example, a company might register a branch in the Cayman Islands in order to shield partial incomes from taxation. The appearance of Cayman Island as one of multiple assignee countries may mean nothing about international collaboration. (3) Patent can only explain a modest part of international collaboration. There are other forms of international collaborations, e.g., foreign direct investment, strategic alliances, join venture [18].

5.5. Future Research

The structure of global interdependence network created in this study is only a snapshot which does not allow understanding the change of interdependency over time. Since the rate of internationalization has been increasing in recent years, it is suggested to conduct longitudinal analysis on how association rules of international collaboration change over time. In addition, the internationalization based on exports, import and foreign direct investment can be measured and compared with the results obtained in current study.

Acknowledgments: The author would like to thank Taiwan's Ministry of Science and Technology for the financial support under the contract: MOST 103-2410-H-005-058-MY3.

Conflicts of Interest: The author declares no conflict of interest.

Appendix A

Table A1. Association Rules with Top 15 Lift Values.

Ranking	II				IA				II-IA			
	LHS ≥ RHS	Support	Confidence	Lift	LHS ≥ RHS	Support	Confidence	Lift	LHS ≥ RHS	Support	Confidence	Lift
1	{TH} ≥ {HK}	0.002	0.314	15.061	{MY} ≥ {SG}	0.001	0.292	14.042	{LI} ≥ {AT}	0.002	0.573	22.032
2	{HK} ≥ {TH}	0.002	0.077	15.061	{SG} ≥ {MY}	0.001	0.059	14.042	{AT} ≥ {LI}	0.002	0.060	22.032
3	{BY} ≥ {RU}	0.001	0.500	14.060	{HK} ≥ {CN}	0.003	0.276	10.144	{MY} ≥ {SG}	0.001	0.202	10.548
4	{RU} ≥ {BY}	0.001	0.033	14.060	{CN} ≥ {HK}	0.003	0.101	10.144	{SG} ≥ {MY}	0.001	0.068	10.548
5	{LI} ≥ {CH}	0.002	0.567	8.000	{CN} ≥ {TW}	0.008	0.299	9.457	{LU} ≥ {BE}	0.001	0.374	7.605
6	{CH} ≥ {LI}	0.002	0.035	8.000	{TW} ≥ {CN}	0.008	0.258	9.457	{BE} ≥ {LU}	0.001	0.030	7.605
7	{UA} ≥ {RU}	0.002	0.227	6.374	{AU} ≥ {AT}	0.001	0.062	3.193	{LI} ≥ {CH}	0.001	0.538	5.783
8	{RU} ≥ {UA}	0.002	0.070	6.374	{AT} ≥ {AU}	0.001	0.054	3.193	{CH} ≥ {LI}	0.001	0.016	5.783
9	{SG} ≥ {AU}	0.002	0.174	5.479	{FI} ≥ {SE}	0.002	0.118	3.026	{NO} ≥ {SE}	0.002	0.178	5.210
10	{AU} ≥ {SG}	0.002	0.056	5.479	{SE} ≥ {FI}	0.002	0.050	3.026	{SE} ≥ {NO}	0.002	0.049	5.210
11	{NZ} ≥ {AU}	0.001	0.158	4.974	{KR} ≥ {SG}	0.001	0.059	2.829	{DK} ≥ {SE}	0.003	0.158	4.645
12	{AU} ≥ {NZ}	0.001	0.042	4.974	{SG} ≥ {KR}	0.001	0.055	2.829	{SE} ≥ {DK}	0.003	0.077	4.645
13	{NO} ≥ {SE}	0.002	0.187	4.924	{BB} ≥ {CA}	0.001	0.241	2.737	{FI} ≥ {SE}	0.002	0.154	4.531
14	{SE} ≥ {NO}	0.002	0.054	4.924	{CA} ≥ {BB}	0.001	0.012	2.737	{SE} ≥ {FI}	0.002	0.068	4.531
15	{FI} ≥ {SE}	0.003	0.180	4.752	{LI} ≥ {DE}	0.003	0.466	2.653	{TW} ≥ {CN}	0.007	0.209	4.461

Ranking	IA-AA				II-IA-AA			
	LHS ≥ RHS	Support	Confidence	Lift	LHS ≥ RHS	Support	Confidence	Lift
1	{CY} ≥ {HU}	0.001	0.800	354.789	{CH,US} ≥ {LU}	0.001	0.077	14.631
2	{HU} ≥ {CY}	0.001	0.571	354.789	{FI} ≥ {SE}	0.002	0.283	10.999
3	{FR,TW} ≥ {KY}	0.001	1.000	191.630	{SE} ≥ {FI}	0.002	0.096	10.999
4	{CN,FR,TW} ≥ {KY}	0.001	1.000	191.630	{LU,US} ≥ {CH}	0.001	0.349	7.470
5	{CN,FR} ≥ {KY}	0.001	0.857	164.254	{CZ} ≥ {BE}	0.001	0.267	6.658
6	{CZ} ≥ {BE}	0.001	0.667	66.333	{BE} ≥ {CZ}	0.001	0.031	6.658
7	{BE} ≥ {CZ}	0.001	0.103	66.333	{LU} ≥ {CH}	0.001	0.235	5.039
8	{BB} ≥ {CA}	0.001	0.471	19.795	{CH} ≥ {LU}	0.001	0.026	5.039
9	{CA} ≥ {BB}	0.001	0.043	19.795	{TW} ≥ {CN}	0.167	0.883	4.399
10	{CN,KY} ≥ {FR}	0.001	1.000	15.855	{CN} ≥ {TW}	0.167	0.831	4.399
11	{CN,KY,TW} ≥ {FR}	0.001	1.000	15.855	{DK} ≥ {SE}	0.002	0.092	3.583
12	{KY,TW} ≥ {FR}	0.001	0.778	12.332	{SE} ≥ {DK}	0.002	0.075	3.583
13	{AT} ≥ {KR}	0.002	0.292	8.914	{JP,US} ≥ {PL}	0.002	0.011	3.214
14	{KR} ≥ {AT}	0.002	0.075	8.914	{AT} ≥ {DE}	0.012	0.558	3.095
15	{ES} ≥ {GB}	0.001	0.386	8.215	{DE} ≥ {AT}	0.012	0.064	3.095

Appendix B

Table A2. Network Properties of Global Interdependence Network (Ranked by OutDegree Centrality).

Country	Outdegree Centrality	Indegree Centrality	Degree Centrality	Closeness Centrality	Betweenness Centrality
United States	36.00	49.00	85.00	0.55	975.01
France	24.00	25.00	49.00	0.48	264.13
Switzerland	22.00	22.00	44.00	0.52	241.26
Germany	21.00	21.00	42.00	0.49	438.07
Sweden	16.00	16.00	32.00	0.47	172.30
Belgium	14.00	13.00	27.00	0.44	38.21
United Kingdom	13.00	13.00	26.00	0.45	174.39
Austria	12.00	12.00	24.00	0.43	31.74
South Korea	12.00	12.00	24.00	0.49	215.47
China	10.00	10.00	20.00	0.37	2.86
Japan	10.00	10.00	20.00	0.46	66.82
Netherlands	10.00	10.00	20.00	0.44	9.66
Canada	9.00	9.00	18.00	0.44	105.98
Italy	9.00	9.00	18.00	0.40	4.19
Taiwan	9.00	9.00	18.00	0.38	13.35
Australia	8.00	8.00	16.00	0.44	112.58
Singapore	8.00	8.00	16.00	0.44	106.66
Hong Kong	7.00	7.00	14.00	0.40	62.89
India	6.00	6.00	12.00	0.43	14.22
Denmark	5.00	5.00	10.00	0.44	23.11
Spain	5.00	5.00	10.00	0.36	0.00
Finland	5.00	5.00	10.00	0.35	9.87
Ireland	5.00	5.00	10.00	0.47	90.67
Israel	5.00	5.00	10.00	0.36	0.00
Liechtenstein	5.00	5.00	10.00	0.38	0.00
Luxembourg	5.00	5.00	10.00	0.48	49.46
Russia	5.00	5.00	10.00	0.40	111.04
Mexico	4.00	2.00	6.00	0.36	0.00
Norway	4.00	4.00	8.00	0.35	0.00
Czech Republic	3.00	3.00	6.00	0.34	0.00
Cayman Islands	3.00	3.00	6.00	0.43	15.38
Poland	3.00	2.00	5.00	0.37	0.00
Argentina	2.00	1.00	3.00	0.36	0.00
Barbados	2.00	2.00	4.00	0.31	0.00
Bermuda	2.00	2.00	4.00	0.36	0.00
Hungary	2.00	2.00	4.00	0.34	90.00
Malaysia	2.00	2.00	4.00	0.31	0.00
New Zealand	2.00	2.00	4.00	0.39	3.69
Philippines	2.00	0.00	2.00	0.36	0.00
Thailand	2.00	1.00	3.00	0.37	0.00
Turkey	2.00	0.00	2.00	0.36	0.00
Brazil	1.00	1.00	2.00	0.33	0.00
Belarus	1.00	1.00	2.00	0.29	0.00
Colombia	1.00	0.00	1.00	0.36	0.00
Costa Rica	1.00	0.00	1.00	0.36	0.00
Cyprus	1.00	1.00	2.00	0.25	0.00
Romania	1.00	0.00	1.00	0.36	0.00
Saudi Arabia	1.00	0.00	1.00	0.36	0.00
Sao Tome and Principe	1.00	1.00	2.00	0.33	0.00
South Africa	1.00	1.00	2.00	0.31	0.00

References

1. Smith, H.L.; Dickson, K.; Smith, S.L. There are two sides to every story: Innovation and collaboration within networks of large and small firms. *Res. Policy* **1991**, *20*, 457–468. [CrossRef]
2. Dodgson, M. The strategic management of R&D collaboration. *Technol. Anal. Strateg. Manag.* **1992**, *4*, 227–244.
3. Brown, S.L.; Eisenhardt, K.M. Product development: Past research, present findings, and future directions. *Acad. Manag. Rev.* **1995**, *20*, 343–378.
4. Duysters, G.; Hagedoorn, J. Technological Convergence in the IT Industry: The Role of Strategic Technology Alliances and Technological Competencies. *Int. J. Econ. Bus.* **1998**, *5*, 355–368. [CrossRef]
5. Ahuja, G. The duality of collaboration: Inducements and opportunities in the formation of interfirm linkages. *Strateg. Manag. J.* **2000**, *21*, 317–343. [CrossRef]
6. George, G.; Zahra, S.A.; Wood, D.R. The effects of business-university alliances on innovative output and financial performance: A study of publicly traded biotechnology companies. *J. Bus. Ventur.* **2002**, *17*, 577–609. [CrossRef]
7. McGill, J.; Santoro, M. Alliance Portfolios and Patent Output: The Case of Biotechnology Alliances. *IEEE Trans. Eng. Manag.* **2009**, *56*, 388–401. [CrossRef]
8. Teece, D.J. Competition, cooperation, and innovation: Organizational arrangements for regimes of rapid technological progress. *J. Econ. Behav. Organ.* **1992**, *18*, 1–25. [CrossRef]
9. Baum, J.A.; Calabrese, T.; Silverman, B.S. Don't go it alone: Alliance network composition and startups' performance in Canadian biotechnology. *Strateg. Manag. J.* **2000**, *21*, 267–294. [CrossRef]
10. Mohnen, P.; Hoareau, C. What type of enterprise forges close links with universities and government labs? Evidence from CIS 2. *Manag. Decis. Econ.* **2003**, *24*, 133–145. [CrossRef]
11. Fritsch, M. Measuring the quality of regional innovation systems: A knowledge production function approach. *Int. Reg. Sci. Rev.* **2002**, *25*, 86–101. [CrossRef]
12. Simonin, B.L. Transfer of marketing know-how in international strategic alliances: An empirical investigation of the role and antecedents of knowledge ambiguity. *J. Int. Bus. Stud.* **1999**, *30*, 463–490. [CrossRef]
13. Simonin, B.L. Ambiguity and the process of knowledge transfer in strategic alliances. *Strateg. Manag. J.* **1999**, *20*, 595–623. [CrossRef]
14. Brakman, S.; Garretsen, H. *Foreign Direct Investment and the Multinational Enterprise*; Mit Press: Cambridge, MA, USA, 2008.
15. Hsu, C.-W.; Lien, Y.-C.; Chen, H. R&D internationalization and innovation performance. *Int. Bus. Rev.* **2015**, *24*, 187–195.
16. Bohnstedt, A.; Schwarz, C.; Suedekum, J. Globalization and strategic research investments. *Res. Policy* **2012**, *41*, 13–23. [CrossRef]
17. Ernst, D.; Kim, L. Global production networks, knowledge diffusion, and local capability formation. *Res. Policy* **2002**, *31*, 1417–1429. [CrossRef]
18. Moore, K.; Lewis, D. *Birth of the Multinational: Two Thousand Years of Ancient Business History, from Ashur to Augustus*; Copenhagen Business School Press: Copenhagen, Denmark, 1999.
19. Criscuolo, P.; Narula, R.; Verspagen, B. *The Relative Importance of Home and Host Innovation Systems in the Internationalisation of MNE R&D: A Patent Citation Analysis*; Eindhoven Center for Innovation Studies (ECIS): Eindhoven, The Netherlands, 2002.
20. Narula, R. R&D collaboration by SMEs: New opportunities and limitations in the face of globalisation. *Technovation* **2004**, *24*, 153–161.
21. Kim, C.-S.; Inkpen, A.C. Cross-border R&D alliances, absorptive capacity and technology learning. *J. Int. Manag.* **2005**, *11*, 313–329.
22. Georghiou, L. Global cooperation in research. *Res. Policy* **1998**, *27*, 611–626. [CrossRef]
23. Van Beers, C.; Berghäll, E.; Poot, T. R&D internationalization, R&D collaboration and public knowledge institutions in small economies: Evidence from Finland and the Netherlands. *Res. Policy* **2008**, *37*, 294–308.
24. Li, J. Global R&D alliances in China: Collaborations with universities and research institutes. *IEEE Trans. Eng. Manag.* **2010**, *57*, 78–87.

25. Srivastava, A.; Srivastava, M.; Rai, S.K. Managing Research and Development in a Global Environment through the Collaboration of Developed and Developing Economies. *Glob. J. Manag. Bus. Stud.* **2013**, *3*, 935–942.
26. Di Minin, A.; Bianchi, M. Safe nests in global nets: Internationalization and appropriability of R&D in wireless telecom. *J. Int. Bus. Stud.* **2011**, *42*, 910–934.
27. Ma, Z.; Lee, Y. Patent application and technological collaboration in inventive activities: 1980–2005. *Technovation* **2008**, *28*, 379–390. [CrossRef]
28. Picci, L. The internationalization of inventive activity: A gravity model using patent data. *Res. Policy* **2010**, *39*, 1070–1081. [CrossRef]
29. Abbott, L.F. *Industry and Enterprise: An International Survey of Modernization and Development*; Industrial Systems Research: Manchester, UK, 2003.
30. Tsukada, N.; Nagaoka, S. International R&D Collaborations in Asia: A First Look at Their Characteristics Based on Patent Bibliographic Data. In *Globalization and Innovation in East Asia*; ERIA Research Project Report 2010-04; Hahn, C.H., Narjoko, D., Eds.; ERIA: Jakarta, Indonesia, 2011; pp. 410–451.
31. Ernst, D. *Innovation Offshoring: Asia's Emerging Role in Global Innovation Networks*; East-West Center Special Reports; U.S.-Asia Pacific Council: Honolulu, HI, USA, 2006.
32. Organisation for Economic Co-operation and Development. *OECD Science, Technology and Industry Outlook*; OECD Publishing: Paris, France, 2008.
33. Serapio, M.G.; Dalton, D.H. Globalization of industrial R&D: An examination of foreign direct investments in R&D in the United States. *Res. Policy* **1999**, *28*, 303–316.
34. Florida, R. The globalization of R&D: Results of a survey of foreign-affiliated R&D laboratories in the USA. *Res. Policy* **1997**, *26*, 85–103.
35. Martínez-Noya, A.; García-Canal, E. Technological capabilities and the decision to outsource/outsource offshore R&D services. *Int. Bus. Rev.* **2011**, *20*, 264–277.
36. Yang, Q.; Jiang, C.X. Location advantages and subsidiaries' R&D activities in emerging economies: Exploring the effect of employee mobility. *Asia Pac. J. Manag.* **2007**, *24*, 341–358.
37. Criscuolo, P. On the road again: Researcher mobility inside the R&D network. *Res. Policy* **2005**, *34*, 1350–1365.
38. Guellec, D.; de la Potterie, B.V.P. The internationalisation of technology analysed with patent data. *Res. Policy* **2001**, *30*, 1253–1266. [CrossRef]
39. Ma, Z.; Lee, Y.; Chen, C.-F.P. Booming or emerging? China's technological capability and international collaboration in patent activities. *Technol. Forecast. Soc. Chang.* **2009**, *76*, 787–796. [CrossRef]
40. Filippetti, A.; Frenz, M.; Ietto-Gillies, G. Are innovation and internationalization related? An analysis of European countries. *Ind. Innov.* **2011**, *18*, 437–459. [CrossRef]
41. Gerybadze, A.; Reger, G. Globalization of R&D: Recent changes in the management of innovation in transnational corporations. *Res. Policy* **1999**, *28*, 251–274.
42. Keller, W. Geographic localization of international technology diffusion. *Am. Econ. Rev.* **2002**, *92*, 120–142. [CrossRef]
43. Jaffe, A.B.; Trajtenberg, M.; Henderson, R. Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. *Q. J. Econ.* **1993**, *108*, 577–598. [CrossRef]
44. Thompson, P. Patent citations and the geography of knowledge spillovers: Evidence from inventor- and examiner-added citations. *Rev. Econ. Stat.* **2006**, *88*, 383–388. [CrossRef]
45. Lee, G. The effectiveness of international knowledge spillover channels. *Eur. Econ. Rev.* **2006**, *50*, 2075–2088. [CrossRef]
46. Branstetter, L. Is foreign direct investment a channel of knowledge spillovers? Evidence from Japan's FDI in the United States. *J. Int. Econ.* **2006**, *68*, 325–344. [CrossRef]
47. Grossman, G.M.; Helpman, E. Trade, knowledge spillovers, and growth. *Eur. Econ. Rev.* **1991**, *35*, 517–526. [CrossRef]
48. Kotabe, M.; Dunlap-Hinkler, D.; Parente, R.; Mishra, H.A. Determinants of cross-national knowledge transfer and its effect on firm innovation. *J. Int. Bus. Stud.* **2007**, *38*, 259–282. [CrossRef]
49. March, J.G. Exploration and exploitation in organizational learning. *Organ. Sci.* **1991**, *2*, 71–87. [CrossRef]
50. Levinthal, D.A.; March, J.G. The myopia of learning. *Strateg. Manag. J.* **1993**, *14*, 95–112. [CrossRef]
51. Furman, J.L.; Kyle, M.K.; Cockburn, I.M.; Henderson, R. Public & private spillovers, location and the productivity of pharmaceutical research. *Ann. Econ. Stat.* **2005**, *79*, 165–188.

52. Singh, J. Distributed R&D, cross-regional knowledge integration and quality of innovative output. *Res. Policy* **2008**, *37*, 77–96.
53. Alnuaimi, T.; Singh, J.; George, G. Not with my own: Long-term effects of cross-country collaboration on subsidiary innovation in emerging economies versus advanced economies. *J. Econ. Geogr.* **2012**, *12*, 943–968. [CrossRef]
54. Branstetter, L.; Li, G.; Veloso, F. The Rise of International Co-invention. In *The Changing Frontier: Rethinking Science and Innovation Policy*; University of Chicago Press: Chicago, IL, USA, 2014.
55. Schilling, M.A.; Phelps, C.C. Interfirm collaboration networks: The impact of large-scale network structure on firm innovation. *Manag. Sci.* **2007**, *53*, 1113–1126. [CrossRef]
56. Allen, J.; James, A.D.; Gamlen, P. Formal versus informal knowledge networks in R&D: A case study using social network analysis. *RD Manag.* **2007**, *37*, 179–196.
57. Granovetter, M.S. The Strength of Weak Ties. *Am. J. Sociol.* **1973**, *78*, 1360–1380. [CrossRef]
58. Watts, D.J. *Six Degrees: The Science of a Connected Age*; WW Norton & Company: New York, NY, USA, 2004.
59. Wasserman, S.; Galaskiewicz, J. *Advances in Social Network Analysis: Research in the Social and Behavioral Sciences*; Sage Publications: Thousand Oaks, CA, USA, 1994.
60. Wellman, B.; Berkowitz, S.D. *Social Structures: A Network Approach*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 1988.
61. Marsden, P.V.; Campbell, K.E. Measuring tie strength. *Soc. Forces* **1984**, *63*, 482–501. [CrossRef]
62. De Prato, G.; Nepelski, D. *Global R&D Network. A Network Analysis of International R&D Centres*; Institute for Prospective and Technological Studies, Joint Research Centre: Seville, Spain, 2012.
63. Guan, J.; Liu, N. Exploitative and exploratory innovations in knowledge network and collaboration network: A patent analysis in the technological field of nano-energy. *Res. Policy* **2016**, *45*, 97–112. [CrossRef]
64. Patel, P.; Pavitt, K. Large firms in the production of the world's technology: An important case of "non-globalisation". *J. Int. Bus. Stud.* **1991**, *22*, 1–21. [CrossRef]
65. Patel, P.; Vega, M. Patterns of internationalisation of corporate technology: Location vs. home country advantages. *Res. Policy* **1999**, *28*, 145–155. [CrossRef]
66. Le Bas, C.; Sierra, C. "Location versus home country advantages" in R&D activities: Some further results on multinationals' locational strategies. *Res. Policy* **2002**, *31*, 589–609.
67. Almeida, P. Knowledge sourcing by foreign multinationals: Patent citation analysis in the US semiconductor industry. *Strateg. Manag. J.* **1996**, *17*, 155–165. [CrossRef]
68. Penner-Hahn, J.; Shaver, J.M. Does international research and development increase patent output? An analysis of Japanese pharmaceutical firms. *Strateg. Manag. J.* **2005**, *26*, 121–140. [CrossRef]
69. Joly, P.B.; de Looze, M.A. An analysis of innovation strategies and industrial differentiation through patent applications: The case of plant biotechnology. *Res. Policy* **1996**, *25*, 1027–1046. [CrossRef]
70. Abraham, B.P.; Moitra, S.D. Innovation assessment through patent analysis. *Technovation* **2001**, *21*, 245–252. [CrossRef]
71. Faber, J.; Hesen, A.B. Innovation capabilities of European nations—Cross-national analyses of patents and sales of product innovations. *Res. Policy* **2004**, *33*, 193–207. [CrossRef]
72. Artz, K.W.; Norman, P.M.; Hatfield, D.E.; Cardinal, L.B. A Longitudinal Study of the Impact of R&D, Patents, and Product Innovation on Firm Performance. *J. Prod. Innov. Manag.* **2010**, *27*, 725–740.
73. Kim, J.; Lee, S. Patent databases for innovation studies: A comparative analysis of USPTO, EPO, JPO and KIPO. *Technol. Forecast. Soc. Chang.* **2015**, *92*, 332–345. [CrossRef]
74. Organisation for Economic Co-operation and Development. *Using Patent Counts for Cross—Country Comparisons of Technology Output*; OECD Publishing: Paris, France, 2001.
75. Organisation for Economic Co-operation and Development. *Measuring Globalisation: OECD Economic Globalisation Indicators 2010*; OECD Publishing: Paris, France, 2010.
76. Goto, A.; Motohashi, K. Construction of a Japanese Patent Database and a first look at Japanese patenting activities. *Res. Policy* **2007**, *36*, 1431–1442. [CrossRef]
77. Archambault, É. Methods for using patents in cross-country comparisons. *Scientometrics* **2002**, *54*, 15–30. [CrossRef]
78. Zuniga, P.; Guellec, D.; Dernis, H.; Khan, M.; Okazaki, T.; Webb, C. *OECD Patent Statistics Manual*; OECD Publications: Paris, France, 2009.
79. Freeman, L.C. Centrality in social networks conceptual clarification. *Soc. Netw.* **1978**, *1*, 215–239. [CrossRef]

80. Brass, D.J.; Burkhardt, M.E. Centrality and power in organizations. *Netw. Organ. Struct. Form Action* **1992**, *191*, 215.
81. Agrawal, R.; Imielinski, T.; Swami, A. Database mining: A performance perspective. *IEEE Trans. Knowl. Data Eng.* **1993**, *5*, 914–925. [CrossRef]
82. Agrawal, R.; Imieliński, T.; Swami, A. Mining association rules between sets of items in large databases. In *ACM SIGMOD Record*; ACM: New York, NY, USA, 1993; Volume 22, pp. 207–216.
83. Aher, S.B.; Lobo, L.M.R.J. A comparative study of association rule algorithms for course recommender system in e-learning. *Int. J. Comput. Appl.* **2012**, *39*, 48–52.
84. Erlandsson, F.; Bródka, P.; Borg, A.; Johnson, H. Finding Influential Users in Social Media Using Association Rule Learning. *Entropy* **2016**, *18*, 164. [CrossRef]
85. Jung, H.-J.; Na, K.-Y.; Yoon, C.-H. The Role of ICT in Korea's Economic Growth: Productivity Changes across Industries since the 1990s. *Telecommun. Policy* **2013**, *37*, 292–310. [CrossRef]
86. Van Looy, B.; du Plessis, M.; Magerman, T. Data Production Methods for Harmonized Patent Statistics: Patentee Sector Allocation. *KUL Working Paper No. MSI 0606*. Available online: https://ssrn.com/abstract=944464 or http://dx.doi.org/10.2139/ssrn.944464 (accessed on 4 April 2017).
87. Cantwell, J.; Piscitello, L. Recent location of foreign-owned research and development activities by large multinational corporations in the European regions: The role of spillovers and externalities. *Reg. Stud.* **2005**, *39*, 1–16. [CrossRef]
88. Bergek, A.; Berggren, C. Technological internationalisation in the electro-technical industry: A cross-company comparison of patenting patterns 1986–2000. *Res. Policy* **2004**, *33*, 1285–1306. [CrossRef]
89. Criscuolo, P.; Narula, R.; Verspagen, B. Role of home and host country innovation systems in R&D internationalisation: A patent citation analysis. *Econ. Innov. New Technol.* **2005**, *14*, 417–433.
90. Tijssen, R.J.W. Global and domestic utilization of industrial relevant science: Patent citation analysis of science–technology interactions and knowledge flows. *Res. Policy* **2001**, *30*, 35–54. [CrossRef]
91. Grupp, H.; Schmoch, U. Patent statistics in the age of globalisation: New legal procedures, new analytical methods, new economic interpretation. *Res. Policy* **1999**, *28*, 377–396. [CrossRef]
92. Yamin, M.; Sinkovics, R.R.; Richardson, C. Internationalisation of innovative activity in Finnish multinational enterprises. *Eur. J. Int. Manag.* **2014**, *8*, 310–330. [CrossRef]
93. Amin, M.; Haidar, J.I. Trade facilitation and country size. *Empir. Econ.* **2014**, *47*, 1441–1466. [CrossRef]
94. Hu, Z.F.; Khan, M.S. Why Is China Growing So Fast? *Staff Pap.* **1997**, *44*, 103–131. [CrossRef]
95. Nemet, G.F.; Johnson, E. Do important inventions benefit from knowledge originating in other technological domains? *Res. Policy* **2012**, *41*, 190–200. [CrossRef]
96. Trajtenberg, M. A penny for your quotes: Patent citations and the value of innovations. *RAND J. Econ.* **1990**, *21*, 172–187. [CrossRef]
97. Albert, M.B.; Avery, D.; Narin, F.; McAllister, P. Direct validation of citation counts as indicators of industrially important patents. *Res. Policy* **1991**, *20*, 251–259. [CrossRef]
98. Lanjouw, J.O.; Schankerman, M. Characteristics of Patent Litigation: A Window on Competition. *RAND J. Econ.* **2001**, *32*, 129. [CrossRef]
99. Harhoff, D.; Scherer, F.M.; Vopel, K. Citations, family size, opposition and the value of patent rights. *Res. Policy* **2003**, *32*, 1343–1363. [CrossRef]
100. Marco, A.C. The option value of patent litigation: Theory and evidence. *Rev. Financ. Econ.* **2005**, *14*, 323–351. [CrossRef]
101. Allison, J.R.; Lemley, M.A.; Moore, K.A.; Trunkey, R.D. Valuable patents. *Georgetown Law J.* **2004**, *92*, 435. [CrossRef]
102. Blind, K.; Cremers, K.; Mueller, E. The influence of strategic patenting on companies' patent portfolios. *Res. Policy* **2009**, *38*, 428–436. [CrossRef]
103. Hall, B.H.; Jaffe, A.B.; Trajtenberg, M. *The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools*; National Bureau of Economic Research: Cambridge, MA, USA, 2001.
104. Lerner, J. The Importance of Patent Scope: An Empirical Analysis. *RAND J. Econ.* **1994**, *25*, 319–333. [CrossRef]
105. Tong, X.; Frame, J.D. Measuring national technological performance with patent claims data. *Res. Policy* **1994**, *23*, 133–141. [CrossRef]

106. Lanjouw, J.O.; Schankerman, M. Patent Quality and Research Productivity: Measuring Innovation with Multiple Indicators. *Econ. J.* **2004**, *114*, 441–465. [CrossRef]
107. Lee, K.-J. From interpersonal networks to inter-organizational alliances for university–industry collaborations in Japan: The case of the Tokyo Institute of Technology. *RD Manag.* **2011**, *41*, 190–201. [CrossRef]
108. Thorsteinsdottir, H. External research collaboration in two small science systems. *Scientometrics* **2000**, *49*, 145–160. [CrossRef]
109. Lin, J.Y.; Cai, F.; Li, Z. *The China Miracle: Development Strategy and Economic Reform*; Chinese University Press: Hong Kong, China, 2003.
110. Kogut, B. Country capabilities and the permeability of borders. *Strateg. Manag. J.* **1991**, *12*, 33–47. [CrossRef]