Dynamics of Multi-National R&D: Evolving Patterns in East Asia

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Abstract--**International R&D collaboration is perceived as important R&D strategy to obtain complementary resources, learn from the partner as well as sharing risks and costs. Previous studies suggested that international R&D collaboration has positive impact but the impact investigated in literature are either not clearly defined or largely focused on business or technological impact. This study attempts to investigate social and legal impacts of international R&D collaboration by analyzing East Asian collaborative patents with multiple assignee countries from the perspectives of social network theory as well as cross-border patent infringement probability. It is found that international R&D collaboration has positive influence on both social and legal impacts. The evolving pattern shows that China and Taiwan are the most prolific and fastest-growing patenting countries. Also, Taiwan is the most important partner country in East Asia's internationalization of R&D. Two important contributions of this study can be summarized as follows: 1) this study defines social and legal impacts based on which the dynamics of East Asia's international R&D collaboration can be obtained, 2) the legal impact defined in this study can be used to evaluate patent value as well as evaluate the quality of R&D partnership in East Asia.**

I. INTRODUCTION

Strategic collaboration facilitates pooling of complementary skills, learning from the partner as well as sharing risks and costs. There have been a significant number of literature examining impact of strategic alliance on firm level innovation [1][2][3]. It is suggested in literature that strategic collaboration allows firms to access strategic assets [4][5], complementary technology [6] and possibility of learning from collaborators and suppliers [7].

The multinational enterprises and its vehicle, foreign direct investment, are key forces in globalized economy [8]. Foreign direct investment which has grown more rapidly since 1990 is the critical driver of international R&D collaboration. The international collaboration is enhanced by reduced air travel cost, international communication cost as well as seeking for greater efficiency as growing competition in domestic and international markets forces firms to become efficient and competitive. International flow of information, technology, capital, goods, services, people have deepened global supply chain and global interdependence through which world economic growth and living standard can be advanced [9] [10].

International R&D collaboration is investigated in literature to exam absorptive capacity and technology learning [11], opportunities and limitations [12], home and host innovation systems [13], collaborative research in developed countries [14], collaboration between developed and developing countries [15], collaboration in developing countries [16]. International R&D collaboration is one of common form of international business activities which include foreign direct investment, joint ventures and strategic alliances [17]. Although international R&D collaboration is perceived as an important R&D strategy but the significance of international R&D collaboration varies by regions. For example, East Asia is one of the most successful regional economies with extensive R&D collaboration among Taiwan, Japan, Korea, and China.

Previous studies provide a significant number of evidence to prove the positive impacts of collaborative R&D. However, the impacts investigated in literature are either not clearly defined or largely focus on business or technological impact. Studies have scarcely analyzed social impacts, nor has attention been paid to the legal impact of international R&D collaboration.

Theoretical and empirical studies fail to take account of social impact and legal impact that can also shape the relation between International R&D collaboration and collaboration performance. Two issues related to social impact and legal impact needs to be considered. First, it is accepted in literature that R&D collaboration has positive influence on social impact because collaboration relies on resource exchange and social interaction. More intensive R&D collaboration leads to higher social impact but how social impact of international R&D collaboration can be measured? Second, legal impact has been scarcely investigated for international R&D collaboration. One important question needs to be answered is whether or not international R&D collaboration has positive influence on legal impact.

Therefore, this study aims to analyze the evolving pattern of dynamic R&D collaboration in East Asia as well as fill these gaps by answering the following research questions:1) How to measure the social impact of international R&D collaboration, 2) Does international R&D collaboration have positive influence on legal impact.

This study examines how social impact and legal impact can be analyzed for understanding the performance of international R&D collaboration. Specifically, this study argues that social and legal impact of international R&D collaboration can both be measured and international R&D collaboration has positive effect on both social impact and legal impact. Research questions are answered by analyzing the patent output of international R&D collaboration in the context of East Asian Countries. It contributes to literature in three aspects: First, this study empirically shows that international R&D collaboration has positive effect on both social impact and legal impact. Second, it measures legal impact quantitatively for East Asia countries. Third, this study provides evidence on the evolving pattern of international R&D collaboration in East Asia.

II. THEORETICAL BACKGROUND

A. International R&D Collaboration

Knowledge flow in the same countries are more intense than cross countries [18]. Geography is believed a constraint of flow of knowledge [19]. Literature investigating International knowledge flow have focused on trade [20], Foreign Direct Investment [21] and firm innovation [22].

International R&D collaboration generates output that can be more applicable to wider variety of preferences and be beneficial to multiple countries. Some prior studies suggested that international R&D collaboration generate better output because diverse knowledge and competences can be integrated from different countries [23]. However, other studies suggested that high coordination cost and communication difficulties, e.g. culture and language, and therefore independent R&D without international collaboration is more efficient and valuable [24]. Although there is no consensus on the influence of international R&D collaboration on the quality of R&D, a number of literature suggest international R&D collaboration generate positive impact on quality of patent. For example, Alnuaimi, Singh and George (2012) found international collaboration bring positive influence on patent value measured by patent citation [25]. Branstetter Li and Veloso investigated China and India's patents and found that patent with foreign inventor is of higher value measured by patent citation [26].

In summary, there has little attention paid to the impact of International R&D collaboration in literature. Also, the impact has scarcely been characterized. International R&D collaboration gives rise to two fundamental issues. First, international R&D collaboration requires social interaction to exchange resource, share experience and communicate between at least two teams in different countries. Second, international R&D collaboration may generate inventions involving in patent infringement lawsuit which is commonly used as a type of usual business strategy in modern knowledge-based economy. Prior studies in literature leave open the question of how to understand the social impact and legal impact of international R&D collaboration.

B. Network Theory for Understanding Social Impact

Firms collaborate with each other in order to access strategic assets [5] or complementary technology [27][6]. Firms collaborate through various forms of interaction in order to exchange resource and finally develop services or products that can generate higher economic benefit. The existence of a certain number of collaborations allows all these firms to form a network-like structure based on which social network theory was developed. The use of social network theory allows understanding the social relations among these collaborating firms.

Social network theory originally studied by sociologist has gradually used in other research fields and become an interdisciplinary concept. Granovertter (1973) proposed the theory of weak tie after his social network research, and argued social network is a proxy of understanding interconnection between microscopic analysis and macroscopic analysis [28]. In the late 1990s, collaboration between researchers from different fields by the use of social network analysis had been initialized so social network analysis become more interdisciplinary. Watts and Strogatz (1998) published a book entitled "Six Degrees: The Science of A Connected Age" [29], together with other interdisciplinary works contribute to expansion of small world concept from conventional neuro-science and bio-information system to any natural or human system that can be modeled by network.

A social network formed on the basis of resource exchange among firms can be used for understanding how resources are exchanged in this collaboration network, how firms are positioned to influence resource exchange, and which resource exchange is important [30]. Each resource exchange can be depicted as a linkage or a tie between a pair of firms. The strength of a network linkage is proportional of how much resources are exchanged or the frequency of resource exchange between two firms [31].

A significant number of studies have used network theory to investigate network of innovators , formal and informal knowledge networks in R&D [32], international R&D centers [33], knowledge network and collaboration network by patent analysis[19]. The constructed collaboration network can be analyzed to obtain network properties through which the collaboration structure can be quantitatively calculated and the social impact of each actor, i.e. researcher, firm, or countries involving in the collaboration, in the network can therefore be analyzed. In a collaboration network, network actor is not necessarily a firm. It can also be a person or a country. Network actor has to be properly selected to meet the required level of studies. Compare to person and firm, country seems to be a more acceptable and proper actor when it comes to a country-level study on international R&D collaboration.

C. Patent Infringement Probability as a Proxy of Legal Impact

It is widely accepted that patent is an important R&D output for protection of R&D results, for creating a better bargaining power as well as for building image of a firm or an organization. A significant number of literature tried to investigate how to estimate value which is usually classified into three types of values: 1) legal value [34][35], 2) technology value [36][37] and 3) economic value [38][39]. For the legal perspective, patent can be used for protecting proprietary process or product technology, and creating retaliatory power against competitors in a knowledge economy [40]. Therefore, it can be observed that the number of patent infringement has been increasingly remarkably over the past two decades [41] and patent infringement has been a popular topic [43]. Patent as a type of R&D output has been used to protect intangible asset in this modern knowledge economy [44]. A large number of previous researches have studied patent value which is strongly related to how much a patent can be legally or strategically functional [45].

It was accepted that patent value is a function of patent characteristics, e.g. no. of forward citation, no. of backward citation. Macro (2005) used several characteristics of patent, e.g. number of forward citation, number of backward citation, number of claim, as variables to create a real option model to investigate the validity and costly enforcement on patent [46]. Due to the fact that whether or not the patent has been involved in infringement is one important patent value indicator [42][47]. Studies have conducted to seek to evaluate patents under the chance of litigation by real option [48], fuzzy method [49] or combination of both [50].

However, patent infringement can be classified into two types. One type of patent infringement is investigated by federal district court and the other type is investigated by International Trade Commission in the US. International Trade Commission is a government agency dealing with cross-border patent infringements and plays a more important role in international trading and global economy than the court dealing with domestic patent dispute. Literature correlating patent infringement and patent characteristics are further extended to the creation of two models for forecasting patent infringement by systematically and holistically analyzing characteristics of patents issued after 1976. First, forecast domestic patent infringement probability which is to calculate the probability of a patent investigating by federal district court [42]. Second, forecast cross-border patent infringement probability which is to calculate the probability of a patent investigating by International Trade Commission [51]. The use of the infringement-based forecasting models [42] provide a channel to understand patent's infringement probability which is positively related to legal value or legal impact.

III. DATA AND METHOD

A. USPTO patent data and Patent Assignment

To understand international R&D in East Asia, patent as one important output of R&D is selected as our research data. This study utilized USPTO as the data source because the US is the biggest market which attracts global investments and collaborations based on which patent can be invented to generate largest value. Also, 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. The patent data used in this study are USPTO utility patents with multiple assignees from more than one country, i.e. patent with multiple assignee countries, to reflect international R&D activities. Each paten contains at least one assignee from East Asia, i.e. Taiwan, Japan, Korea and China, to allows understanding International R&D activities in East Asia.

Patents with multi assignee from different countries complicates their assignment to countries or regions [19]. There are a number of different assignment principles used in literature. 1) Assigning patents to the country of residence of the first-named inventors [52], 2) Assigning patent by fractional counting, each owner is attributed an equal part of the patent [53][54], 3) Assigning patents by multiple counting, usually used in studying cross-country collaboration [55][56]. Assigning patent by multiple counting is to attribute a patent to every relevant countries and is primarily used in investigating patenting activities in a particular region [57]. Therefore, this study also utilizes multiple-counting to reflect international patenting activities in East Asia.

The obtained patents with multiple assignee country are categorized into seven time periods 1) 1980-1984, 2) 1985-1989, 3) 1990-1994, 4) 1995-1999, 5) 2000-2004, 6) 2005-2009, 7) 2010-2013. Each time period is 5 years except the last one 2010-2013 which contains only 4 years because the patent data were downloaded in early 2014. Patent information, i.e. 1) Patent Number, 2) Number of Assignee, 3) Assignee Countries, 4) Issued Year, are recorded for following analyses.

B. Measuring Social Impact by Network Theory

The obtained patents are analyzed to create international R&D network by social network theory. Social and international relation can be depicted by analyzing which countries are the co-assignee countries in a patent document. Co-assignee countries are countries co-invent the patent and therefore own the patent right together. These countries work together by sharing information or resources and therefore knowledge, technology, capital, human resource flow from one country to the other ones along with personnel interaction. These countries co-invent a patent and are listed as the co-assignee countries in a patent, so these countries are linked together so represent their co-inventing activities and their co-assignee role in a patent. For example, a patent with three assignee countries, i.e. Taiwan and Japan, China, is depicted as three network actors which are Taiwan, Japan, China, and three network ties which are ties between Taiwan and Japan, Japan and China, Taiwan and China. The three actors and three ties represent the international R&D collaboration of the three co-assignee countries in one patent. Every patent is analyzed to construct an international R&D collaboration network with countries as network actor and co-assignee behavior as network tie. The focus of this study is East Asia, so each patent must contain at least one assignee county from Taiwan, Japan, Korea or China. However, the four countries may collaborate with countries other than the four East Asian countries, this study considers all of the countries as long as they are listed as the co-assignee countries of a patent with multiple-assignee countries and at least one assignee country is from Taiwan, Japan, Korea or China.

After the international R&D network is created, network property is calculated. In social network theory, "Centrality" is a key network property to estimate how easy an actor retrieves or controls resources from the network. Freeman (1979) proposed three ways of measuring network centrality, Degree Centrality, Betweenness Centrality, and Closeness

Centrality [58]. The higher centrality indicates more associations with actors in a network. Brass and Burkhardt (1992) pointed out the higher centrality of a person in a social network, the more power he possesses from the viewpoint of organizational behavior [59]. This research utilizes Degree Centrality as the way to measure social impact of each actor because Degree Centrality is the property that substantially correlated to social interactions among countries in international R&D collaboration.

Degree Centrality: the number of time that country i collaborates with other countries. The higher Degree Centrality, the more times that country i collaborates internationally, meaning the higher momentum of international R&D collaboration between country i and other countries j.

$$d(i) = \sum_j m_{ij}$$

$m_{ij}=1$ if country i collaborate with country j

C. Measuring Legal Impact by Patent Infringement Probability

To measure legal impact of a patent, it is suggested in literature that number of claim can be adopted to calculate legal value [60][61] However, counting number of claims in a patent seems insufficient to describe legal issues which may comprises factors other than the scope of claims listed in a patent. For example, a lawsuit can be filed because of technological development strategy which is irrelevant to the number of claims. To resolve this issue, this study utilizes the infringement-based model proposed by Lee and Su (2004) to measure patent's cross-border infringement probability which is positively related to legal value or legal impact [51]. Since cross-border infringement is investigated by international Trade Commission in the US. The legal impact is also designated as ITC probability. By the use of this model, legal impact is not only a function of claim but also a function of the other eight patent characteristics, i.e. number of assignee, number of assignee country, number of inventor, no. of Inventor Country, no. of patent reference, number of patent citation received, number of UPC, number of non-patent reference. This is consistent to the fact that legal impact is related to the integration of complex behaviors which should be described by multiple indicators or patent characteristics. The model for measuring Legal Impact or ITC probability takes the form [51].

$$LI_i = \exp(z_i) / \exp(z_i+1)$$

$$z_i = -8.5323 - 2.1167\ \alpha_{1i} + 2.7986\ \alpha_{1i} + 0.0940^*\ \alpha_{3i} - 0.95270\ \alpha_{4i} + 0.0013\ \alpha_{5i} + 0.00572\ \alpha_{6i} + 0.0141\ \alpha_{7i} + 0.0117\ \alpha_{8i} + 0.00174\ \alpha_{9i}$$

where LI_i is the legal impact or ITC probability of patent i; α_{1i}~ α_{9i} are patent characteristics of patent i: α_{1i} is number of assignee; α_{2i} is number of assignee country; α_{3i} is number of inventor; α_{4i} is number of inventor country; α_{5i} is number of patent reference; α_{6i} is number of patent citation received; α_{7i} is number of UPC; α_{8i} is number of claim; α_{9i} is number of non-patent reference.

IV. RESULTS AND DISCUSSION

A. Descriptive Analysis for International Patents in East Asia

It can be expected in this globalized society, international R&D is greatly enhanced by reduced air travel cost, international communication cost as well as seeking for greater efficiency. As shown in Figure 1, the share of patents generated by international R&D activities is increasing from less than 0.1% in 1980 to about 1.4% in 2013. In the total of 4,417,512 patents between 1980 and 2013, there are 28,102 patents with multiple assignee countries, 18,507 East Asian patents with assignee country count larger than one, and 1,347 patents with assignee country count equal to 3 and only 49 patents with assignee country count equal to or larger than 4. It is calculated in this study that international patents with multiple assignee countries are only about 0.70% of total patents. In this 0.63% patents with multiple assignee countries, East Asian R&D collaboration plays a very significant role because the number of East Asian multi-assignee country patents is 60% of global multi-assignee country patents. Also, the very limited number of patents with 4 assignee countries indicates that collaboration difficulty increases as the number of countries involving in collaborative R&D increases. Two or three countries working on the same R&D project is the most acceptable collaboration that can reach the balance between seeking for collaborative synergy and possible administration costs.

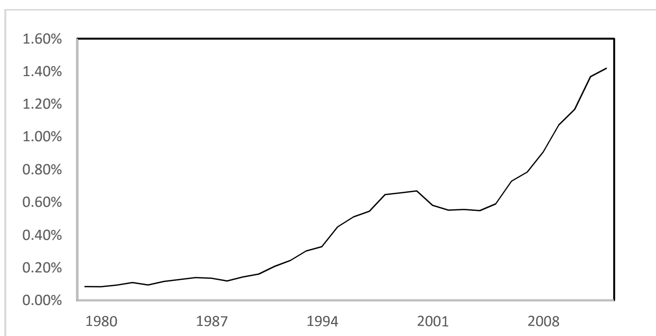


Figure 1. Percentage of Patent with Multiple Assignee Countries.

Although the number of international patents is not significant, the increasing trends can be observed to reflect that international R&D is getting popular. As shown in Table 1 and Figure 2, there are only 79 international patents in East Asia in 1980-1984, but increase dramatically to 8,498 patents which are 68.68% of all international patents in 2010-2013.

Japan is the leading country with the highest number of international patents in East Asia before 2010. Japan has only 150 international patents in 1985-1989 but increases very rapidly to 1,614 international patents in 1990-1994. In the same period of 1995-1999, Taiwan, Korea and China have only 13~89 patents which are close to Japan's number of international patents in 1980-1984. This indicates Japan's leading role of international R&D collaboration due to its early industrial development.

Taiwan's number of international patents increases significantly from 32 patents in 2000-2004 to 1,277 patents in 2005-2009. Compare to the number of Japan's international patents in 1990-1994 (1,614 patents), Taiwan paid attention to international R&D at least a decade later than Japan. However, Taiwan surpassed Japan and filed more international patents than Japan in 2010-2013. This might have something to do with the fact that Taiwan is one of the key players in global value chain particularly in electronic and semiconductor industries.

Korea has the smallest number of patents in East Asian countries. From 1980-1989, Korea does not have any international patent. Its number of international patents glows slowly and reaches only 484 patents which are 5.7% of the total East Asia's international patents in 2010-2013.

China's number of international patents grows from zero in 1980-1984 to 5,343 patents in 2010-2013. The share of China's international patent in East Asia is as high as 62.87% which indicates China has the dominating role of international collaboration not only in East Asia but also in the global economy. The high intensity of international R&D collaboration results from the fast growing industries in China. For example, China has been playing the role of global manufacturing hub, multinational enterprises create a significant number of regional headquarters in China and the headquarters have stimulated inflows and outflows of knowledge which encourage filing of international patents.

TABLE 1. INTERNATIONAL PATENTS WITH ASSIGNEE COUNTRY COUNT LARGER THAN ONE

Patent Count		1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2013
Patents with Assignee Country >1	Global	293	519	3330	3321	5077	5775	12368
	East Asia	79 (26.96%)	164 (31.60%)	1724 (51.77%)	1715 (51.64%)	2779 (54.74%)	3548 (61.44%)	8498 (68.68%)
	JP	78[98.73%]	150[91.46%]	1614 [93.62%]	1606 [93.64%]	2508 [90.25%]	1977 [55.72%]	2556 [30.08%]
	TW	1 [1.27]	4 [2.44]	29 [1.68%]	29 [1.69%]	32 [1.15%]	1277 [35.99%]	4841 [56.97%]
	KR	0 [0%]	0 [0%]	89 [5.162%]	89 [5.19%]	153 [5.51%]	243 [6.85%]	484 [5.70%]
	CN	0 [1%]	12 [7.32%]	14[0.81%]	13 [0.76%]	36 [1.30%]	1211[34.14%]	5343 [62.87%]
Total Patent Count, regardless of Assignee Country		309487	398927	484305	624030	824157	799983	976623

( ): global percentage, [ ]: East Asian percentage

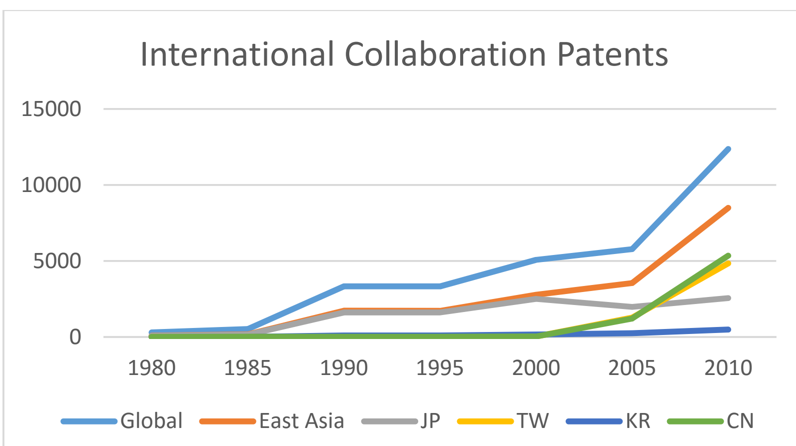


Figure 2. International patents with multiple assignee countries

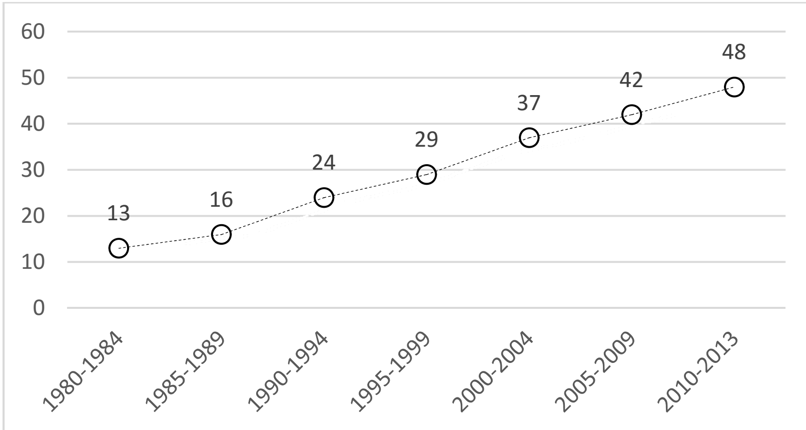


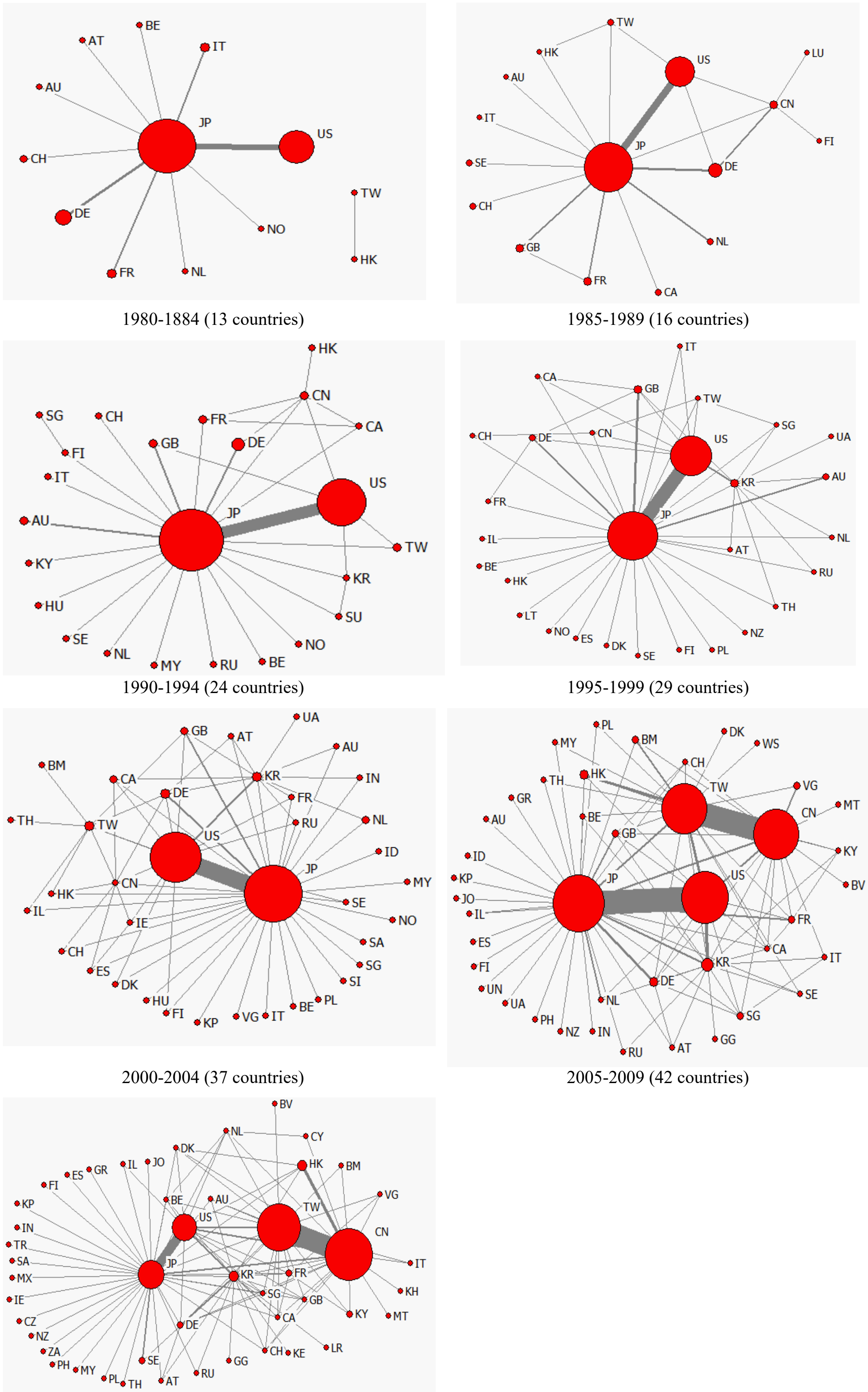
Figure 3. the number of countries participating the international R&D collaboration in East Asia.

V. SOCIAL IMPACT ANALYSIS

The international R&D network based on co-assignee country is created to demonstrate how countries, as network actors, play their social roles in international collaboration. Also, degree centrality as one important network property in social network theory is calculated to estimate how central network actors are, i.e. how easy actors retrieve or control resources from the network. Figure 3 shows the number of countries participating in the international R&D collaboration in East Asia. It can be observed that the number of countries involving East Asian international R&D increases almost linearly from 13 countries in 1980-1984 to 49 countries in 2010-2013.

Figure 4 show the international R&D collaboration network in East Asia. Each network actor is a country. Two countries are linked together if the two countries collaborate and generate a patent output. The size of the network actor is proportional to the number of patents of the country. In 1980-1984, there are only 13 countries and the strongest collaboration, represented by the thickest tie, is between Japan and the US. In 1985-1989, there are a total of 16 countries. China shows up and forms a strong cluster with Japan, US and Germany. In 1990-1994, there are a total of 24 countries, Korea shows up in the collaboration network. In 1995-1999, there are a total of 29 countries. The network becomes more complicated due to the increased number of countries and R&D collaboration. In 2000-2004, Taiwan and China are still not as significant as Korea. The two dominating countries are still Japan and the US. However, in 2005-2009, both Taiwan and China become as important as Japan and China. Also, the strong tie between Taiwan and China can be observed. In 2010-2013, Taiwan and China are dominating the international R&D collaboration in East Asia. The strongest tie between Taiwan and China indicates the significant collaboration between Taiwan and China. However, Korea is connected to many other countries but the number of Korean patents is much less than those of Taiwan, Japan and China.

As explained previously in research method, degree centrality is used as a proxy to measure social impact of each country in East Asia because degree centrality is positively correlated to the degree of social interaction in an international R&D collaboration network. The International R&D collaboration networks created in Figure 4 are analyzed to obtain degree centrality of each country in each period of time. The seven degree centralities and patent counts of East Asian countries and the US in the seven time periods are plotted in Figure 5. It can be observed in Figure 5 that all of the five countries have exponentially increasing patent counts and their degree centralities increase in a relatively linear way. The US has the highest degree centrality after 2000 due to the fact that the US is the most important market and innovation hub where rigorous R&D activities are usually centered in the US. Japan is traditionally the East Asian country with large number of patents but was surpassed by Taiwan and China in terms of both degree centrality and patent count after 2010. The increasing pattern of Korea in terms of patent count and degree centrality is quite similar to that of the US before 1994 and China before 2004. Taiwan, Korea, China and the US are intertwined together before 2000. This may suggest that Taiwan, China and Korea have a certain degree of similarity among Taiwan, China and Korea in their internationalizing process of industrial development influenced by the US before 2000. However, Taiwan and China deviated from Korea and the two countries intertwined in 2004-2013, the high intensity of co-patenting activities can be evident by stable political interaction and strong economic exchange between Taiwan and China.



1980-1884 (13 countries)

1985-1989 (16 countries)

1990-1994 (24 countries)

1995-1999 (29 countries)

2000-2004 (37 countries)

2005-2009 (42 countries)

2010-2013 (48 countries)

Figure 4. International R&D collaboration network in East Asia

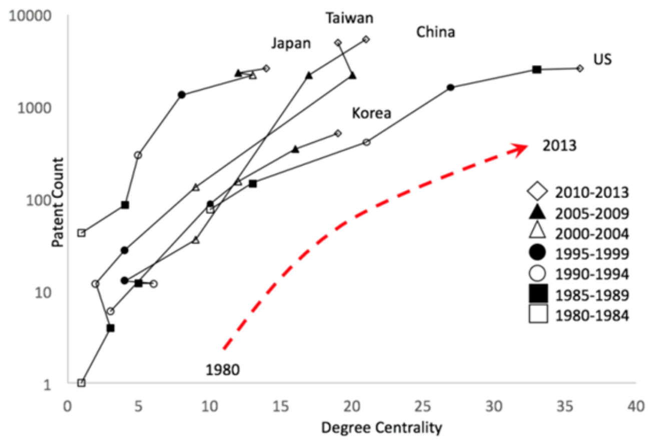


Figure 5. Degree Centrality and Patent Count of East Asian Countries from 1980 to 2013

To focus on the international collaborative patents specifically in East Asia, patent counts of collaborative inventions among Taiwan, Japan, Korea and China are illustrated in Figure 6. The period of 1980-1084 is precluded because there is no collaborative patent in the four countries in this time period. The evolving pattern of international collaborative patents in East Asia can be observed in Figure 6. Collaborative patents are very limited, less than 10 patents, before 1999 but increase to 19 patents between Taiwan and Japan, 21 patents between Korea and Japan in 2000-2004. However, collaborative patents can be found in any pair of the four countries in 2005-2009 and reaches as high as 1,818 patents between Taiwan and China. In 2010-2013, although patent counts of any pair of collaboration increases but it dramatically reaches 4,495 between Taiwan and China. The booming effect between Taiwan and China can not only be observed in technology related co-patenting activities but also other types of interactions such as academic exchange, tourism market between Taiwan and China. From 2008, negotiations between Taiwan and China began to restore transportation, commerce, and communications between the two sides. Therefore, it is expected that co-patenting activities between Taiwan and China is still increasing. The traditional powers dominating industrial development of East Asia has been shifted from the US and Japan to China since 2005.

The above social impact analysis answers to the first question of this study, i.e. how to measure the social impact of international R&D collaboration. International R&D collaboration increases a country's social impact obtained by degree centrality measurement of the international R&D collaboration network. The always increasing degree centralities of the four East Asian countries indicate the stably increasing networking behavior through R&D and patenting. In other words, East Asia has increasing social impact triggered by international collaboration and can be evaluated quantitatively by degree centrality measurement.

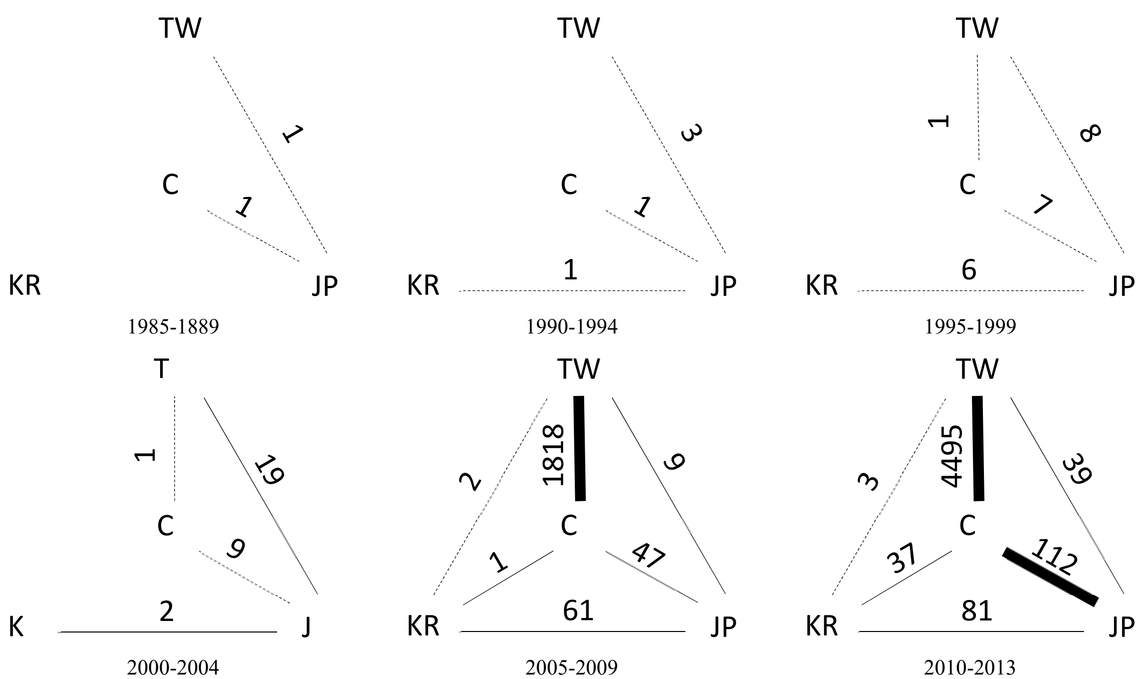


Figure 6. Patent counts of collaborative inventions among Taiwan, Japan, Korea and China (dash line: patent count < 10, thin solid line: patent count between 10 and 100, thick solid line: patent count larger than 100)

VI. LEGAL IMPACT ANALYSIS

In order to answer whether or not international R&D collaboration has positive influence on legal impact, legal impact of collaborative patents and legal impact of non-collaborative patents are compared. If legal impact of collaborative patent is higher than that of non-collaborative patents, it can be suggested that international R&D collaboration has positive influence on legal impact. As previously explained in research method, cross-border patent infringement probability is measured as a proxy to reflect legal impact. Patents with two assignee countries are selected as collaborative patents. Similarly, patents with single assignee country are selected as non-collaborative patents. Table 2 shows the legal impacts of global and East Asian patents with one assignee country or two assignee countries from 1980 to 2013. Three types of comparisons are organized as follows to test if patents with two assignee countries have higher legal impacts than patents with only one assignee country: 1) East Asian patents with two and one assignee country, 2) East Asian patents with and without the US as co-assignee country, 3) Global patents with two and one assignee country,

1) East Asian patents with two and one assignee country

Legal impacts of East Asian patents with two assignee countries and legal impacts of East Asian patents with one assignee country are compared from 1980-2013. It is found that patents co-assigned to two East Asian countries have higher legal impact than patents assigned to only one East Asian country. The case of China and Taiwan is used as an example for detailed comparison. The legal impacts can only be compared in the case of China and Taiwan after 1995 because there is no patent co-assigned to both China and Taiwan before 1995. In 1995-1999, legal impact of patents co-assigned to China and Taiwan (0.0559%) is higher than the legal impact of patents assigned to China (0.0237%) or Taiwan (0.0270%). The same comparison results, which show patents co-assigned to China and Taiwan has higher legal impact than patents assigned to only China or Taiwan, can be observed for the rest time periods from 2000 to 2013.

Similar results can be obtained in the rest pairs of countries, i.e. China and Japan, China and Korea, Japan and Taiwan, Japan and Korea, Korea and Taiwan, where patents co-assigned to two countries have larger legal impacts than patent assigned to only one country. The phenomenon that patents with two assignee countries have larger impacts can be observed in each pair of East Asian countries in each time period with only two exceptions (legal impact of patents co-assigned to Japan and Taiwan (0.0209%) is not larger than the legal impact of patents assigned to Taiwan (0.0227%) or Japan (0.0301%) in 1985-1989, legal impact of patents co-assigned to Japan and Korea (0.0236%) is not larger than the legal impact of patents assigned to Taiwan (0.0229%) or Japan (0.0247%) in 2010-2013). However, the exception in the case of Japan and Taiwan in 1985-1989 is due to the statistical bias caused by the only one patents co-assigned to Japan and Taiwan in 1985-1989. In overall, 23 out of the total available 25 legal impacts of patents co-assigned to two East Asian countries are higher than the legal impacts of corresponding patents assigned to one assignee country confirms that international R&D collaboration in East Asia has positive influence on legal impact.

2) East Asian patents with and without the US as co-assignee country

Legal impacts of patents co-assigned to one East Asian country and the US are compared with the legal impacts of patents assigned to only one East Asian country from 1980 to 2013. It is found that patents co-assigned to one East Asian country and the US have higher legal impact than patents assigned to only one East Asian country. The case of Taiwan and the US is used as an example for detailed comparison. The legal impacts can only be compared in the case of Taiwan and the US after 1985 because there is no patent co-assigned to both Taiwan and the US before 1985. In 1985-1989, legal impact of patents assigned to Taiwan and the US (0.0424%) is higher than the legal impact of patents assigned to Taiwan (0.0227%). In 1990-1994, legal impact of patents assigned to Taiwan and the US (0.0280%) is higher than the legal impact of patents assigned to Taiwan (0.0250%). The same comparison results, which show patents co-assigned to Taiwan and the US has higher legal impact than patents assigned to Taiwan, can be observed for the rest time periods from 1995 to 2013.

Similar results can be obtained in different pairs of co-assignee countries, i.e. Japan and the US, Korea and the US, China and the US, where patents co-assigned to one East Asian country and the US have larger legal impacts than patents assigned to only one East Asian country. The phenomenon can be observed in each pair of countries between East Asia and the US in each time period with only one exception (legal impact of patents co-assigned to China and the US (0.0179%) is not larger than the legal impact of patent assigned to China (0.0298%) in 1990-1994). In overall, 23 out of the total available 24 legal impacts of patent co-assigned to one East Asian country and the US are higher than the legal impacts of corresponding patents assigned to one East Asian country confirms that international R&D collaboration between East Asia and the US has positive influence on legal impact.

3) Global patents with two and one assignee country

Legal impacts of global patents with two assignee countries and legal impacts of global patents with one assignee country are compared. Global patents represent patents assigned to both inside and outside East Asian countries. It is found that legal impacts of global patens with two assignee countries in the seven time periods, i.e. 0.0351% (1980-1984), 0.0404% (1985-1989), 0.0384% (1990-1994), 0.0497% (1995-1999), 0.0472% (2000-2004), 0.0429% (2005-2009), 0.0360% (2010-2013), are all higher

TABLE 2. AVERAGED LEGAL IMPACT BASED ON CROSS-BORDER PATENT INFRINGEMENT PROBABILITY

Assignee Country (Country Count)	Averaged Legal Impact (Cross-border Patent Infringement Probability)							
	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2013	1980-2013
Taiwan (1)	0.0248% (0.00005)	0.0227% (0.00007)	0.0250% (0.00007)	0.0270% (0.00008)	0.0268% (0.00011)	0.0258% (0.00022)	0.0229% (0.00007)	0.0249% (0.00014)
Japan (1)	0.0330% (0.00708)	0.0301% (0.00540)	0.0284% (0.00177)	0.0300% (0.00092)	0.0290% (0.00029)	0.0265% (0.00028)	0.0224% (0.00017)	0.0274% (0.00232)
Korea (1)	0.0232% (0.00004)	0.0238% (0.00006)	0.0252% (0.00007)	0.0265% (0.00054)	0.0284% (0.00017)	0.0279% (0.00009)	0.0247% (0.00009)	0.0263% (0.00019)
China (1)	0.0252% (0.00003)	0.0272% (0.00016)	0.0298% (0.00026)	0.0237% (0.00012)	0.0229% (0.00011)	0.0252% (0.00011)	0.0222% (0.00008)	0.0229% (0.00009)
China, Taiwan (2)	-	-	-	0.0559%*	0.0509%*	0.0396% (0.018%)	0.0362% (0.014%)	0.0368% (0.015%)
China, Japan (2)	-	0.0359%*	0.0349%*	0.0310% (0.024%)	0.0460% (0.028%)	0.0407% (0.030%)	0.0327% (0.015%)	0.0352% (0.021%)
China, Korea (2)	-	-	-	-	-	0.0427% (0.022%)	0.0310% (0.014%)	0.0335% (0.016%)
Japan, Taiwan (2)	-	0.0209%*	0.0295% (0.025%)	0.0400% (0.016%)	0.0327% (0.017%)	0.0458% (0.017%)	0.0360% (0.023%)	0.0408% (0.019%)
Japan, Korea (2)	-	-	0.0449%*	0.0349% (0.017%)	0.0518% (0.019%)	0.0283% (0.017%)	0.0236% (0.026%)	0.0292% (0.024%)
Korea, Taiwan (2)	-	-	-	-	-	0.0544% (0.012%)	0.0569%*	0.0552% (0.009%)
Taiwan, US (2)	-	0.0424% (0.004%)	0.0280% (0.013%)	0.0366% (0.015%)	0.0416% (0.020%)	0.0400% (0.017%)	0.0319% (0.016%)	0.0351% (0.017%)
Japan, US (2)	0.0337% (0.019%)	0.0408% (0.020%)	0.0413% (0.025%)	0.0593% (0.046%)	0.0572% (0.033%)	0.0545% (0.034%)	0.0411% (0.021%)	0.0517% (0.034%)
Korea, US (2)	-	-	0.0441% (0.032%)	0.0649% (0.050%)	0.0555% (0.046%)	0.0398% (0.024%)	0.0294% (0.017%)	0.0414% (0.034%)
China, US (2)	-	0.0419%*	0.0179% (0.009%)	0.0331% (0.022%)	0.0420% (0.024%)	0.0281% (0.014%)	0.0278% (0.011%)	0.0289% (0.014%)
All countries (1)	0.0280% (0.00339)	0.0310% (0.00474)	0.0316% (0.00266)	0.0354% (0.00367)	0.0333% (0.00199)	0.0296% (0.00096)	0.0246% (0.00075)	0.0302% (0.00251)
All countries (2)	0.0351% (0.00042)	0.0404% (0.00051)	0.0384% (0.00025)	0.0497% (0.00051)	0.0472% (0.00039)	0.0429% (0.00029)	0.0360% (0.00023)	0.0411% (0.00033)

(Standard Deviation), *Standard Deviation not is available because Patent Count=1

TABLE 3. RANKING OF COLLABORATION EFFICIENCY BASED ON LEGAL IMPACT CALCULATION.

Ranking of Collaboration Efficiency	Taiwan	Japan	Korea	China
1	Korea* (0.0552%)	US (0.0517%)	Taiwan* (0.0552%)	Taiwan* (0.0368%)
2	Japan (0.0408%)	Taiwan* (0.0408%)	US (0.0414%)	Japan (0.0352%)
3	China (0.0368%)	China (0.0352%)	China (0.0335%)	Korea (0.0335%)
4	US (0.0351%)	Korea (0.0292%)	Japan (0.0292%)	US (0.0289%)

*Best East Asian Collaboration Partner, (Legal Impact)

than the legal impacts of global patents with only one assignee country, 0.0280% (1980-1984), 0.0310% (1985-1989), 0.0316% (1990-1994), 0.0354% (1995-1999), 0.0333% (2000-2004), 0.0296% (2005-2009), 0.0246% (2010-2013). The higher legal impacts of global patent with two assignee countries than that of one assignee country indicates global international R&D collaboration has positive influence on legal impact.

The above legal impact analysis answers to the second question of this study, i.e. Does international R&D collaboration have positive influence on legal impact. Internationally collaborative patents generate higher cross-border patent infringement probability than non-collaborative patents. In other words, International R&D collaboration shows positive influence on legal impact. Furthermore, the above legal impact analysis shows that different collaboration countries leads to varying legal impacts. Comparing with the legal impacts of patents with two assignee countries, possible implications related to collaboration efficiency as well as identifying collaboration partner can be derived. The higher legal impact suggests greater collaboration efficiency and thus more potential partnership between the two countries. Table 3 shows the ranking of collaboration efficiency based on legal impact calculation. It can be observed in Table 3 that the best East Asian partner for Taiwan, Japan, Korea and China are Korea, Taiwan, Taiwan and Taiwan, respectively. This reveals the important role of Taiwan in internationalization of R&D in East Asia.

VII. CONCLUSION

This study demonstrates methods to assess social and legal impact of international R&D collaboration and confirms that international R&D collaboration does have positive influence on both social and legal impact. Degree centrality of social network theory substantially describes the social impact generated by international R&D collaboration. Also, cross-border patent infringement probability measurement shows that legal impact of internationally collaborative patents than that of non-collaborative patents.

In addition to answering the two questions regarding social impact and legal impact, dynamics of multi-national R&D in East Asia is investigated in this study. The results show that China and Taiwan are the most prolific and fastest-growing patenting countries but Korea is not active in R&D collaboration with East Asian countries. Japan's slower patent growth rate is consistent to the observation that Japan's R&D in Asia is aimed at assisting their strong manufacturing presence and is focused on adaptive R&D rather than patentable inventions [62]

With regard to social impact, the four East Asian countries show a gradual increase of social impact over time. By examining patent count and degree centrality, Figure 5, Taiwan, China, Korea and the US are intertwined together before 2000. This may suggest that Taiwan, China and Korea have a certain degree of similarity in terms of their internationalizing processes of industrial developments influenced by the US before 2000. Taiwan and China deviated from Korea and the intertwined together in 2004-2013. The strong relationship or mutual dependence between Taiwan and China are resulted from stable political interaction and strong economic exchange between Taiwan and China.

Legal impact analysis suggests that international R&D collaboration generates patents with higher social impact than single assignee country patents. It is found in this study that the legal impacts of the four East Asian countries do not generally increase over time. The collaboration partner leads to varying legal impact. Comparing with the legal impacts of patents with two assignee countries, the best selection of partner country for generating largest legal impact can be identified. The best East Asian partner for Taiwan, Japan, Korea and China are Korea, Taiwan, Taiwan and Taiwan, respectively. This reveals the important role of Taiwan in internationalizing R&D.

A. Management Implication

Previous studies support the positive impacts of collaborative R&D. However, the impacts investigated in literature are either not clearly defined or largely focus on business or technological impact. This study fills the research gap by demonstrating how social impact and legal impact can be measured in international R&D collaboration within East Asian countries, i.e. Taiwan, Japan, Korea and China. The increasing social impact indicates East Asian countries are likely to internationalize R&D to enhance competitive advantages by obtaining foreign resource or knowledge to complement existing capability of home country. The higher legal impact generated by international R&D collaboration not only indicates higher patent value but also suggests higher probability of product commercialization as well as propensity of international trading activities. East Asian countries absorb know-how from each other and enhance their learning capabilities through East Asia's R&D network in order to obtain patents with higher legal impacts for protecting products to be internationalized commercialized.

B. Limitation and Future Study

R&D activities generate inventions which are generally protected by patents. Patents seem to be a good proxy of inventions [63]. However, the use of USPTO patent as proxy for understanding East Asian international R&D collaboration in this study leads to following research limitations. First, patent data do not fully reflect firms' actual R&D activity. Some firms might keep their technological know-how as classified information or unsuccessful results are not submitted to the Patent Office [64]. Also, SMEs might not have sufficient resource to file patents. Therefore, patent may not be chosen as a mean for SME in deterring imitation and constructing defensive blockades [65]. Second, international R&D results from many types of business activities, e.g. outsourcing, licensing, join-venture, co-patenting activities, and scientific collaborations. This study investigates international R&D only based on co-patenting activities without considering which type of business activities involved. Third, East Asian countries may not file patent applications with the USPTO and thus lead to possible bias when measuring patenting activities. Fourth, the legal impact measured in this study is only based on the probability of cross-border patent infringement investigated by the International Trade Commission in the US without considering patent infringements in other countries. Therefore, some research directions are suggested for future works. For example: 1) choose EPO or JPO as patent data sources, 2) differentiate international R&D results from different business activities, e.g. outsourcing, licensing, join-venture, co-patenting activities, and scientific collaborations, 3) consider legal impact outside the US, 4) investigate how patent's assignee country sequence influences social impact and legal impact.

ACKNOWLEDGEMENTS

The authors would like to thank National Science Council of Republic of China, Taiwan, for the financial support under the contract: MOST 103-2410-H-005-058-MY3

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