



University-Industry Knowledge Collaboration in Chinese Water Pollution Abatement Technology Innovation System

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ABSTRACT

University-industry knowledge collaboration is one of the keys to overcoming the current development bottleneck in water pollution abatement technology in China. To explore university-industry knowledge collaboration in Chinese water pollution abatement technology innovation system, characteristics and dynamic evolution law of knowledge collaboration were analyzed by using patent data from China for the period 2000-2018. Results show that university-industry knowledge collaboration continues to increase and experiences three development phases in Chinese water pollution abatement technology innovation system. University-industry knowledge collaboration in each province (city) keeps growing and the difference between provinces (cities) is decreasing, but the difference remains significant. The scale, scope, and depth of inter-regional university-industry knowledge collaboration continue to increase, but they are still not large enough. Although the scale and linking efficiency of university-industry knowledge collaboration improve significantly, the subgroups are too many and the agglomeration degree of networks is low.

Nat. Env. & Poll. Tech.

Website: www.neptjournal.com

Received: 05-05-2020

Revised: 17-06-2020

Accepted: 12-07-2020

Key Words:

Water pollution abatement

Knowledge collaboration

Patent

Social network analysis

INTRODUCTION

Water Pollution Abatement (WPA) plays a major role in ensuring water security, preserving ecosystems, and supporting sustainable development. Thus, most countries pay great attention to the development of WPA technology, the patents of which account for approximately 1% of overall patents. As a country with high water stress and serious water pollution, China has been increasing investments in WPA technology innovation in the past two decades. Today, China has the third largest share in global WPA patented inventions. However, high-value WPA technologies from China account for only 3.7% (Proskuryakova et al. 2018). Hence, for China to address the increasing WPA stress, greater efforts must be made to innovation more high-value WPA technologies.

Aside from increasing investment in R&D, greater importance must be attached to the development of knowledge collaboration in Chinese WPA technology innovation system to overcome the innovation bottleneck. Knowledge collaboration refers to activities such as co-development, co-authorship, and collaborative R&D (McKelvey et al. 2003) and it is widely acknowledged as an important vehicle for technology diffusion and technology innovation in any innovation system (Ye et al. 2008, Dooley et al. 2016). Innovation system theory claims that technology innovation is essentially the result of collective knowledge development.

Firms and universities are two of the most important actors in national and industrial innovation systems. Triple helix theory highlights that industry, university, and government interact to enhance innovation (Etzkowitz et al. 1996). Knowledge collaboration among industry, university, and research institution not only leads to innovation benefits directly but also improves the marginal contribution of “division of knowledge” (Yu et al. 2017). In this sense, knowledge collaboration between university and industry (hereafter UI knowledge collaboration) is one of the keys to Chinese high-value WPA technology innovation.

Previous literature has analyzed WPA technology innovation in China. The patents on WPA technology in China have been increasing rapidly since 2007, and currently, China has become one of the top WPA inventor countries (Tan et al. 2019). Most of the applicants in Chinese WPA technology domain are from those more economically-developed regions such as Jiangsu, Beijing and so forth (Yang et al. 2016). In addition, amongst all the applicants, universities account for the largest share in China’s overall WPA technology patents (Wang et al. 2013). At the same time, studies have been conducted on knowledge collaboration analysis in China (Ma et al. 2011, Lei et al. 2011) and in some technology domains such as ICT and new energy vehicles (Gao et al. 2016, Cao et al. 2019). However, little attention is given to knowledge collaboration in the WPA technology domain. This study analyzes the characteristics and evolution of UI

knowledge collaboration in Chinese WPA innovation system and contributes to WPA technology innovation literature as well as knowledge collaboration literature.

METHODOLOGY

Patent Statistics and Social Network Analysis

Patents contain rich information, such as technology field, applicant, and priority, which are easy to access. The statistics and analysis of patent data can yield numerous useful and relevant information or knowledge. Co-application for a patent between a university and a firm is a major form of UI knowledge collaboration. Hence, this study uses patent data and a series of patent indicators to analyze UI knowledge collaboration in Chinese WPA innovation system.

Social network analysis (SNA) is a visualization technique used to analyze networks that consist of a set of nodes and links. A node can be a person, an institute, or a region, whereas links represent relationships between two adjacent nodes. SNA can depict how nodes link with one other directly and indirectly in qualitative and quantitative

ways. This study constructs several UI knowledge collaboration networks and then analyzes their characteristics and evolution.

Data

This study uses a search strategy developed by OECD (Table 1) to search the patent database of the State Intellectual Property Office of China for WPA technology patents that are co-applied by Chinese universities and firms. Only patents for inventions are considered for their high level of innovation. The time horizon is set from 2000 to 2018, and the locations of applicants are limited to 31 Chinese provincial administrative regions, which consist of 27 provinces and 4 cities, excluding Hong Kong, Macao, and Chinese Taipei.

2,024 patents that meet the requirements are collected. Between 2000 and 2018, the scale of UI co-application for WPA technology patent in China keeps expanding year by year, and its growth rate is almost the same with that of the overall applications for WPA technology patents in China (Fig. 1).

Table 1: IPC Class/Code of WPA Technologies.

| IPC Class/Code | Description |
|----------------|---|
| B63B35/32 | Vessels or like floating structures adapted for special purposes- for collecting pollution from open water |
| B63J4 | Arrangements of installations for treating waste-water or sewage |
| C02F | Treatment of water, wastewater, sewage, or sludge |
| C05F7 | Fertilizers from wastewater, sewage sludge, sea slime, ooze, or similar masses |
| C09K3/32 | Materials for treating liquid pollutants, e.g. oil, gasoline or fat |
| E02B15/04-10 | Devices for cleaning or keeping clear the surface of open water from oil or like floating materials by separating or removing these materials |
| E03C1/12 | Plumbing installations for wastewater |
| E03F | Sewers-Cesspools |

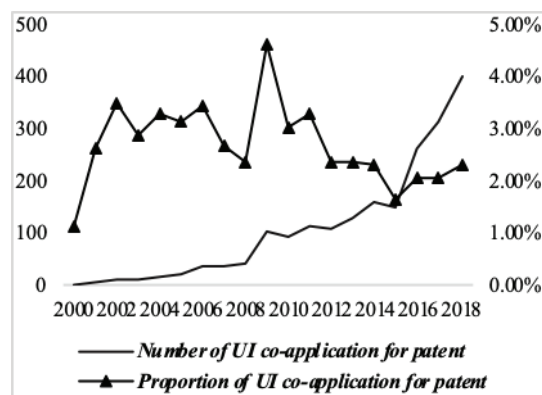


Fig. 1: Chinese UI Co-application for Patent in WPA Technology, 2000-2018.

RESULT ANALYSIS

Overall Trend in UI Knowledge Collaboration

In Chinese WPA technology innovation system, the scale of UI knowledge collaboration continues to expand in terms of actors, ties, and activities between 2000 and 2018, with a growth rate of approximately 30% (Fig. 2).

Furthermore, the development of UI knowledge collaboration in Chinese WPA technology innovation system is in three phases (Table 2). Phase I is the initial stage. In this phase, the scale of UI knowledge collaboration is small, whereas the growth rate is approximately 40%. At the end of Phase I, the scale of UI knowledge collaboration experienced a surge in 2009, and then began to grow slowly at a speed of approximately 8% until 2015, that is phase II. In phase II (2009-2015), the scale of UI knowledge collaboration is four times larger than that in phase I, but the growth rate is only about a fifth of that in phase I. After phase II, the scale of UI knowledge collaboration experienced a surge again in 2016, which is the beginning of phase III (2016-2018). In phase III, not only the scale is much higher than that in the two previous phases, but the growth rate is also higher.

The Geography of UI Knowledge Collaboration

Knowledge collaboration can be categorized as intra-regional or inter-regional according to whether actors are located in

the same region. In Chinese WPA technology innovation system, intra-regional UI knowledge collaboration accounts for more than 70% of overall UI knowledge collaboration. This figure indicates that actors prefer to collaborate with partners who are close to them. First, as shown in Table 3, the top provinces (cities) account for more than 76% of overall intra-regional UI knowledge collaboration. These regions are basically the regions with high economic level and where several universities are located. Second, the commutative share of the top provinces (cities) in intra-regional UI knowledge collaboration has been declining from phase I to phase III. This trend indicates that UI knowledge collaboration is thriving in other regions. Third, the difference among the top provinces (cities) has been decreasing from phase I to phase III on the whole. Finally, from phase I to III, the ranks of Jiangsu, Guangdong, and Beijing have grown steadily, and they have become the top 3 in phase III. Shandong, Hunan, and Chongqing have enjoyed the most rapid growth in intra-regional UI knowledge collaboration, resulting in a great leap in their ranks. Shanghai, Zhejiang, and Tianjin are the three provinces (cities) whose ranks have been declining, indicating that their development in intra-regional UI knowledge collaboration is slow.

Despite a lower share in overall UI knowledge collaboration, inter-regional UI knowledge collaboration plays a critical role in facilitating technology diffusion in the whole innovation system. Inter-regional UI knowledge

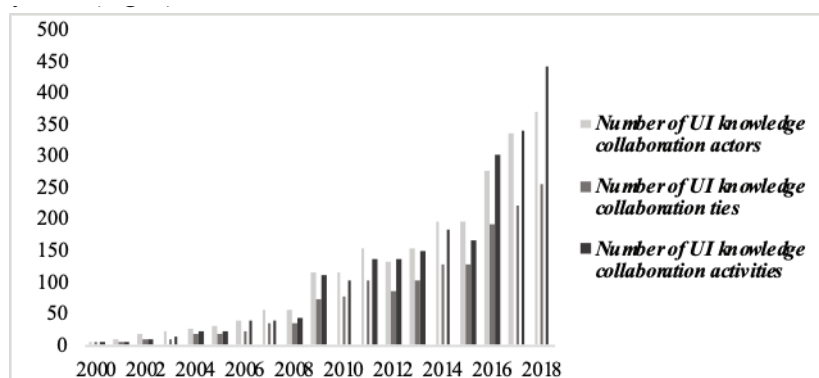


Fig. 2: UI knowledge collaboration in Chinese WPA technology innovation system, 2000-2018.

Table 2: Scale and growth rate of UI knowledge collaboration in each phase.

| Phases | Number of UI knowledge collaboration actors | | Number of UI knowledge collaboration ties | | Number of UI knowledge collaboration activities | |
|-----------------------|---|-------------|---|-------------|---|-------------|
| | Average | Growth rate | Average | Growth rate | Average | Growth rate |
| Phase I (2000–2008) | 29 | 39.08% | 18 | 43.01% | 23 | 47.98% |
| Phase II (2009–2015) | 153 | 9.16% | 100 | 9.46% | 141 | 7.21% |
| Phase III (2016–2018) | 327 | 15.78% | 223 | 15.70% | 361 | 21.18% |

Table 3: Top provinces/cities in intra-regional UI knowledge collaboration.

| Phases | Regions | UI knowledge collaboration activities | | | UI knowledge collaboration ties | | |
|--------------------------|-----------|---------------------------------------|--------|-------------------|---------------------------------|--------|-------------------|
| | | Number | Share | Commutative share | Number | Share | Commutative share |
| Phase I (2000–2008) | Shanghai | 41 | 29.50% | 29.50% | 28 | 28.28% | 28.28% |
| | Jiangsu | 38 | 27.34% | 56.83% | 16 | 16.16% | 44.44% |
| | Guangdong | 12 | 8.63% | 65.47% | 12 | 12.12% | 56.56% |
| | Zhejiang | 11 | 7.91% | 73.38% | 8 | 8.08% | 64.64% |
| | Beijing | 10 | 7.19% | 80.58% | 10 | 10.10% | 74.74% |
| | Hubei | 5 | 3.60% | 84.17% | 5 | 5.05% | 79.80% |
| | Tianjin | 5 | 3.60% | 87.77% | 5 | 5.05% | 84.85% |
| | Yunnan | 4 | 2.88% | 90.65% | 3 | 3.03% | 87.88% |
| | Anhui | 2 | 1.44% | 92.09% | 2 | 2.02% | 89.90% |
| | Guangxi | 2 | 1.44% | 93.53% | 1 | 1.01% | 90.91% |
| Phase II (2009–2015) | Jiangsu | 150 | 21.55% | 21.55% | 78 | 20.05% | 20.05% |
| | Shanghai | 103 | 14.80% | 36.35% | 44 | 11.40% | 31.51% |
| | Beijing | 97 | 13.94% | 50.29% | 40 | 10.36% | 41.93% |
| | Guangdong | 75 | 10.78% | 61.06% | 46 | 11.92% | 53.90% |
| | Zhejiang | 45 | 6.47% | 67.53% | 29 | 7.51% | 61.46% |
| | Shandong | 34 | 4.89% | 72.41% | 15 | 3.89% | 65.36% |
| | Hubei | 26 | 3.74% | 76.15% | 20 | 5.18% | 70.57% |
| | Tianjin | 26 | 3.74% | 79.88% | 20 | 5.18% | 75.52% |
| | Hunan | 17 | 2.44% | 82.33% | 7 | 1.81% | 77.34% |
| | Anhui | 14 | 2.01% | 84.34% | 12 | 3.11% | 80.47% |
| Phase III (2016–2018) | Jiangsu | 160 | 19.88% | 19.88% | 78 | 18.06% | 18.06% |
| | Guangdong | 98 | 12.17% | 32.05% | 52 | 12.04% | 30.10% |
| | Beijing | 71 | 8.82% | 40.87% | 44 | 10.19% | 40.28% |
| | Shandong | 62 | 7.70% | 48.58% | 37 | 8.56% | 48.85% |
| | Shanghai | 56 | 6.96% | 55.53% | 29 | 6.71% | 55.56% |
| | Hubei | 55 | 6.83% | 62.36% | 30 | 6.94% | 62.50% |
| | Hunan | 37 | 4.60% | 66.96% | 26 | 6.02% | 68.52% |
| | Chongqing | 28 | 3.48% | 70.44% | 13 | 3.01% | 71.53% |
| | Zhejiang | 25 | 3.11% | 73.54% | 20 | 4.63% | 76.16% |
| | Anhui | 22 | 2.73% | 76.28% | 8 | 1.85% | 78.01% |

collaboration also enhances innovativeness due to greater cognitive diversity. Fig. 3 shows the geographic distribution of inter-regional UI knowledge collaboration. In phase I, the scale of inter-regional UI knowledge collaboration network is relatively small, with only 23 nodes and 46 links (weighted). Moreover, 82.61% of links (weighted) are focused on only four nodes, that is, Beijing, Shanghai, Jiangsu, and Tianjin. These four provinces (cities) are the centres in inter-regional UI knowledge collaboration in phase I. In phase II, the inter-regional UI knowledge collaboration network

consists of 27 nodes and 193 links (weighted). This result means that the scope, scale, and depth of inter-regional UI knowledge collaboration significantly increase in this phase. Additionally, more local hubs are found in the network, with 10 nodes whose degree values are above 7, indicating that more provinces (cities) have become centres of inter-regional UI knowledge collaboration. In phase III, inter-regional UI knowledge collaborations are distributed across more provinces (cities). Meanwhile, the links (weighted) are far more than that in phase II,

considering the time horizon. The number of nodes with degree values above 7 is still 10.

Evolution of UI Knowledge Collaboration Network

To demonstrate how universities and firms interact with each other, the UI knowledge collaboration network in each phase is constructed (Fig. 4). In UI knowledge collaboration network, a node represents a university or a firm engaged in knowledge collaboration, and a link represents knowledge collaboration ties between a university and a firm. The size of a node indicates its degree value, and the strength of a link indicates its weighted value.

It further uses SNA indicators, like scale, degree, K-core, and length to illustrate characteristics and evolution of UI knowledge collaboration networks in Chinese WPA technology innovation system (Table 4).

Firstly, as shown in Figure 4 and Table 4, the scale of UI knowledge collaboration keeps expanding from phase

I to phase III. In phase I, nodes and links (weighted or unweighted) are comparatively few, and many links are isolated. Moreover, the nodes of the main component account for only 16% of all nodes. Hence, UI knowledge collaboration network in phase I is characterized by a small scale and low density. In phase II, the scale of the UI knowledge collaboration network increases significantly from phase I, and the nodes of its main component account for 40% of all nodes. In phase III, the scale of UI knowledge collaboration network and its main component further expand, and links among nodes become denser.

Secondly, the overall agglomeration degree of networks in each phase is relatively low. On one hand, the average degree of nodes is below 2, indicating that knowledge collaboration among actors is not wide. On the other hand, no significant change occurs in k-core, which means that knowledge collaboration among actors lacks diversity. According to network theory and social capital theory, networks with high agglomeration degree

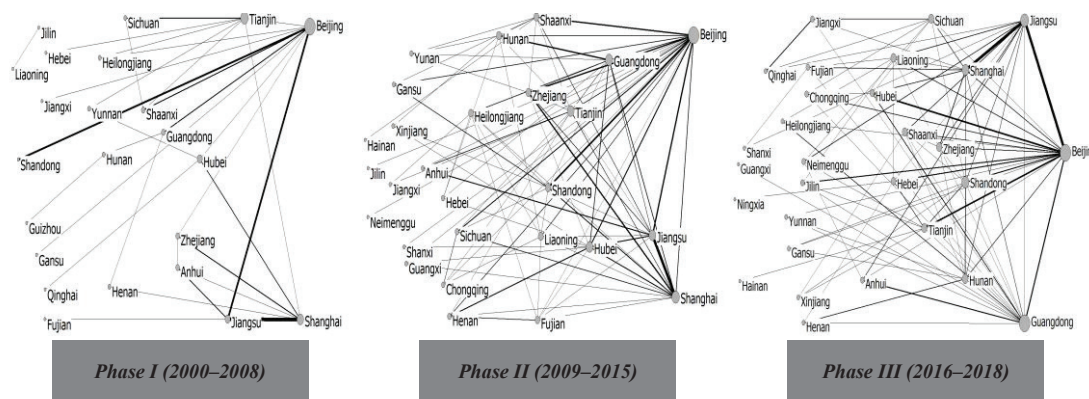


Fig. 3: Inter-regional UI knowledge collaboration network in each phase.

Table 4: Indicators of UI knowledge collaboration networks in each phase.

| Indicators | Phase I | Phase II | Phase III |
|----------------------------|----------------|-----------------|-----------------|
| Number of nodes | 195 | 695 | 786 |
| Number of links | 145 | 580 | 615 |
| Number of links (weighted) | 204 | 987 | 1,082 |
| Average degree | 1.49 | 1.67 | 1.56 |
| K-core | 2 | 2 | 2 |
| Number of components | 51 | 124 | 147 |
| Scale of main component | 32 (16.41%) | 280 (40.29%) | 362 (46.01%) |
| Diameter of main component | 4 | 21 | 32 |

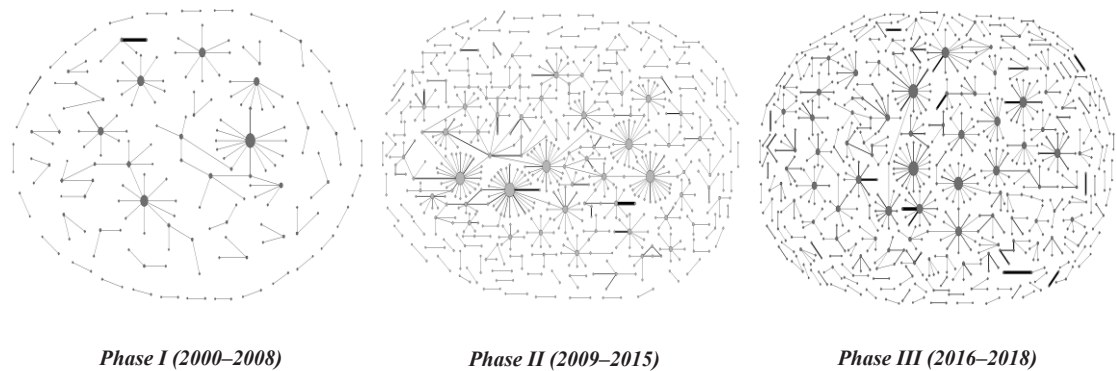


Fig. 4: UI Knowledge collaboration network in each phase.

and density perform better in knowledge exchange and knowledge creation.

Finally, the linking efficiency of the network continues to improve from phase I to phase III. The main component is the largest subgroup in the network, in which all nodes are linked either directly or indirectly. Thus, knowledge and information exchange among actors in the main component are most fluent and intensive. As seen in Table 4, the scale of the main component increases from 32 (16.41%) to 362 (46.01%) from phase I to phase III. The diameter of the main component is another indicator of the connectedness of nodes, and it increases from 4 to 32 from phase I to phase III. The improvement in linkage efficiency is expected to facilitate knowledge flow in UI knowledge collaboration network, thereby enhancing knowledge creation. A superior network is conducive to knowledge exchange in large scope and with high speed, thereby generating scale effect, complementary effect, and cross-fertilization effect of knowledge creation (Pyka 2002).

CONCLUSIONS

UI knowledge collaboration in Chinese WPA technology innovation system based on patent data was investigated and analyzed. The main conclusions are as follows:

Firstly, between 2000 and 2018, UI knowledge collaboration in Chinese WPA technology innovation system is in three phases. Phase I is characterized by a low level and high growth rate. Phase II is characterized by a moderate scale and low growth rate. Phase III is characterized by a high level and moderate growth rate.

Secondly, UI knowledge collaboration is mainly distributed in a few provinces (cities) that are characterized by high economy and several universities, whereas other

provinces (cities) fall behind those top provinces (cities) in the development of UI knowledge collaboration. However, the difference between provinces (cities) decreases from phase I to III, indicating that UI knowledge collaboration is thriving in more regions. Also, the growth pace of provinces (cities) in UI knowledge collaboration varies. Among the top provinces (cities), the ranks of Jiangsu, Guangdong, and Beijing grow steadily, and they have become the top 3 in phase III. Shandong, Hunan, and Chongqing enjoy the most rapid growth in intra-regional UI knowledge collaboration, resulting in a great leap in their ranks. Shanghai, Zhejiang, and Tianjin are three provinces (cities) whose ranks are declining, indicating that their development in intra-regional UI knowledge collaboration is slow.

Thirdly, despite a low share in the overall UI knowledge collaboration, inter-regional UI knowledge collaboration keeps developing from phase I to III. The scale, scope, and depth of inter-regional knowledge collaboration increase significantly, and the geographic distribution becomes wider. Inter-regional UI knowledge collaboration plays a significant role in facilitating knowledge exchange in the whole innovation system.

Finally, from phase I to III, not only the scale keeps growing, but also the linking efficiency of UI knowledge collaboration network. This trend indicates that the UI knowledge collaboration network in Chinese WPA technology innovation system is developing and upgrading. However, the agglomeration degree and the connectedness of UI knowledge collaborative network are low, which limits knowledge diffusion and exchange among universities and firms.

ACKNOWLEDGEMENT

This study is supported by the Chinese National Natural Science (No. 71372201).

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