



# Comprehensive metrological and content analysis of the public–private partnerships (PPPs) research field: a new bibliometric journey

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## Abstract

Studies around public–private partnerships (PPPs) have shaped a complex and colorful research field. A series of review studies have been performed to explore the knowledge base of this field. Despite their significant contributions, bibliometric research on the PPPs literature is still needed to capture more comprehensive, diverse and detailed information in this area from a holistic perspective, for reducing subjectivity and one-sidedness. Under this situation, this paper continues the bibliometric journey by conducting a comprehensive metrological and content analysis of the PPPs research field. By applying a newly developed Bibliometrix R-package tool, the overview of PPPs research is presented via metrological analysis using a series of indexes. The intellectual structure of this domain is then explored via content analysis using the methods of keywords analysis and citation analysis from both static and dynamic perspectives. Consequently, the panoramic view including the overview, pivotal points of topics, thematic evolution and research focuses of this domain are depicted visually and intuitively via a set of science maps. This new attempt crystallizes out key findings and valuable information of PPPs research, which can consolidate and broaden the bibliometric findings of previous PPPs literature studies and act as a guidance for analyzing the knowledge base of other research fields.

**Keywords** Public–private partnerships (PPPs) · Bibliometric research · Metrological analysis · Content analysis · Intellectual structure · Bibliometrix

## Introduction

With the advantage to promote the quality and efficiency of the delivery of public infrastructure and services, public–private partnerships (PPPs) has been globally and broadly applied to a variety of projects including transportation, energy, water and sewage, public health, environment protection and so on (Wang et al. 2018). Meanwhile, it has also attracted wide attention of scholars from different research fields in recent decades (Button 2016; Quelin et al. 2019; Xiong et al. 2018). Research interest around PPPs has given rise

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to a rapidly growing number of publications and a diversity of research topics, approaches and subdomains (Cui et al. 2018), shaping a PPPs research field.

Up to present, despite considerable research into the PPPs field, a great deal of controversy exists in this field due to a variety of problems such as inappropriate risk transfer, complex negotiation, unfair benefit allocation, time consuming and high cost tendering, and conflicts among stakeholders (Akintoye et al. 2003; Jin 2010a; Liu and Cheah 2009; Sharafi et al. 2018; Xiong and Zhang 2016; Zhang 2004). These topics were studied by scholars from different disciplines ranging from *Management Science* to *Public Administration* and *Economics* (Spielman et al. 2010), hence voluminous, fragmented and controversial research streams have been formed (Weihe 2008), making the PPPs research field complex and colorful.

The existing body of knowledge on PPPs provides opportunity for researchers to explore the PPPs research field from different perspectives on the basis of previous publications, which is important for unveiling the true appearance of this domain and helping researchers better understand the status quo and future trends of PPPs related topics and focus their studies more effectively (Ke et al. 2009). Historically, some prior studies have attempted to analyze the previous papers to explore the PPPs research field. These studies can be classified into two types (qualitative and quantitative review studies). Among the qualitative PPPs review studies, Weihe (2008) identified four approaches (i.e. the infrastructure approach, the urban regeneration approach, the development approach and the policy approach) around PPPs through an inductive review of the PPPs literature. Ke et al. (2009) conducted a two-stage review of the PPPs related articles published from 1998 to 2008 in seven construction journals, and identified the research trends of the PPPs field. Via a thorough review of 20-years PPPs related research, Kwak et al. (2009) discussed the definitions, types, obstacles and benefits, and examples of worldwide applications of PPPs. Tang et al. (2010) systematically reviewed the PPPs research published in six top construction journals and provided some insights for guiding further PPPs study. Papajohn et al. (2011) provided an overview of the studies on American transportation PPPs in the domains of law, economics and public opinion. Andon (2012) derived five research themes of PPPs research via an analysis of the PPPs literature published up to December 2010. Osei-Kyei and Chan (2015) conducted a three-stage review of the studies on the critical success factors (CSFs) for PPPs from 1990 to 2013, and provided a CSFs checklist for PPPs. Zhang et al. (2016) carried out a comparative review of PPPs publications searched from the International and Chinese journals through statistical analysis and content analysis. Bao et al. (2018) reviewed the PPPs literature and analyzed the status and possible future research from a project lifecycle perspective.

In recent years, to supplement the existing qualitative reviews of PPPs research, scholars have also explored the PPPs field through quantitative support such as meta-analysis and bibliometric analysis. Among these quantitative studies, Marsilio et al. (2011) applied a bibliometric method to the published PPPs research and outlined four main subfields constituting the intellectual structure of the PPPs field. Chen et al. (2016) analyzed 95 empirical studies selected from a PPPs research database and examined the impact of PPPs data on each research theme by using a meta-analysis. Castro e Silva Neto et al. (2016) used a bibliometric analysis to perform a quantitative review of PPPs and private finance initiatives (PFIs) papers published from 1990 to 2014. Song et al. (2016) conducted a bibliometric review on global PPPs research from January 2000 to July 2015 through the CiteSpace software, and identified the hot topics and essential emerging trends of PPPs. By means of social network analysis, Wang et al. (2018) carried out a systematic literature review on PPPs studies published in journals of the *Public Administration* discipline, and

identified four main topics in this discipline. Cui et al. (2018) implemented a three-stage word frequency analysis and cluster analysis on the PPPs literature for infrastructure projects, and derived six main PPPs research topics. Song et al. (2019) applied a bibliometric approach using the CiteSpace software to conduct cluster analysis and burst analysis of PPPs research over the last 20 years, and summarized some emerging trends of the PPPs field. Narbaev et al. (2020) also performed a bibliometric meta-review on extensive PPPs literature from different disciplines.

A summary of the abovementioned PPPs review studies is presented in Table 1. As regards the qualitative PPPs review studies (ID: 1–9), notwithstanding the value of them in providing insights into PPPs, these traditional labor literature reviews are primarily depended on subjective and qualitative analysis and limited to specific areas (e.g. Construction engineering and management, Economics, law, and public opinion, Accounting), which are not enough for precisely and comprehensively presenting the overall knowledge structure and various streams of PPPs studies (Song et al. 2019). The quantitative literature studies (ID: 10–17) revealed the details of the PPPs research field from different angles, which are of significant contributions for understanding the PPPs research field.

Amongst previous quantitative literature studies of PPPs, Chen et al. (2016) conducted a meta-analysis by using multinomial regressions and only focused on the data characteristics of empirical transportation PPPs research. The rest of quantitative PPPs literature studies (ID: 11–17) are all based on bibliometric analysis. Wang et al. (2018) discussed PPPs limited to a specific area (the public administration domain), and Cui et al. (2018) only concentrated on a specific type of PPPs project (the infrastructure PPPs project) mainly from the perspective of project management. These two studies have a certain degree of one-sidedness and lack multidisciplinary scrutiny of the PPPs field. Marsilio et al. (2011) provided a cross-disciplinary view on the intellectual structure of PPPs research field. However, they merely applied bibliometric techniques of citation and author co-citation analysis, and only identified cited works and authors of PPPs publications. Castro e Silva Neto et al. (2016) presented some basic information of the research on PPPs and PFIs including the evolution of the quantity of papers, the main publishing journals, research areas, geographic scope, project sector, and topics, using only number of papers as a measurement criterion. These two papers partially presents the knowledge state of the PPPs domain. To provide a holistic analysis of this field, Song et al. (2016) adopted Citespace to examine a massive amount of PPPs literature using co-author, co-word, co-citation and cluster analyses. Based on Song et al. (2016), Song et al. (2019) expanded the cluster analysis by detailed and in-depth investigation of the representative documents in each cluster to clarify the intellectual structure and knowledge domains of PPPs field. Narbaev et al. (2020) ranked top journals in the PPPs field through some objective bibliometric measures (citation-based metrics) and identified main topics and research domains of this field by using keyword frequency analysis and keyword relevance scoring. These three recently published papers intuitively presented comprehensive insights into the intellectual structure of PPPs research through science mapping analysis. Nevertheless, it doesn't mean that all the details worth exploring in this field have been covered. We believe multi-disciplinary bibliometric research on the PPPs literature is still needed for researchers to capture more comprehensive, diverse and detailed information in this area. To serve as a complement of previous bibliometric studies, this paper attempts to continue the bibliometric journey to explore the PPPs research field from a more holistic perspective.

A comprehensive metrological and content analysis of the PPPs research field is conducted in this paper. Three key factors distinguish this study from previous bibliometric studies on PPPs. First, a new bibliometric technique, the Bibliometrix R-package developed

**Table 1** A summary of previous PPPs review studies

ID	Study	Size	Period	Source	Type of research	Main method	Main focus	Software tool	Primary discipline focused
1	Weihe (2008)	–	–	–	No bibliometric	Inductive review	PPPs notions	–	Not specific
2	Ke et al. (2009)	170 papers	1998–2008	Seven leading construction management journals from Scopus	No bibliometric	Content analysis	Research trend of PPPs	–	Construction engineering and management
3	Kwak et al. (2009)	–	Last 20 years	–	No bibliometric	Qualitative literature review	Definitions, types, benefits and obstacles of PPPs	–	Not specific
4	Tang et al. (2010)	107 papers	1998–2007	Six leading construction management journals	No bibliometric	Systematic literature review	Empirical and non-empirical of PPPs studies	–	Construction engineering and management
5	Papajohn et al. (2011)	34 questionnaires	–	Questionnaires targeting state transportation planning engineers	No bibliometric	Comprehensive research overview	National survey on transportation PPPs in the US	–	Economics, law, and public opinion
6	Andon (2012)	97 papers	1997–2010	25 scholarly accounting journals	No bibliometric	Qualitative literature review	Implications of PPPs for public investment	–	Accounting
7	Osei-Kyei and Chan (2015)	27 papers	1990–2013	Nine top tier academic journals	No bibliometric	Content analysis	Critical success factors for PPPs	–	Not specific

**Table 1** (continued)

ID	Study	Size	Period	Source	Type of research	Main method	Main focus	Software tool	Primary discipline focused
8	Zhang et al. (2016)	685 papers	2005–2014	CNKI and Scopus databases	No bibliometric	Content analysis and statistical analysis	Comparison of PPPs research in Chinese and international journals	Excel	Construction engineering and management
9	Bao et al. (2018)	282 papers	1996–2016	Seven leading construction management journals	No bibliometric	Systematic literature review	Project lifecycle of PPPs	–	Construction engineering and management
10	Chen et al. (2016)	95 papers	2002–2014	A PPPs research database at George Mason University	No bibliometric	Meta-Analysis	Data characteristics of empirical PPPs research	–	Transportation
11	Marsilio et al. (2011)	323 papers	1990–2007	Social Science Citation Index database	Bibliometric analysis	Social Network analysis <sup>a</sup>	Intellectual structure of PPPs research field <sup>A</sup>	Bibexcel, Pajek	Multi-disciplinary
12	Castro e Silva Neto et al. (2016)	575 papers	1990–2014	Web of Science	Bibliometric analysis	Metrological analysis <sup>b</sup>	Overview of PPPs research <sup>B</sup>	–	Multi-disciplinary
13	Song et al. (2016)	1072 papers	2000–2015	Web of Science core collection	Bibliometric analysis	Scientific visualization <sup>c</sup>	Mapping global PPPs research <sup>C</sup>	CiteSpace	Multi-disciplinary
14	Wang et al. (2018)	186 papers	1983–2016	Web of Science	Bibliometric analysis	Social Network analysis <sup>d</sup>	Topics of PPPs domain <sup>D</sup>	Ucinet	Public Administration

Table 1 (continued)

ID	Study	Size	Period	Source	Type of research	Main method	Main focus	Software tool	Primary discipline focused
15	Cui et al. (2018)	754 papers	1990–2016	Web of Science, ASCE Library, Emerald, Elsevier-Science Direct, and Taylor & Francis	Bibliometric analysis	Content analysis <sup>e</sup>	Overview of infrastructure PPPs research <sup>E</sup>	NVivo	Infrastructure
16	Song et al. (2019)	1428 papers	1996–2016	Web of Science core collection	Bibliometric analysis	Scientific visualization <sup>f</sup>	Intellectual structure of PPPs research field <sup>F</sup>	CiteSpace	Multi-disciplinary
17	Narbaev et al. (2020)	1970 papers	1989–2018	Scopus	Bibliometric analysis	Extensive meta-review <sup>g</sup>	Integrated overview of PPPs research <sup>G</sup>	VOSViewer	Multi-disciplinary

<sup>a</sup>Citation and author co-citation analysis; <sup>A</sup>cited works and authors

<sup>b</sup>Number of papers; <sup>B</sup>evolution of the quantity of papers, main publishing journals, research areas, geographic scope, project sector, and topics

<sup>c</sup>Co-author analysis, co-word analysis, co-citation analysis and cluster analysis; <sup>C</sup>core authors and institutions, high-frequency categories and keywords, journal of author contributions, highly cited papers and hot research topics and trends

<sup>d</sup>Co-word analysis; <sup>D</sup>main topics of PPPs in the Public Administration area

<sup>e</sup>Word frequency and cluster analyses; <sup>E</sup>status quo, trends, and gaps in infrastructure PPPs research

<sup>f</sup>Cluster analysis and burst analysis; <sup>F</sup>pivotal points of representative documents

<sup>g</sup>Citation-based metrics, keyword frequency analysis, keyword relevance scoring; <sup>G</sup>top journals, main topics and research domains

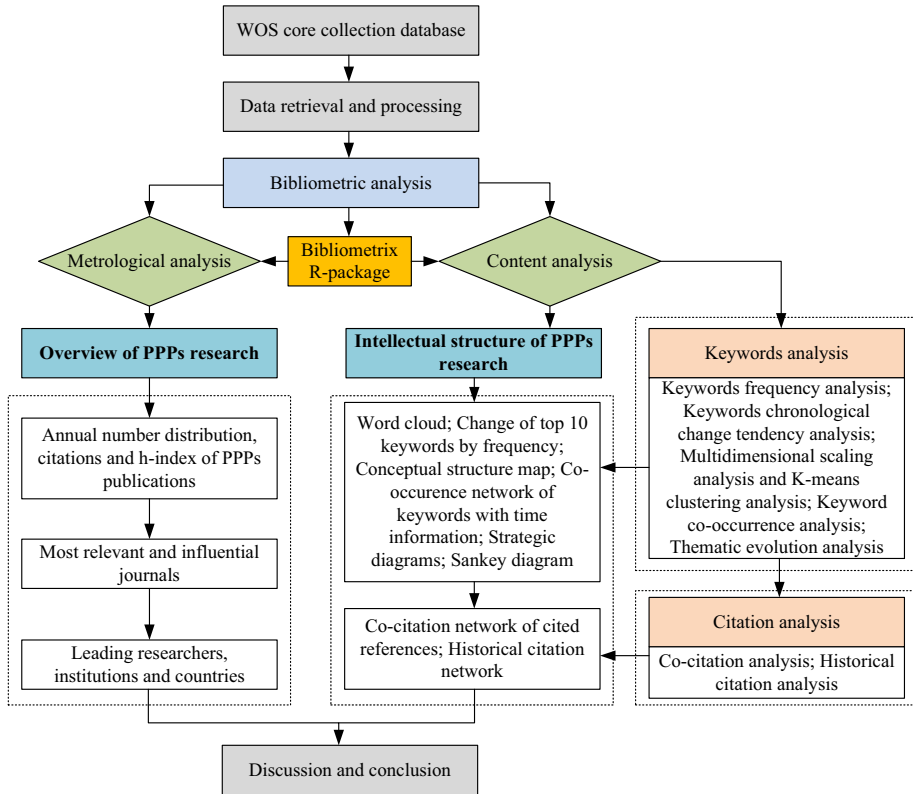
in the R language in 2017, which provides a series of tools for quantitative bibliometric analysis (Aria and Cuccurullo 2017), is applied in this paper. This new technique is flexible and integrates a set of other statistical and graphical packages. The use of R language for bibliometric analysis is a new attempt that could facilitate a more in-depth analysis of the PPPs field. Second, this study presents the overview of PPPs research through metrological analysis using a series of indexes. Although some of them (e.g. number of publication) have been used in previous PPPs literature studies, some other indexes (e.g. *h*-index, the year of first publication of authors, multiple countries production) are initially applied in this paper. Using diverse measurement criteria helps uncover more detailed information in this area. Third, this study explores the intellectual structure of the PPPs domain by adopting keywords analysis and citation analysis. Keywords and citation analyses have been broadly applied in earlier bibliometric studies on PPPs. However, compared with the static aspects, the dynamic aspects of the intellectual structure have been paid much less attention in previous PPPs literature studies. This study examines the intellectual structure of PPPs research from both static and dynamic perspectives. Diverse maps of science including word cloud of keywords, change of top 10 keywords by frequency, conceptual structure map, keywords co-occurrence network with time information, strategic diagrams, Sankey diagram, reference co-citation network and historical citation network are constructed to depict the intellectual structure of the PPPs field from different angles. The science maps in this paper provides a global view, structure details and salient characteristics of the PPPs domain, which are different from earlier PPPs bibliometric studies. With these three key factors, this paper can consolidate and broaden the bibliometric findings of previous PPPs literature studies, and provide a new reference for future bibliometric analysis in other research fields.

The remainder of this paper is organized as follows. The next section describes the method, data and software tool used in this paper. “[Overview of PPPs research](#)” section provides the general aspects of the PPPs domain. “[Intellectual structure of the PPPs research field](#)” section presents the intellectual structure of this domain. “[Discussions and conclusions](#)” section closes this paper with discussions and conclusions.

## Research methodology

This paper applies a comprehensive bibliometric approach to explore the PPPs research field through the combination of metrological analysis with content analysis. The bibliometric method can provide valuable insight into the characteristics and structure of a specific research domain in a systematic, transparent and reproducible process (Broadus 1987; Kamalski and Kirby 2012; Pollack and Adler 2015), which is considered more reliable and objective than other techniques (Aria and Cuccurullo 2017). Figure 1 shows the research framework of this study.

The first step of the bibliometric journey of this study is to select a database for collecting high-quality data for the bibliometric analysis. Similar to many previous bibliometric studies (Si et al. 2019; Song et al. 2016, 2019; Zhao 2017; Zhao et al. 2018), the core collection database of Web of Science (WOS) (<https://webofknowledge.com>) is used in this paper to collect data. WOS is treated as the gold standard database for bibliometric analysis by strictly indexing the most important literature worldwide (Modak et al. 2019). The WOS core collection database covers the most high-quality and influential publications



**Fig. 1** Research framework of this study

worldwide under strict peer reviews (Zhao 2017), hence it can help search the most representative PPPs literature for analysis.

The second step is to extract and filter data from the selected database. In previous review studies of the PPPs field, different retrieval codes are used for collecting data. A summary of retrieval codes in existing PPPs review studies is presented in the “Appendix”. Considering the coverage of these retrieval codes, the search strategy of Song et al. (2019) is adopted in this paper, because the most various patterns of PPPs are considered in their retrieval string. Accordingly, the following retrieval string was used in the WOS core collection database:  $TS = [(PPP^* AND public AND private AND partnership^*) OR (PFI^* AND private AND finance AND initiative^*) OR (BOT AND build AND operate AND transfer) OR (BOO AND build AND own AND operate) OR (BOOT AND build AND operate AND own AND transfer) OR (DBFO AND design AND build AND finance AND operate) OR (TOT AND transfer AND operate AND transfer) OR (BT AND build AND transfer) OR (BTO AND build AND transfer AND operate) OR (ROT AND renovate AND operate AND transfer) OR (BLT AND build AND lease AND transfer) OR (BOS AND build AND own AND sell)]$ . Here, ‘TS’ represents the topic of a publication (i.e. search in the fields of the title, abstract and keywords), ‘\*’ means a fuzzy search. The search was conducted in August 2019, so the time span ranging from the earliest available date up to 2018 was taken into consideration in this study. The literature type was limited to journal



article since this type of publications usually provides higher quality and more important research on PPPs. This search yielded a preliminary list of 1252 publications. A manual check on the title, abstract and keywords of these records was adopted to remove unrelated publications. After this data cleaning process, 95 articles which are not related to PPPs were removed. Finally, 1157 bibliographic records were obtained. These 1157 records were then used as the data set for the bibliometric analysis in this paper.

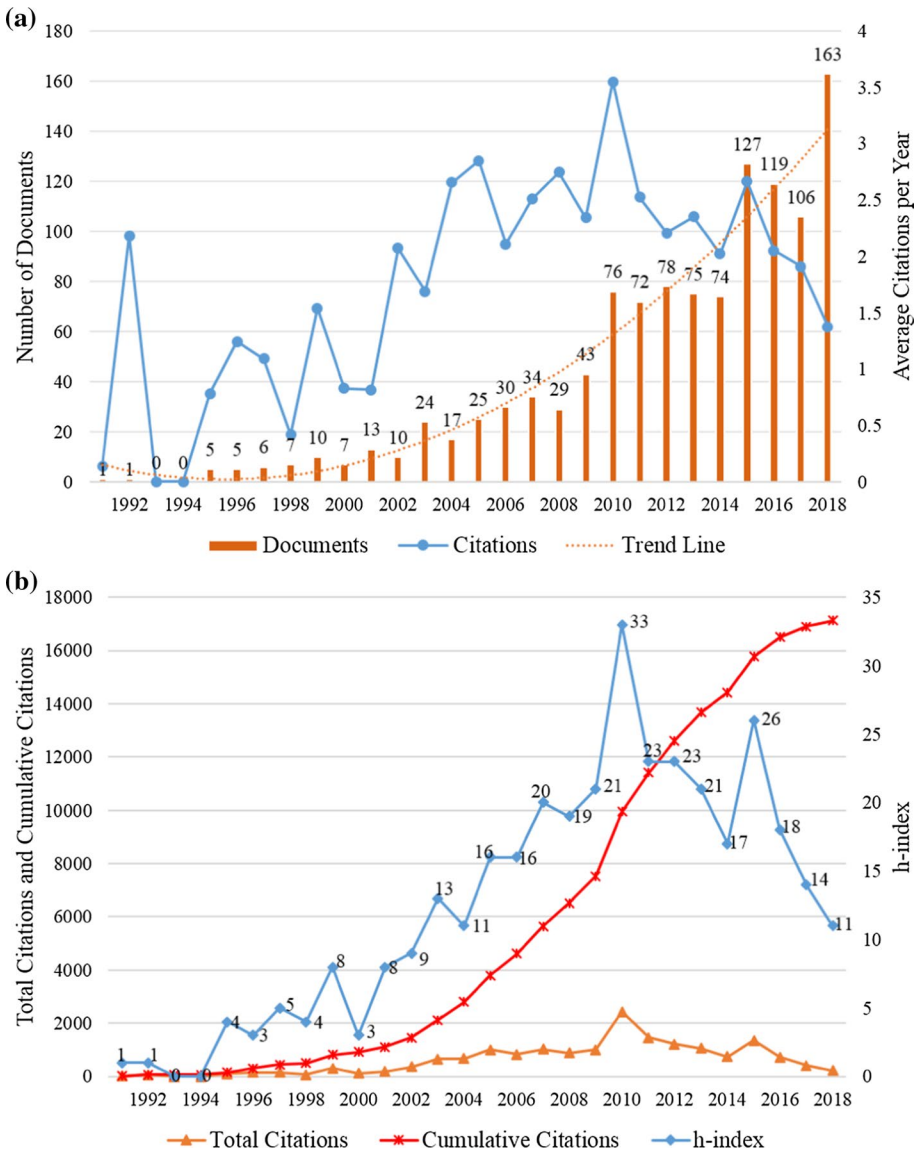
The third step is to conduct the bibliometric analysis. Bibliometric analysis can be conducted by a series of software tools such as CiteSpace, VOSViewer, Bibexcel, SciMAT, CitNetExplorer and so on (Cobo et al. 2011). However, most of these tools have the cumbersome nature of the process, and cannot help researchers analyze literature in a complete recommended workflow (Aria and Cuccurullo 2017). By comparison, as a newly developed R-environment based software package, Bibliometrix is more flexible and integrates the visualization functions of a variety of bibliometric tools. Using the command code of Bibliometrix, other software can also be called to conduct bibliometric analysis. It's able to complete a set of literature information analysis and science mapping. Therefore, it is utilized in this paper to perform a new comprehensive bibliometric analysis of the PPPs research field.

In this study, the 1157 articles are used to analyze the overview and the intellectual structure of this research field. On the one hand, to present the overview of PPPs research, metrological analysis of PPPs publications, journals, researchers, institutions and countries of the PPPs domain are conducted through a series of indexes. On the other hand, to explore the intellectual structure of the PPPs field, content analysis including keywords analysis and citation analysis are combined applied to detect hot topics, thematic evolution and research focuses of PPPs research from both static and dynamic perspectives. The results of the bibliometric analysis are presented in the next two sections.

## Overview of PPPs research

### Annual number distribution, citations and *h*-index of PPPs publications

The general aspects of the PPPs domain are presented in this section. With the help of Bibliometrix, the annual number distribution, citations (including average citations per year, total citations and cumulative citations) and *h*-index of these documents can be obtained as shown in Fig. 2. The *h*-index is a widely accepted indicator to measure the impact of scholars, journals, organizations, countries and so on, with the advantage of being objective (Hirsch 2005). It was originally defined as *h* of *N* papers have at least *h* citations, while the other (*N*–*h*) papers have  $\leq h$  citations. It can be observed from Fig. 2a that, from 1991 to 2018, despite some small fluctuations, the number of PPPs related publications is steadily increasing with an annual growth rate of 22.6% and reaches the peak of publication in 2018. It indicates that the PPPs topic is increasing in its popularity. As regards the average citations per year of each document, publications in 2010 have the most average citations of 3.55. As a whole, publications from 2002 to 2017 have more average citations than other documents with more than 1.6 citations per year. It should be noted that the one paper published in 1992 (Tiong et al. 1992) also has relatively high average citations (with the citation number of 2.19), indicating its prominent impact in the PPPs domain. Figure 2b shows that 2010 is also the most prominent year with the highest values of total citations and *h*-index. The citation trend shows a relatively stable growth until 2002. From 2002 to

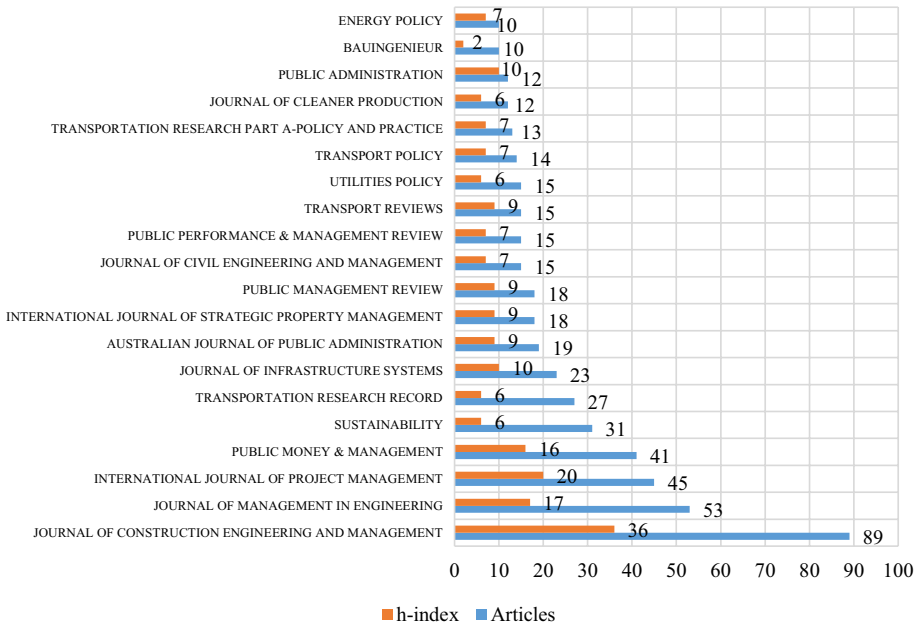


**Fig. 2** Annual number distribution, citations and *h*-index of PPPs publications

2017, the cumulative citations increase dramatically because of considerable total citations in these years.

**Most relevant and influential journals**

The PPPs related articles are published in a wide variety of journals. The 1157 papers we obtained come from 395 different journals. The number of PPPs related articles and the *h*-index of each journal are used as measures here to identify the most relevant and



**Fig. 3** Top 20 relevant journals on PPPs research

influential journals in the PPPs research domain. Figure 3 shows the top 20 journals which published the most PPPs related articles. These 20 journals can be considered as the most relevant sources in the PPPs field. As can be seen in Fig. 3, the top four journals including *Journal of Construction Engineering and Management*, *Journal of Management in Engineering*, *International Journal of Project Management* and *Public Money & Management* publishing the most number of PPPs related articles are also the most influential sources with the highest value of *h*-index. It can be seen from these 20 most relevant journals in the PPPs field that the PPPs topics mainly pivot on the domains of construction management and public management.

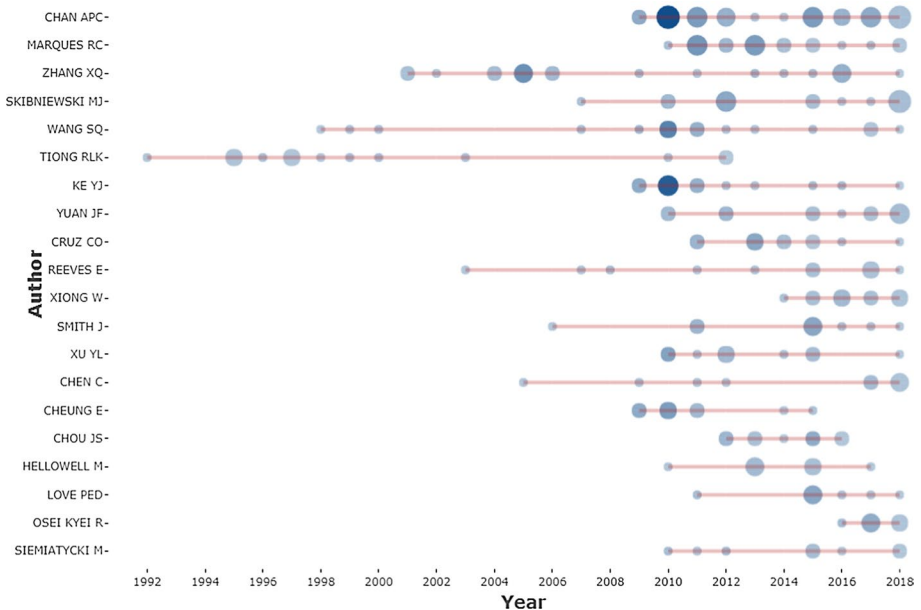
**Leading researchers, institutions and countries**

Using the author information contained in the collected data, the leading authors in the PPPs domain, their institutions and countries can be identified and revealed. The *h*-index, total citations (TC), number of publications (NP) and the year of first publication in the PPPs field (PY-start) of the top 20 influential authors who contribute to the most PPPs publications are presented in Table 2. Figure 4 shows their productions over time. In Fig. 4, the volume of the spheres is proportional to NP in each year, while the color depth of the spheres is proportional to TC per year (TC/Y).<sup>1</sup> It can be observed from Table 2 that Chan APC is the most prominent researcher in this domain, as the *h*-index, TC and NP of him

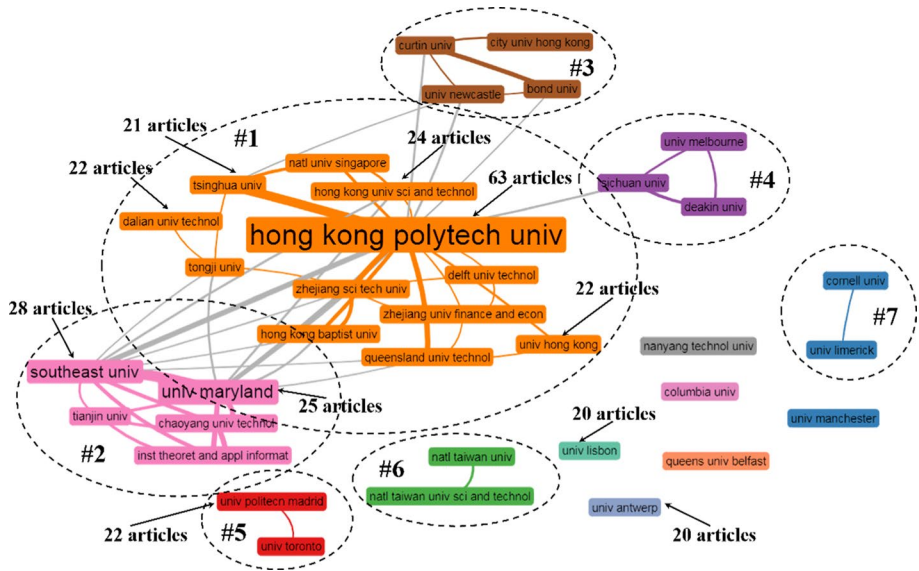
<sup>1</sup> TC/Y means average annual citations since publication. For example, TC of Chan APC’s productions at 2010 is 611, then the corresponding TC/Y = 611/(2019–2010) = 67.89.

**Table 2** Top 20 influential authors in the PPPs research field

Author	<i>h</i> -index	TC	NP	PY-start
CHAN APC	18	1255	40	2009
MARQUES RC	12	517	21	2010
ZHANG XQ	15	889	21	2001
SKIBNIEWSKI MJ	8	283	19	2007
WANG SQ	12	846	16	1998
TIONG RLK	12	537	15	1992
KE YJ	12	872	14	2009
YUAN JF	6	185	14	2010
CRUZ CO	8	244	11	2011
REEVES E	7	163	11	2003
XIONG W	5	91	11	2014
SMITH J	7	201	10	2006
XU YL	8	311	10	2010
CHEN C	6	120	10	2005
CHEUNG E	8	441	9	2009
CHOU JS	6	181	9	2012
HELLOWELL M	5	86	9	2010
LOVE PED	5	144	8	2011
OSEI KYEI R	5	72	8	2016
SIEMIATYCKI M	4	153	8	2010



**Fig. 4** Top 20 authors’ productions over time in the PPPs research field



**Fig. 5** Institution cooperation network of PPPs research

are all the highest. He is followed by Zhang XQ, Marques RC, Wang SQ, Tiong RLK, and Ke YJ in terms of *h*-index. Figure 4 shows that the peak annual outputs of these researchers are 7 papers (produced by Chan APC at 2010 and 2018; Skibniewski MJ at 2018). It’s worth pointing out that Chan APC’s productions at 2010 also has the highest TC/Y (67.89), followed by Ke YJ’s productions (5 papers) at 2010 with the second highest TC/Y (59.33) and Wang SQ’s productions (3 papers) at 2010 with the third highest TC/Y (38.00). It implies that their 1-year-productions at 2010 are of higher impact than other scholars to some extent. It can be also seen from Fig. 4 that Chan APC, Marques RC, Xiong W and Osei-Kyei R are the researchers who have successive productions in recent years, which reflects their prominent contributions to the PPPs research from another perspective.

In order to characterize the distribution of the PPPs publications, the leading institutions and countries of the PPPs research are further analyzed in this paper. Figure 5 shows the cooperation network of the major institutions contributing to the PPPs research. The top 10 institutions publishing the most number of PPPs related articles are also marked in Fig. 5. The most productive institution is Hong Kong Polytechnic University (63 articles), followed by Southeast University (28 articles), University of Maryland (25 articles), Hong Kong University of Science and Technology (24 articles), Dalian University of Technology (22 articles), The University of Hong Kong (22 articles), Universidad Politécnic de Madrid (22 articles), Tsinghua University (21 articles), University of Antwerp (20 articles) and University of Lisbon (20 articles). Table 3 presents NP, *h*-index, TC and average citations per article (AC) of these top 10 institutions and ranks them by the value of *h*-index. Hong Kong Polytechnic University is considered the most impactful because its scores of *h*-index and TC are the highest, followed by Tsinghua University, The University of Hong Kong and Hong Kong University of Science and Technology. It should be mentioned that Tsinghua University has the most number of AC, implying that its PPPs research productions are more influential than other productions to some extent. Seven network clusters including at least two institutions have been identified in Fig. 5. The largest cluster (marked

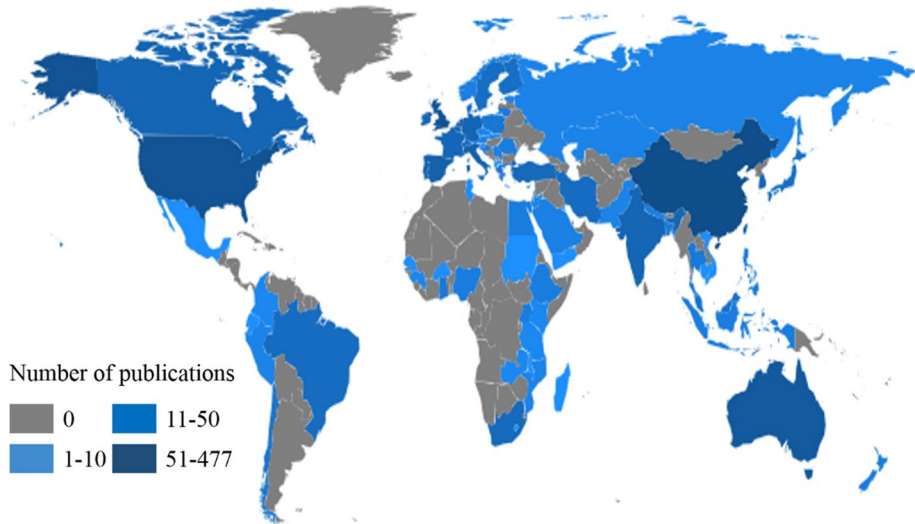
**Table 3** Top 10 institutions of PPPs research ranked by *h*-index

Institution	NP	<i>h</i> -index	TC	AC
Hong Kong Polytechnic University	63	27	2441	38.75
Tsinghua University	21	14	1265	60.24
The University of Hong Kong	22	14	769	34.95
Hong Kong University of Science and Technology	24	14	547	22.79
University of Lisbon	20	12	474	23.70
Southeast University	28	11	716	25.57
University of Maryland	25	11	477	19.08
University of Antwerp	20	11	318	15.90
Universidad Politécnica de Madrid	22	9	260	11.82
Dalian University of Technology	22	8	198	9.00

as #1) is composed by 12 institutions, in which Chinese institutions are the most active as four of these 12 institutions come from Hong Kong, and five come from mainland China. In cluster #1, Hong Kong Polytechnic University is the considered the core institution as it has the most PPPs productions and most collaborations with other institutions. Its collaboration strength with Tsinghua University is the greatest as can be seen from the thickness of the line between them. The second largest cluster (marked as #2) contains five institutions. Southeast University and University of Maryland are considered the two core institutions in cluster #2 because they produce the highest number of PPPs articles in this cluster, and the collaboration between them is the strongest as well. Cluster #3–#7 are some other institution cooperation groups which also actively study the PPPs issues. It should be noted that there are also varying degrees of cooperation between clusters. The cooperation between cluster #1 and cluster #2 is the strongest, as institutions from each of them also have the most frequent cooperation relationships. Cluster #1 has some connections with cluster #3 and cluster 4 as well. Institutions in these clusters can be regarded as the main-stream research community in the PPPs domain.

Figure 6 illustrates the countries around the world where the PPPs related articles were published. A total of 84 countries/regions participate in the publication of PPPs research. Among them, there are 48 countries with only 1–5 publications, implying that there is still much room for PPPs research in these countries. The four most prolific countries of PPPs articles are China (477 articles), USA (275 articles), UK (253 articles) and Australia (154 articles), which are far ahead of other countries.<sup>2</sup> The number of articles includes those published in cooperation between different countries based on co-authorship. To further analyze the details of PPPs research at the country level, the top 10 corresponding authors' countries/region are presented in Table 4, and major countries publishing PPPs articles as well as their cooperation relationships are shown in Fig. 7. Table 4 shows that China, UK, USA and Australia are still the leading countries in terms of corresponding authors, indicating their dominant positions in the PPPs field. The MCP-Ratios of all the countries except for Singapore are less than 50%, which implies that the transnational cooperation is

<sup>2</sup> The countries/region ranked from 5 to 10th are Taiwan (78 articles), Netherlands (67 articles), Spain (67 articles), Italy (62 articles), Portugal (54 articles) and Germany (53 articles).



**Fig. 6** Worldwide publications on PPPs

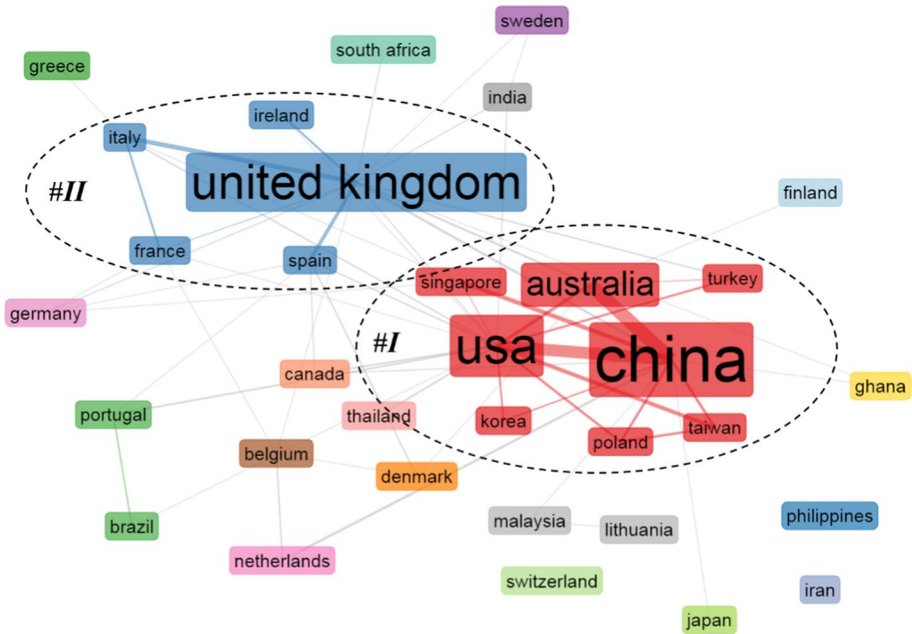
**Table 4** Top 10 corresponding authors' countries/region of PPPs research

Country	Articles	SCP	MCP	MCP-ratio
CHINA	220	153	67	0.3045
UNITED KINGDOM	146	115	31	0.2123
USA	116	84	32	0.2759
AUSTRALIA	69	42	27	0.3913
NETHERLANDS	40	28	12	0.3000
ITALY	36	19	17	0.4722
SPAIN	36	21	15	0.4167
TAIWAN	35	30	5	0.1429
PORTUGAL	29	24	5	0.1724
SINGAPORE	29	11	18	0.6207

SCP stands for single country production. MCP stands for multiple countries production. MCP-ratio stands for the proportion of MCP in total articles

not enough to some extent.<sup>3</sup> It can be observed from Fig. 7 that two clusters (marked as #I and #II) dominate in the whole cooperation network. Cluster #I consists of eight countries/region, including China, USA, Australia, Taiwan, Singapore and so on, while cluster #II is composed by five European countries including UK, Spain, Italy, France and Ireland. In cluster #I, the strongest cooperation relationship occurs between China and Australia (with the frequency of 39), followed by China and USA (frequency: 34) and China and Singapore

<sup>3</sup> Actually, among all the 74 countries with corresponding authors, only MCP-Ratio of Singapore is higher than 50%.



**Fig. 7** Country collaboration network based on co-authorship of PPPs research

(frequency: 12).<sup>4</sup> The strongest cooperation relationship in cluster #II occurs between UK and Italy (frequency: 13), followed by UK and Spain (frequency: 10) and France and Italy (frequency: 6). Certainly, countries between these two clusters also cooperate frequently. Thus, this bunch of countries can be considered the most active and largest contributor of PPPs publications.

## Intellectual structure of the PPPs research field

In this section, as key ways of content analysis, keywords analysis and citation analysis are combined applied here to identify core elements of the knowledge base of the PPPs research field. A series of bibliometric methods are adopted to present the intellectual structure of this domain from both static and dynamic perspectives.

### Keywords analysis

Keywords are used as a clear, representative and concise description of the research content by authors, thus it's plausible to identify hot topics and themes of a research domain on the basis of keywords analysis (Zheng et al. 2016).

<sup>4</sup> Frequency here means the number of articles published by co-authors from both of the two countries.



**Fig. 8** Word cloud of keywords of the PPPs research field



**Keywords frequency analysis: static perspective**

Firstly, we use Bibliometrix to get information about the keywords frequency of the PPPs domain. After this step, variations of keywords with the same meanings are merged. For instance, ‘public private partnership(s)’, ‘PPP’ and ‘PPPs’ are merged as ‘PPPs’; ‘build operate transfer’ and ‘BOT’ are grouped as ‘BOT’, ‘private finance initiative(s)’ and ‘PFI(s)’ are merged as ‘PFI’. Then we use the resulting phrase count lists to generate the word cloud of keywords of the PPPs research field (see Fig. 8). The word cloud is a clear and entire graphical display of hot topics in the PPPs research field. High frequency keywords used in PPPs related papers can be presented intuitively. It can be used to map the conceptual structure of the research domain, which is conducive to understanding the main elements of the text information in the whole PPPs field. In Fig. 8, keywords occurring more than three times are highlighted, and the size of the keywords is positively correlated to the frequency of their appearance in the data set. From the word cloud, hot keywords such as ‘infrastructure’, ‘risk management’, ‘project management’, ‘concession period’ and ‘value for money’ can be observed.

**Keywords chronological change tendency analysis: dynamic perspective**

To further understand the change of topics during different time periods, the 28-year time span from 1991 to 2018 is divided into seven 4-year time slices. It can be observed from the word cloud, that some of the high frequency keywords occurring in different forms actually depict the same topics. These keywords reflecting the same topics but with different forms are merged together. For example, ‘risk analysis’, ‘risk allocation’ and ‘risk management’ dealing with the risk of PPPs project are merged as ‘Risk’; ‘infrastructure’, ‘infrastructure projects’ and ‘infrastructure development’ are merged as ‘Infrastructure’. Besides, common terms which are not useful for identifying topics (such as ‘partnerships’) are removed. Finally, the top 10 most frequent keywords of the PPPs domain are obtained and visualized in Fig. 9. Without doubt ‘PPPs’ is the most prevalent keywords with much higher frequency than other nine keywords. It develops very slowly during the first three time slices, but takes off since the fourth time slice with a high growth rate. As for the

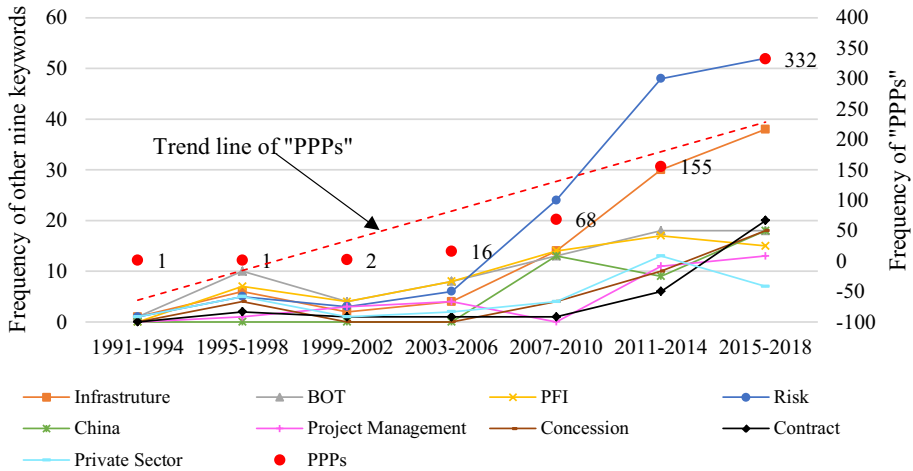


Fig. 9 The change of the top 10 keywords by frequency in the PPPs field



Fig. 10 Conceptual structure map of the PPPs research field

other nine keywords, the first four time slices seem to witness a sprout of these research topics. During these four periods, ‘BOT’ and ‘PFI’ attract more interest of scholars in the PPPs domain. This is hardly surprising because PFI is the very first term employed by British government carrying the PPPs idea and regarded as the forerunner of PPPs (Wang

et al. 2018), while BOT is the most popular vehicle in early years of PPPs development and usage (Ke et al. 2009). From the fourth time slice to the last, all of the keywords show an upward trend as a whole, despite some small fluctuations. ‘Risk’ and ‘Infrastructure’ are the most prominent topics experiencing a surge in terms of frequency, and research on ‘Contract’ also shows an obvious increasing tendency during the last three time slices. Through this part of bibliometric-based analysis, the macro changes of hot topics in the PPPs domain have been visually and quantitatively reflected.

### Multidimensional scaling analysis and K-means clustering analysis: static perspective

Subsequently, using the *conceptualStructure* function of Bibliometrix, we further generate the conceptual structure map of the PPPs research field as shown in Fig. 10.<sup>5</sup> This function performs a multidimensional scaling analysis of keywords to draw the conceptual structure of a research domain and K-means clustering analysis to detect clusters of keywords which express common concepts (Aria and Cuccurullo 2017). Multidimensional scaling analysis is an exploratory analysis method, which can show the relationship between multi-variables in the two dimensional space and is helpful for detecting the spatial distribution of topics. While K-means clustering analysis is one of the most commonly applied approaches in cluster analysis, which can cluster topics based on the distribution of the keywords along the dimensions and their relative positions. In Fig. 10, keywords are distributed as points in the two-dimension space, as they are more similar in distribution, the closer they are presented in the conceptual structure map. As can be seen from Fig. 10, Bibliometrix automatically generates eight keywords clusters.<sup>6</sup> The largest cluster contains 29 keywords dots (cluster 3), while the smallest clusters has only one keyword (cluster 8).

Cluster 1 is composed by five keywords, among which ‘real options’ and ‘Monte Carlo simulation’ are the two keywords depicting the approaches employed to PPPs project. In this cluster, contract flexibility and government guarantees are mostly explored, and the concession period and risk analysis of PPPs project are among the hottest topics. To further show more information from this cluster, some relevant papers of this cluster are also investigated.<sup>7</sup> To name a few, Ashuri et al. (2012) employed the real option theory to price the government minimum revenue guarantee (MRG) options in BOT project, for determining a reasonable MRG. Huang and Chou (2006) discussed the flexibility of concession contract by using the real option method to value the abandon option and MRG in BOT infrastructure projects. Buyukyoran and Gundes (2018) established a real-option-based model for identifying optimum lower and upper boundaries of the MRG and maximum revenue cap (MRC) options in BOT toll road projects. As a computerized risk analysis methodology, Monte Carlo simulation was also employed to obtain meaningful descriptive statistics for this model. Using real option theory and Monte Carlo simulation, concession period and risk analysis of PPPs project were dealt with by scholars broadly (Ma et al. 2018; Marzouk and Ali 2018; Pellegrino et al. 2013; Shahrara et al. 2017; Vasudevan et al. 2018).

<sup>5</sup> The top 50 high frequency keywords in the PPPs literature are used to generate the conceptual structure map. Since there are several keywords with the same frequency ranking the 50th (frequency: 9), a total of 53 keywords are included in Fig. 10.

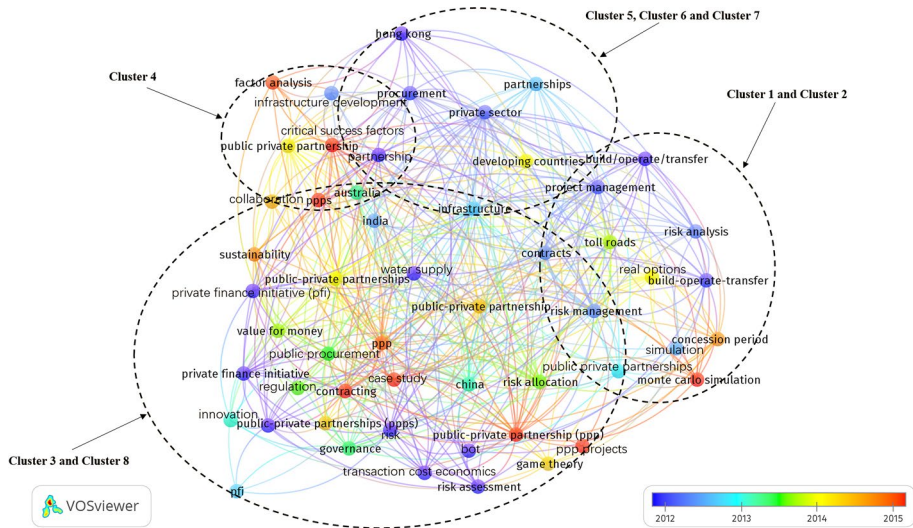
<sup>6</sup> Different numbers of clusters can be generated by adjusting the parameters of the command code. In this paper, eight keywords clusters are generated for obtaining fine-grained topic categories.

<sup>7</sup> The most relevant papers associated with each cluster can be detected by Bibliometrix. Some of these relevant papers are used to illustrate the clusters of the conceptual structure map.

Cluster 2 involves seven keywords, which mainly focuses on the research around contract related risk management and project management of toll road PPP/BOT projects. For example, Heravi and Hajihosseini (2012) employed a case study of one of the largest highway projects in Iran, the Tehran–Chalus Toll Road project. In their paper, the contract organization of this PPPs project were analyzed, the most important risks were identified and the ways to improve risk allocation for better project performance were also proposed. Chiara and Kokkaew (2013) presented a new type of revenue risk hedging contract (i.e. dynamic revenue insurance contract) for the PPPs project to act as an alternative of the traditional government guarantees. The contract was modeled as multiple exercise real options and priced through Monte Carlo methods. The model presented in their paper was proved to be effective through a numerical example of a typical build-operate-transfer (BOT) toll road project.

Cluster 3 is the largest cluster with 29 keywords dots. Apart from various spectrums of PPPs modes (i.e. PPPs and its variants, PPP, BOT, PFI) and their different nomenclatures (e.g. public private partnership(s), private finance initiative), different topics, approaches or contents in PPPs studies can be reflected by other keywords. The clustering of these keywords indicates that the topics around some of them are often combined studied in the same paper. Like Cluster 1 and Cluster 2, the topics around the risk of PPPs project are also presented in this cluster, as can be seen from the keywords ‘risk’, ‘risk allocation’ and ‘risk assessment’. This further illustrates the popularity of ‘risk’ in the PPPs domain. Besides, the keywords ‘governance’, ‘regulation’, ‘public procurement’, ‘value for money’, ‘innovation’, ‘sustainability’, and the like depict colorful topics in the PPPs area. According to Ke et al.’s (2009), Zhang et al.’s (2016) and Cui et al.’s (2018) categorization of research topics, the risk related keywords in this cluster can be categorized as the topic of “risk management”. In contrast, the “risk management” topic in this cluster represents the two main themes in the sub-domain of PPPs risk management, i.e. identification & assessment of risk factors and suitable allocation of risk factors between different stakeholders (Zhang et al. 2016), while the risk related topics in Cluster 1 and Cluster 2 mainly reflect the risk issues within the contract management framework. The keywords ‘governance’ and ‘regulation’ can be treated as the reflection of the topic of “governance issue”, which focuses on the concerns of government policy environment and project governance for PPPs (Cui et al. 2018). The keyword ‘public procurement’ can be grouped into the topic of “procurement” which focuses on the procurement tendering issues within the PPPs framework (Ke et al. 2009). ‘Value for money’ in this cluster can be regarded as the label of the topic “value for money tests” which concentrates on the economic viability of PPPs (Cui et al. 2018; Castro e Silva Neto et al. 2016). The two high frequency keywords ‘innovation’ and ‘sustainability’ that are not identified as hot topics in previous review studies of PPPs, already have a place in the conceptual structure map, implying their potential to develop into hot topics for future study. Regarding other keywords in this cluster, the keyword ‘water supply’ shows that the water infrastructure is one of the sectors that PPPs study has frequently concentrated on. ‘China’ and ‘India’ are the developing countries where PPPs has been widely studied. Some frequently used theories/approaches in PPPs studies are also mapped in this cluster, including ‘case study’ and ‘transaction cost economics’.

Cluster 4 contains five keywords, which highlights the research of the CSFs for PPPs in infrastructure development. The keywords ‘factor analysis’ and ‘Australia’ appear in this cluster because ‘factor analysis’ is one of the most widely used technique for analyzing CSFs (Chan et al. 2010), and ‘Australia’ is among the countries of focus for most studies on the CSFs for PPPs (Osei-Kyei and Chan 2015). Among some related papers of this cluster, Li et al. (2005b) studied the relative importance of 18 potential CSFs for British PPPs



**Fig. 11** Co-occurrence network of high frequency keywords of PPPs literature

construction projects through questionnaire survey, and used factor analysis to group these 18 CSFs. Chan et al. (2010) gathered the viewpoints of some Chinese experts through a questionnaire survey to rate 18 CSFs for PPPs in infrastructure development and grouped them into five underlying factors by the factor analysis technique. Cheung et al. (2012) carried out a comparative analysis of the CSFs for PPPs between Australia, Hong Kong and the UK, and found that there are certain common CSFs for PPPs, irrespective of the geographical locations.

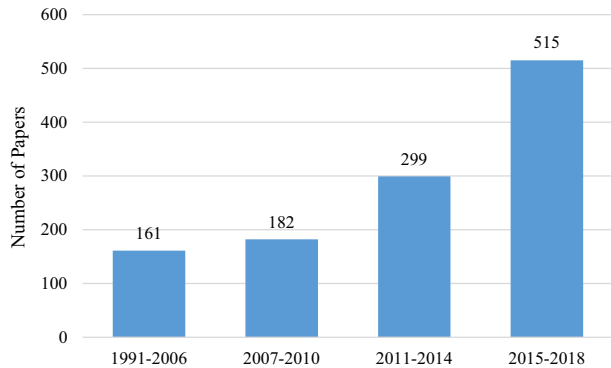
Apart from these main clusters, the rest clusters (Cluster 5–8) are some small clusters of the conceptual structure map, presenting other high frequency keywords of the PPPs field. For instance, ‘game theory’ in Cluster 8 is one of the most widely utilized approaches in the PPPs domain. ‘Infrastructure’ in Cluster 5 indicates that the infrastructure sector, especially water and road, is the sector that PPPs research has frequently focused on.

### Keywords co-occurrence analysis: static perspective

Next, we further use Bibliometrix to call the VOSViewer software (van Eck and Waltman 2010) to show the co-occurrence network of the top 50 high frequency keywords of PPPs literature with time information as shown in Fig. 11. In the co-occurrence network, the overall distance between keywords reflects their relatedness. In general, the shorter the distance between two keywords, the stronger their relationship (van Nunen et al. 2018). The color of each keyword represents the keyword’s average publication year, which is determined by taking the average of the publication years of all the documents with the keywords in their titles or abstracts. Keywords which are utilized more towards 2012 are shown in blue, while keywords which are used more towards 2015 are shown in red.

Keywords clusters corresponding to the conceptual structure map are also marked in the co-occurrence network. As can be seen, Cluster 1 and Cluster 2 of the conceptual structure map intermingle closely, indicating their close relation in terms of research themes. By and large, the topic “contract design and management” can be summarized to be the label

**Fig. 12** Number distribution of articles per sub-period



of these two clusters, as Cluster 1 tends to discuss the issues around contract design at the procurement phase of PPPs projects, while Cluster 2 seems to deal with the contract management issues during the implementation phase. Cluster 4 of the conceptual structure map is still individually marked in the co-occurrence network, as this cluster distinguishably highlight the topic of CSFs of PPPs. According to their relative position in the co-occurrence network, Cluster 3 and Cluster 8 of the conceptual structure map are marked together in Fig. 11, as the keywords ‘case study’ and ‘transaction cost economics’ in Cluster 3 and ‘game theory’ in Cluster 8 are among the hottest theories/methods in the PPPs field. Lastly, the rest small clusters (Cluster 5–7) are grouped together.

From a temporal view of the co-occurrence network, the average publication year of these high frequency keywords mainly ranges from 2012 to 2015. It can be observed from the “blue” keywords that most research around 2012 focuses on the content related to project management, risk analysis, risk assessment, risk management, transaction cost economics, BOT, and so on. The “redder” keywords such as ‘sustainability’, ‘factor analysis’, ‘critical success factors’, ‘case study’, ‘contracting’, ‘developing countries’, ‘real options’, ‘concession period’ and ‘Monte Carlo simulation’ seem to gain more attention recently, as their average publication year is closer to 2015, which are more likely to continue to flourish in the PPPs field. It’s worth mentioning here that this doesn’t mean that lesser attention is being paid to those “bluer” keywords. In fact, lots of research on these topics is still needed and conducted, but the research on the “redder” topics gains the upper hand currently.

### Thematic evolution analysis: dynamic perspective

In this sub-section, we attempt to analyze the thematic evolution of PPPs research between 1991 and 2018 from a dynamic perspective. Borrowing from some existing papers detecting thematic evolution (Murgado-Armenteros et al. 2015; Xie et al. 2020), we divide the research period (1991–2018) into four consecutive sub-periods considering the number of documents and the fixed time window. Although determining sub-periods covering the same time span seems common, the first sub-period is fixed at 16 years due to limited articles published in early years. This case can ensure a reasonable size of the first sub-period when compared with the succeeding sub-periods. The last three sub-periods are determined to cover 4 years each. Consequently, the entire research period (1991–2018) is

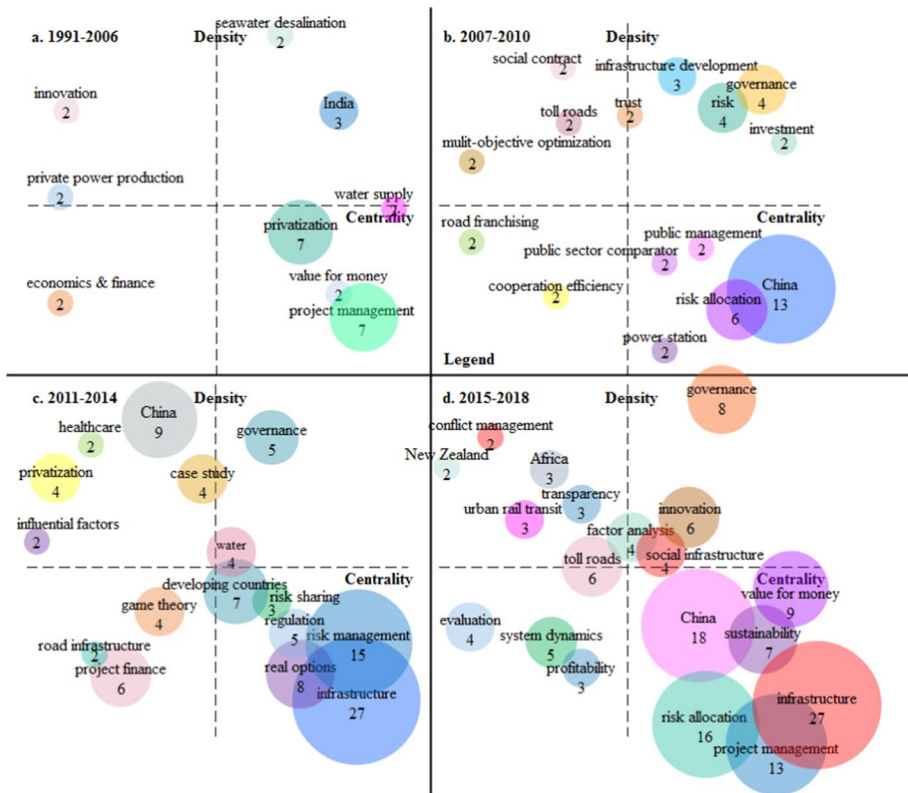
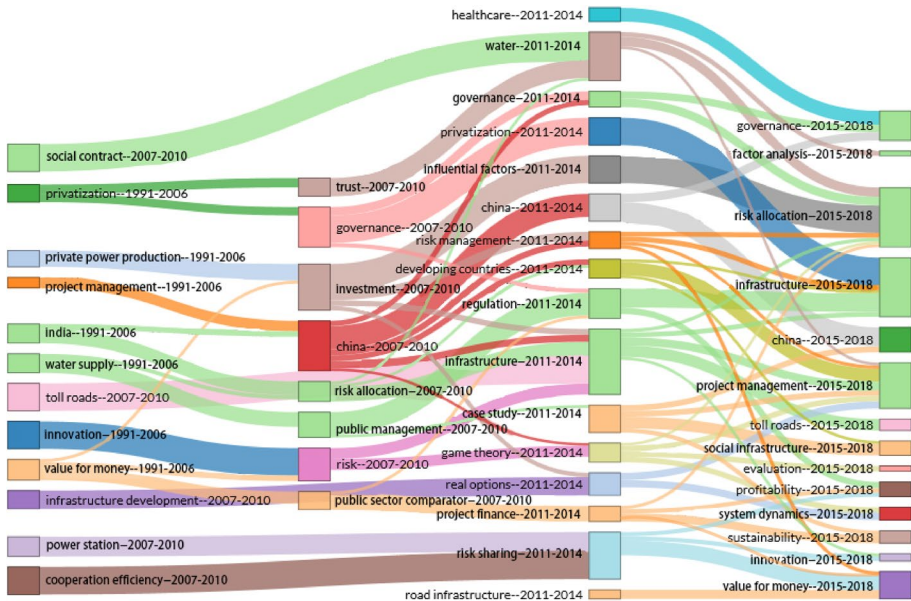


Fig. 13 Strategic diagrams of PPPs research (1991–2018)

divided into four consecutive sub-period, 1991–2006, 2007–2010, 2011–2014, 2015–2018. Figure 12 depicts the number distribution of the articles per sub-period.

The strategic diagrams of PPPs research in each sub-period are presented in Fig. 13. It is constructed by Bibliometrix using a co-word analysis based on the authors’ keywords. To detect the most emphasized and detailed themes in this field, only the keywords with a minimum occurrence of two times are retained for analysis. Different forms of keywords reflecting common themes (PPPs, BOT, PFIs) are removed. After this step, the highly relevant keywords are grouped into theme clusters, which are named by the keywords with the highest frequency. According to Callon et al. (1991), each sub-figure of Fig. 13 is divided into four quadrants representing different kinds of themes. Two measures including centrality and density are used to characterize each theme cluster. Themes in the first quadrant are known as motor themes, which have high-centrality and high-density values, implying that they are important and well developed for shaping the PPPs field. Themes in the second quadrant are known as well-developed and isolated themes, which have low-centrality and high-density values. These themes have well developed internal ties but are of marginal importance for the PPPs domain. The third quadrant includes themes with low-centrality and low-density values, which are known as declining or emerging themes. These themes are not only weakly developed but also of marginal importance for the PPPs domain. The fourth quadrant includes themes with high-centrality and low-density values, which are



**Fig. 14** Thematic evolution of PPPs research (1991–2018)

known as basic and transversal themes. These themes are of importance for the development of the PPPs field but are not adequately developed. The size of the sphere in Fig. 13 is proportional to the keywords frequency of the name of each theme, which is marked in each sphere.

It can be observed from Fig. 13 that the themes with high number of publications are mainly located in the fourth quadrant, which is quite logical, because basic and transversal themes are the main focus in the PPPs field. From the first to the last sub-period, the number of theme clusters increases, which indicates that the PPPs domain has evolved into a more and more complex and colorful research field covering a diversity of themes.

A Sankey diagram is further constructed to analyze how these theme clusters (themes in Fig. 13) interact with each other in a longitudinal framework and detect the main evolutionary paths of the themes, as shown in Fig. 14. In the Sankey diagram, each node represents a theme cluster which is labelled by the keyword with the highest frequency and the corresponding sub-period. The size of the node is proportional to the number of keywords for the corresponding theme. The flow between nodes indicates the evolutionary direction of the theme clusters. The edge width is proportional to the inclusion index between two linked themes. A set of themes evolving over different sub-periods can be considered a thematic area. Note that the themes which have no linkage with other themes are not presented in Fig. 14.

From an overall perspective, it can be found that the number of connections amongst themes increases over time. Some themes have stably evolved and developed, and some other themes gain importance and appear in the last sub-period. Several main thematic areas can be detected in the PPPs field, which are named as (1) *Governance and Regulation*; (2) *Project Management*; (3) *Project Finance*; and (4) *Risk Management*.

The evolution paths of the *Governance and Regulation* thematic area can be described as (a) privatization → governance → governance → governance, and (b) water supply → public



management → regulation → infrastructure. This thematic area mainly deals with PPPs issues from the perspective of public management. The theme clusters in the two evolution paths are all motor and basic themes (Fig. 13), which implies their importance for the PPPs field. Evolution path (a) shows that governance has become more and more important in the PPPs field, as its weight increases over time. It indicates that governance has grown into a stable and mature sub-area of the PPPs field, and this domain increasingly emphasizes the importance of diverse involved stakeholders. Evolution path (b) shows that the development of government regulations stand out in the area of public management, which is also likely to grow into a prominent tributary thematic area of the PPPs field in the future.

The evolution path of the *Project Management* thematic area is: project management → China → China, developing countries → China, project management. The “Project Management” theme cluster appears in the first and last sub-periods. However, this case does not mean that it completely disappears in the second and third sub-periods. It is because the weight of this concept is not the largest in the concept set during these two sub-periods, resulting in the change of the name of the theme cluster. This evolution path reflects the important role of project management (especially in developing countries represented by China) in the PPPs field. It can be also observed from the keyword elements of each theme cluster in this evolution path that the topics such as risk management, risk analysis and financial management dominate and steadily grow in this sub-area.<sup>8</sup>

The evolution path of the *Project Finance* thematic area can be treated as value for money → public sector comparator → project finance → value for money, sustainability. This thematic area concentrates on the economic and financial aspects of PPPs. The weight of the theme clusters in the evolution path shows an increasing trend (Fig. 13), implying that the economic viability and sustainability of PPPs is gaining importance, and is very likely to continue to evolve into an important tributary area of the PPPs domain.

*Risk Management* is not a well-defined thematic area in respect to the thematic coherence, with several evolution paths such as India, water supply → risk allocation → infrastructure → risk allocation, and private power production, value for money → investment → influential factors, risk management → risk allocation. This thematic area focuses on the topics of risk identification, risk assessment, risk analysis and risk allocation of PPPs project. Amongst these main topics, risk allocation has attracted the most significant interest from researchers in the PPPs field. Risk allocation firstly appears as a basic theme cluster in the second sub-period (frequency: 6), and evolves into the infrastructure theme as one keyword element (frequency: 14) in the third sub-period, and then appears as a basic theme cluster again in the last sub-period (frequency: 16). This result implies that the research around risk allocation may continue to flourish in the PPPs field in the future.

## Citation analysis

As a widely utilized approach to investigate the underlying intellectual structure and evolution dynamics of a research domain, citation analysis is conducted here to identify and investigate the most frequently cited papers in the PPPs domain, as well as their relationships. Table 5 shows the top 20 local cited papers in the PPPs domain and their global citations (GC) in descending order by number of local citations (LC). LC refers to the number

<sup>8</sup> The keyword elements of each cluster in the Sankey diagram can also be detected by Bibliometrix.

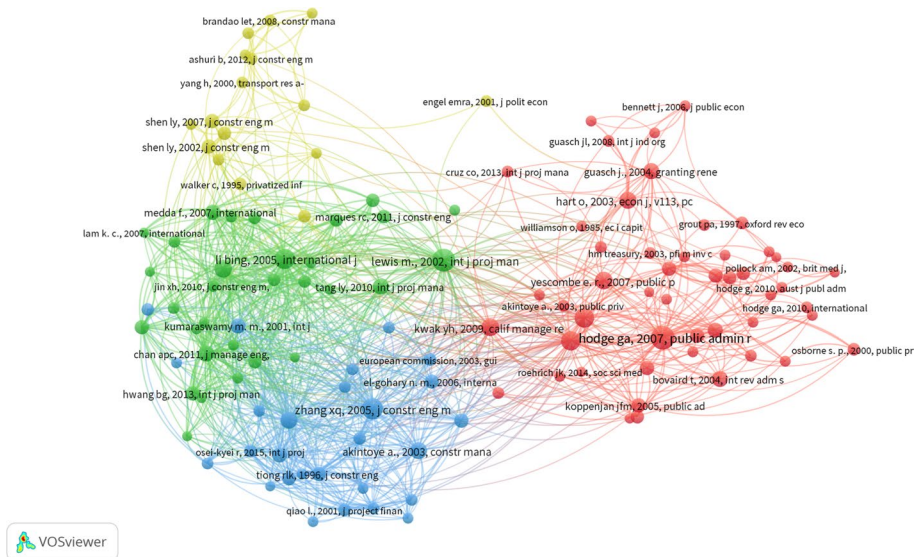
**Table 5** Top 20 local cited papers in the PPPs field

Document	LC	GC	TLC/Y	TGC/Y	Topic
Zhang (2005a)	135	256	9.6429	18.2857	CSFs of PPPs
Kwak et al. (2009)	57	166	5.7000	16.6000	Understandings of PPPs
Zhang (2005b)	56	66	4.0000	4.7143	Barriers of PPPs
Ke et al. (2010)	56	155	6.2222	17.2222	Risk allocation of PPPs
Zhang (2005c)	55	55	3.9286	3.9286	Criteria for selecting private partner in PPPs
Chan et al. (2010)	51	133	5.6667	14.7778	CSFs of PPPs
Chan et al. (2011)	48	93	6.0000	11.6250	Risk assessment and allocation of PPPs
Bovaird (2004)	47	192	3.1333	12.8000	Understandings of PPPs
Klijn and Teisman (2003)	45	156	2.8125	9.7500	Barriers of PPPs
Froud (2003)	41	112	2.5625	7.0000	Risk and uncertainty of PFIs
Xu et al. (2010)	40	117	4.4444	13.0000	Risk assessment of PPPs
Zhang (2001)	38	50	2.1111	2.7778	Experience of BOT project
Shen et al. (2002)	38	91	2.2353	5.3529	Concession period of BOT
Shen et al. (2007)	38	85	3.1667	7.0833	Concession period of BOT
Tiong (1996)	37	94	1.6087	4.0870	CSFs in BOT tender
Koppenjan (2005)	37	116	2.6429	8.2857	Experience of PPPs projects
Hwang et al. (2013)	37	97	6.1667	16.1667	CSFs, critical risk factors and risk allocation of PPPs
Hodge (2004)	36	113	2.4000	7.5333	Risk transfer in PPPs
Shen and Wu (2005)	35	85	2.5000	6.0714	Concession period of BOT
Marques and Berg (2011)	35	97	4.3750	12.1250	Risk allocation of PPPs

TLC/Y means average annual local citations since publication. TGC/Y means average annual global citations since publication

of times that a document cited by papers in the collected data set (i.e. the set of 1157 documents), which can be used as an indicator to represent the influence of these papers in the PPPs domain. GC refers to the number of times that a paper cited in the WOS core collection database, representing the influence of them in the circle of WOS core collection database. It's obvious that Zhang (2005a) received both the highest LC (135) and GC (256), which are much higher than other documents. The most recent high cited paper in Table 5 belongs to Hwang et al. (2013), with considerable LC (37) and GC (97). Normally, early published papers have more time to accumulate citations. In order to eliminate the impact of publication years of these papers, the parameters Total Local Citations per Year (TLC/Y) and Total Global Citations per Year (TGC/Y) are used here as well to show the influence of these publications. Specifically, Zhang (2005a), Ke et al. (2010), Hwang et al. (2013), Chan et al. (2011) and Kwak et al. (2009) were ranked in the top five in terms of TLC/Y, implying that these papers might be the most influential papers in the PPPs research field, to some extent.

To further analyze the intellectual structure of the PPPs domain, we apply the co-citation analysis and historical citation analysis to explore the PPPs field from static and dynamic perspectives respectively.



**Fig. 15** Co-citation network of cited references in the PPPs field

**Co-citation analysis: static perspective**

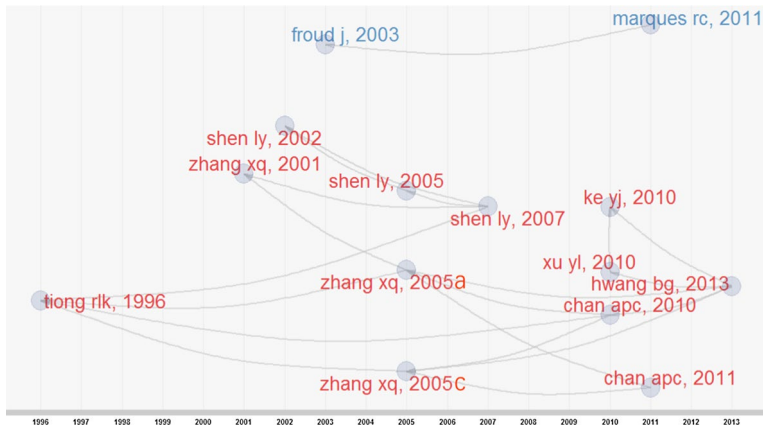
A total of 32,443 references cited by the collected 1157 papers on PPPs research constitutes a citation base of the PPPs field. Co-citation analysis, which measures the frequency of together cited papers, is applied here to explore the citation base of the PPPs field from a static perspective. If two documents are jointly cited by a subsequent document, then these two documents constitute a co-citation relationship. The more times two documents are jointly cited, the more similarities between them could be assumed (van Nunen et al. 2018). Co-citation analysis can help identify the most influential papers in a research domain and represent their co-citation relationships. In this section, Bibliometrix is used to call the VOSViewer software again to draw the co-citation network of cited references in the PPPs field as shown in Fig. 15. The co-citation network is generated by using a threshold of 20 times of citations, and a total of 124 nodes are contained in the network. In Fig. 15, each node represents a paper, the size of the nodes is proportional to the number of citations of each paper. The lines between nodes represent their co-citation relationships. Nodes with the same color indicate a similar topic among these papers. The co-citation network shows how references of these PPPs papers group together. Four distinct clusters are clearly illustrated in the network where each of them indicates a sub-domain of the PPPs field: a red cluster (right), a yellow cluster (upper left), a green cluster (middle left) and a blue cluster (bottom left). The yellow and red clusters stand more alone, while the green and blue clusters are more closely intermingled.

On the basis of the investigation of the titles and abstracts of all documents in the four clusters, a suitable label can be attached to each of them. The yellow cluster is the smallest cluster in the co-citation network. It can be observed from the themes of these papers that this cluster mainly focuses on the sub-domain of BOT infrastructure project. Topics such as the concession period (Shen et al. 2002, 2007), government guarantee (Ashuri et al. 2012; Brandao and Saraiva 2008; Cheah and Liu 2006), and capacity choice (Yang and

Meng 2000) of BOT infrastructure projects are discussed in this cluster. The green cluster mainly pivots on the risk management related issues of PPPs project, especially risk allocation (Chan et al. 2011; Hwang et al. 2013; Jin 2010b; Li et al. 2005b; Marques and Berg 2011; Medda 2007), risk assessment (Chan et al. 2011; Grimsey and Lewis 2002) and risk identification (Cheung and Chan 2011). A review study of PPPs is also included in the green cluster (Tang et al. 2010). In that paper, risk is considered as an always active research topic in the PPPs field, and discussed in detail from both empirical and non-empirical studies. Publications in the blue cluster mostly concentrate on the success of PPPs projects, among which CSFs of PPPs are mostly studied in this cluster (Jamali 2004; Jefferies et al. 2002; Li et al. 2005a; Ng et al. 2012; Osei-Kyei and Chan 2015; Qiao et al. 2001; Tiong 1996; Tiong et al. 1992; Zhang 2005a). Not limited to this topic, stakeholder management (El-Gohary et al. 2006), successful delivery (Abdel Aziz 2007), performance and value (Akintoye et al. 2003; Yuan et al. 2009) and the government role (Kumaraswamy and Zhang 2001) of PPPs are also explored in this cluster. It can be seen from the publications in the yellow, green and blue clusters, these clusters mainly concentrate in the field of construction management, as most papers in these clusters are published in construction journals.

The red cluster is the largest cluster of the co-citation network. Compared with other three clusters, more diverse topics are dealt with in this cluster. Some publications discuss PPPs/PFIs at the conceptual level (Bovaird 2004; Brinkerhoff and Brinkerhoff 2011; Froud 2003; Hodge and Greve 2007, 2010; Kwak et al. 2009; Wettenhall 2003). For example, Bovaird (2004) pointed out that PPPs is a strongly contested concept, and defined PPPs as ‘working arrangements based on a mutual commitment between a public sector organization with any organization outside of the public sector’. Hodge and Greve (2007) reviewed a variety of PPPs definitions and proposed two dimensions of PPPs, i.e. the financial and organizational dimensions. Hodge and Greve (2010) examined the PPPs phenomenon and suggested that PPPs might be viewed as either a language game or a governance scheme. Some publications focus on the financial and accounting aspects of PPPs/PFIs (Grimsey and Lewis 2005; Grout 1997; Heald 2006; Pollock et al. 2002; Shaoul 2005; Sollño and de Santos 2010), especially the topics around transaction cost (Sollño and de Santos 2010; Vining and Boardman 2008) and value for money (Grimsey and Lewis 2005; Heald 2006; Pollock et al. 2002; Shaoul 2005). Some publications study the contractual aspect issues of PPPs/PFIs (Cruz and Marques 2013; Guasch et al. 2008; Hart 2003; Lonsdale 2005; Reeves 2008). Apart from these topics, the political and institutional issues (Bennett and Iossa 2006; Flinders 2005), relationship management (Smyth and Edkins 2007), lessons of PPPs experience (Bloomfield 2006; Koppelman 2005; Spackman 2002) can be also reflected in publications of this cluster. In general, publications in the red cluster are more theoretical than the other three clusters. PPPs are mostly discussed in the frameworks of public management, public administration, accounting, and economics, as can be seen from the journals of this cluster.

It’s worth pointing out that in the co-citation network, there is a small number of references which belongs to other research domains but has an relatedness with the PPPs domain. By examining this part of references, important influences of related topics in PPPs research can be detected. For example, in the green cluster, ‘Modelling risk allocation decision in construction contracts’ from Lam et al. (2007) can be regarded as an critical influence which doesn’t belong to the main field of PPPs, but presents hot topics including risk allocation and contractual issues highly correlated to PPPs research. In the red cluster, ‘Underestimating costs in public works projects: Error or lie?’ from Flyvbjerg et al. (2002), ‘The proper scope of government: Theory and an application to prisons’ from Hart



**Fig. 16** Historical citation network of the PPPs field

et al. (1997), and ‘Building theories from case study research’ from Eisenhardt (1989) also do not belong to the main domain of PPPs research, but bear significance to influence the PPPs research, discussing cost estimating, incomplete contract, and case study research, respectively.

### Historical citation analysis: dynamic perspective

Historical citation analysis supplies a dynamic perspective to the PPPs research. Using the *histNetwork* and *histPlot* functions of Bibliometrix, the historical citation network of the PPPs field is generated as shown in Fig. 16. This figure draws the citation relationships between the top 20 local cited papers, which reveals the evolution of the research focuses of key literature in the PPPs domain over time. In this network, each node represents a paper, the links between nodes represent their citation relationship. If one paper is cited by a subsequent paper, then these two documents constitute a citation relationship. The historical citation network has two sub-networks with 14 nodes, each of the nodes has citation relationship with other papers. The left 6 disconnected papers are not shown in Fig. 16.

Digging into the full-text of these 20 key documents can help comprehend the evolution of research focuses in the PPPs field. The first sub-network contains only two nodes, both discussing risk in PPPs/PFIs. As regards their specific research contents, Froud (2003) analyzed PFIs from the conceptual perspective by focusing on risk management. He believed that PFIs rests on a conceptual conflation of uncertainty and risk, and regarded risk as critical to the presentation and rationale of PFIs. Marques and Berg (2011) studied the contractual risk associated with infrastructure PPPs projects by taking two contracts in the water sector as examples. These two papers argue that risk reflects both opportunities and threats, presenting the underlying uncertainty of developing and operating projects.

The second sub-network is a large cluster with 12 papers connected together. The earliest seed of this sub-network is the paper of Tiong (1996), which studies the CSFs and their sub-factors in BOT tendering, and analyzes the relative importance of these factors. There are four papers which form citation relationships with this paper in the historical citation network. Among them, Zhang (2005a) identified, analyzed and categorized a series of CSFs for PPPs on the basis of a systematic research method, and developed a CSFs

package containing five main CSFs. Zhang (2005c) then identified a set of important criteria for choosing the private-sector partner in PPPs on the basis of a systematic study process including the review of previous studies on CSFs, lessons learning from international PPPs practice, evaluation of the existing selection criteria and interviews with international PPPs practitioners and experts. Shen et al. (2007) described the selection of a specific concession period in a BOT type contract as a bargaining process between the private sector and the government, and applied the bargaining-game theory to examine how a particular concession period is agreed upon between the two parties. Chan et al. (2010) explored the CSFs for infrastructure PPPs projects from the Chinese perspective by collecting the viewpoints of Chinese experts through an empirical questionnaire survey.

The other two early papers independently sowing the seeds in the second sub-network are from Zhang (2001) and Shen et al. (2002). Zhang (2001) discussed key aspects of five BOT tunnels in Hong Kong and summarized some experience in managing BOT projects. Shen et al. (2002) established an alternative concession quantitative model for determining a suitable concession period of BOT infrastructure projects. Citing that paper, Shen and Wu (2005) extended the BOT concession model by taking the influence of risks into consideration, and presented an additional risk concession model for BOT contractual projects.

The last four papers in the second sub-network pivot on the risk of PPPs. Among them, Ke et al. (2010) performed a two-round Delphi survey with experienced practitioners to identify the preferred risk allocation in China's PPPs projects. Citing this paper, Xu et al. (2010) developed a risk evaluation model for China's PPPs projects based on a fuzzy synthetic assessment method. Hwang et al. (2013) examined the CSFs and the relative importance of negative and positive factors influencing PPPs project in Singapore and identified the critical risk factors as well as preferred risk allocation for Singapore's PPPs project. Chan et al. (2011) performed an empirical questionnaire survey to identify and assess the main risks of China's PPPs projects and analyzed the risk allocation between the public and private sectors.

Isolated from the above research "woods", there are six of the top 20 local cited papers disconnected from each other. Among these keystone papers, Klijn and Teisman (2003) conducted an analysis of three Dutch cases to study the institutional and strategic barriers to PPPs. Bovaird (2004) explored the PPPs knowledge state and analyzed how the move to PPPs has happened, the weakness/strength and the future of PPPs development. Hodge (2004) investigated risk transfers in PPPs based on an empirical case and established the notions of risk sharing and risk shifting. Zhang (2005b) identified a diversity of barriers to infrastructure PPPs via a questionnaire survey and developed an improved framework for infrastructure PPPs projects. Koppenjan (2005) identified three PPPs patterns based on a comparative analysis of nine Dutch transportation infrastructure projects and drew lessons from the PPPs cases. Kwak et al. (2009) collected, codified and consolidated the research findings of 20-years PPPs literature and derived some key conclusions to facilitate a comprehensive understanding of PPPs.

## Discussions and conclusions

Although there are already some literature studies on PPPs research, bibliometric research on the PPPs literature is still needed for researchers to capture more comprehensive, diverse and detailed information in this area. To serve as a complement of previous bibliometric studies, this paper continues the bibliometric journey by conducting a comprehensive

metrological and content analysis of the PPPs research field. With the help of a newly developed Bibliometrix R-package tool, the overview of PPPs research is presented through metrological analysis, and the intellectual structure of this domain is explored via content analysis. The analysis is based on a large, reliable and high quality dataset including 1157 journal articles published from 1991 to 2018 and collected from the WOS core collection database.

The scenery of PPPs research is depicted from two aspects. As regards the overview of PPPs research, the annual number distribution, citations and *h*-index of PPPs literature, most relevant and influential journals, leading researchers, institutions and countries of the PPPs field are presented. Major findings of this aspect can be summarized as follows: (1) the international study of PPPs starts at 1991 and shows a steady increasing trend with some small fluctuations, 2010 is the most prominent year with the highest values of total citations, average citations and *h*-index; (2) *Journal of Construction Engineering and Management*, *Journal of Management in Engineering*, *International Journal of Project Management* and *Public Money & Management* are the most relevant and influential journals of the PPPs field; (3) Chan APC is the most prominent researcher in the PPPs domain followed by Zhang XQ, Marques RC, Wang SQ, Tiong RKL, and Ke YJ in terms of *h*-index; (4) Hong Kong Polytechnic University is the most productive and impactful institution in terms of PPPs publications, total citations and *h*-index, while Tsinghua University gains the highest score of average citations per article; (5) China, USA, UK and Australia are the four most prolific countries of PPPs articles far ahead of other countries.

Regarding the intellectual structure of the PPPs domain, keywords analysis and citation analysis are combined applied to identify core elements of the knowledge base of this field. Based on keywords analysis, the word cloud of keywords, change of top 10 keywords by frequency, conceptual structure map, co-occurrence network with time information, strategic diagrams and Sankey diagram are presented to identify dominant semantic topics hidden in the textual data and detect thematic evolution of the PPPs domain from both static and dynamic perspectives. In this way, hot keywords of this field are intuitively displayed (Fig. 8). The research around ‘risk’, ‘infrastructure’ and ‘contract’ are detected to be prominently potential to gain more attention in the future considering the chronological change tendency of these keywords (Fig. 9). Several clusters bearing hot topics such as “contract design and management” (Cluster 1 and Cluster 2), “critical success factors” (Cluster 4), “risk management” (Cluster 3), “governance issue” (Cluster 3), “procurement” (Cluster 3), “value for money tests” (Cluster 3) and hot theories/methods including “case study” (Cluster 3), “transaction cost economics” (Cluster 3) and “game theory” (Cluster 8) are drawn to map the prominent themes of the PPPs field (Figs. 10, 11). From a temporal view of the co-occurrence network, the “younger” keywords such as ‘sustainability’, ‘factor analysis’, ‘critical success factors’, ‘case study’, ‘contracting’, ‘developing countries’, ‘real options’, ‘concession period’ and ‘Monte Carlo simulation’ are found to be more likely to flourish in the PPPs field in the future (Fig. 11). Through thematic evolution analysis, several main thematic areas named as (1) *Governance and Regulation*; (2) *Project Management*; (3) *Project Finance*; and (4) *Risk Management* have been detected and analyzed in a longitudinal framework (Figs. 13, 14).

Furthermore, using citation analysis, the co-citation network of the PPPs field and historical citation network of the top 20 local cited papers are analyzed from static and dynamic perspectives respectively. Through content analysis of the co-citation network, four distinct clusters representing some outstanding sub-domains of PPPs research are illustrated and analyzed (Fig. 15). Specifically, the yellow cluster mainly focuses on the sub-domain of BOT infrastructure project bearing the topics of concession period,

government guarantee, and capacity choice, etc., which is consistent with the theme of “contract design and management” of BOT infrastructure project reflected by Cluster 1 and Cluster 2 in Figs. 10 and 11. The green cluster involves the risk management related issues (e.g. risk identification, risk assessment and risk allocation) of PPPs project. The blue cluster mostly concentrates on the success of PPPs project involving the topics of CSFs, stakeholder management, successful delivery, performance and value, and the government role of PPPs. The red cluster mainly involves the conceptual, financial and accounting, contractual, political and institutional aspects of PPPs, whose publications are more theoretical than the other three clusters. Via content analysis of the historical citation network, some main chronological research focuses of the PPPs field are tracked using the top 20 local cited papers, which mainly involve the risk, CSFs, concession period, barriers, understandings and experience of PPPs (Fig. 16).

The main objective of this paper is to act as a complement of previous bibliometric studies on PPPs research by providing a new panoramic view of this field. In contrast with previous bibliometric studies of this domain, this paper conducts a comprehensive metrological and content analysis of the PPPs field relying on a newly developed bibliometric tool, from a holistic perspective. A set of indexes firstly used in this domain (e.g. *h*-index, PY-start, TC/Y, MCP-Ratios, TLC/Y) improves the level of metrological analysis, and the bibliometric techniques (i.e. a series of methods of keywords analysis and citation analysis) adopted in this paper broadens the depth of PPPs literature studies. The overview, pivotal points of topics, thematic evolution and research focuses of this domain are depicted visually and intuitively via a set of science maps, from both static and dynamic perspectives. This new attempt can consolidate and broaden the bibliometric findings of previous PPPs literature studies. The research framework established in this paper also provides a guidance for analyzing the knowledge base of other research fields.

Some limitations of this paper should be mentioned. Firstly, only journal articles from the WOS core collection database are used for analysis. Although WOS is one of the largest global database, it does not contain all PPPs publications. The second limitation is correlated to the retrieval code for collecting data. Although a set of specific types of PPPs are considered, some other “concessions” related to PPPs may be overlooked. Given that there is still no consensus on the meanings of PPPs, this limitation cannot be completely overcome currently. In future study, the research could be extended to use more additional databases including Scopus, JSTOR, and so on. In addition, expanding the research to conference papers, theses and dissertations could be another attempt to enrich the analysis. The retrieval code could also be improved by containing more PPPs types in future work. Despite the current limitations, the quality of bibliometric analysis in this paper has been maintained.

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## Appendix

See Table 6.



**Table 6** A summary of retrieval codes in existing PPPs review studies

Study	Retrieve codes described by the authors
Weihe (2008)	–
Ke et al. (2009)	TITLE-ABS-KEY (“public private partnership” OR “public private partnerships” OR “build operate transfer” OR “build-operate-transfer” OR “build/operate/transfer” OR “private finance initiative” OR “public-private” OR “privately financed” OR “private finance” OR “public/private” OR “private infrastructure” OR “privatized infrastructure” OR pfi OR bot OR “PPP/PFI” OR “PFI/PPP”)
Kwak et al. (2009)	–
Tang et al. (2010)	Public–Private Partnership, Private Finance Initiative, Build–Operate–Transfer, Build–Operate–Own, and joint ventures
Papajohn et al. (2011)	–
Andon (2012)	–
Osei-Kyei and Chan (2015)	TITLE-ABS-KEY(“critical success factors” OR “success factors” OR “critical factors”) AND TITLE-ABSKEY(“public–private partnership” OR “private finance initiative” OR “private infrastructure” OR “BT” OR “TOT” OR “public infrastructure” OR “ppp” OR “pfi” OR “bot” OR “boot” OR “dbfo” OR “PPP/PFI”)
Zhang et al. (2016)	For Chinese journals, PPP/PFI/BOT/BT/TOT/BOOT were used as the search keywords. For international journals, the full search code is TITLE-ABS-KEY (“PPP” OR “PFI” OR “BOT” OR “BT” OR “TOT” OR “BOOT”) AND TITLE-ABS-KEY (“Chinese” OR “China”)
Bao et al. (2018)	This study added search terms “private participation infrastructure” and “private finance 2” and their acronyms to keywords widely used by previous researchers
Chen et al. (2016)	–
Marsilio et al. (2011)	Public–private partnership (PPP); public–private collaboration (PPC)
Castro e Silva Neto et al. (2016)	PPP; PFI
Song et al. (2016)	TS=((public AND private AND partnership* AND PPP*) OR (private AND financ* AND initiative AND PFI) OR (build AND operate AND transfer AND BOT) OR (build AND operate AND own AND transfer AND BOOT) OR (build-transfer AND BT) OR (build AND own AND operate AND BOO) OR (build AND lease AND transfer AND BLT) OR (transfer AND operate AND transfer AND TOT) OR (renovate AND operate AND transfer AND ROT) OR (design AND build AND finance AND operate AND DBFO))]
Wang et al. (2018)	Title = Public–Private Partnership or PPP or Private Finance Initiatives or Build Operate Transfer or BOT or Design Build Finance Maintain or DBFM or Transfer Operate Transfer or Build Operate Own Transfer
Cui et al. (2018)	TITLE-ABS-KEY (“public private partnership” OR “public private partnerships” OR “build operate transfer” OR “build-operate-transfer” OR “build/operate/transfer” OR “private finance initiative” OR “transfer operate transfer” OR “build own operate” OR “build own operate transfer” OR “build transfer operate” OR “reconstruct operate transfer” OR “PFI” OR “BOT” OR “PPP” OR “BOO” OR “BOOT” OR “BTO” OR “TOT” OR “ROT”) AND FULL-TEXT (“infrastructure”)

**Table 6** (continued)

Study	Retrieve codes described by the authors
Song et al. (2019)	TS = [(PPP* AND public AND private AND partnership*) OR (PFI* AND private AND finance AND initiative*) OR (BOT AND build AND operate AND transfer) OR (BOO AND build AND own AND operate) OR (BOOT AND build AND operate AND own AND transfer) OR (DBFO AND design AND build AND finance AND operate) OR (TOT AND transfer AND operate AND transfer) OR (BT AND build AND transfer) OR (BTO AND build AND transfer AND operate) OR (ROT AND renovate AND operate AND transfer) OR (BLT AND build AND lease AND transfer) OR (BOS AND build AND own AND sell)]
Narbaev et al. (2020)	“Public–private partnership(s)”, “private finance initiative(s)” and “build operate transfer”

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