Technological Forecasting & Social Change 112 (2016) 347–356

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Development trajectory and research themes of foresight

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ARTICLE INFO

Article history:
Received 28 May 2015
Received in revised form 24 March 2016
Accepted 29 July 2016
Available online 9 August 2016

Keywords:
Foresight
Forecasting
Futures studies
Development trajectory
Research themes
Citation network analysis
Main path analysis

ABSTRACT

This study integrates the edge-betweenness clustering technique and key-route main path analysis to analyse the 'broad foresight' literature. We retrieve the relevant papers from the Thomson Reuters Web of Science databases and construct the citation network among them. The edge-betweenness clustering identifies six research groups in the 'broad foresight' literature. Three major research groups and their major research themes are 'technology foresight', 'futures studies', and 'technology forecasting'. The other three are 'scenario analysis', 'future-oriented technology analysis (FTA)', and 'technology forecasting using data envelopment analysis (TFDEA)'. We apply main path analysis to explore the overall development trajectory and the linkage among different research groups. We believe that the results are valuable for those who are interested in comprehending the overall development picture of 'broad foresight'. The approach used herein is also applicable to other fields.

1. Introduction

Technology foresight has been widely studied over the past decades, but the current literature lacks a systematic review work that covers such a large amount of foresight articles. Researchers of this topic also often ask about what to research when looking at foresight. We believe that this is a tough question to answer well. Thus, this paper aims at exploring the overall development trajectory and identifying the major research themes of the foresight literature.

There are several terminologies that are relevant to foresight, including futures studies, futures research, forecasting, la prospective, and anticipation. Hereafter, we name them together as 'broad foresight'. Some researchers argue that they are different themes, such as Sardar (2010) who emphasized that the term used to describe the study of alternative futures is important. Valaskakis (2010) suggested that la prospective is not futurism, forecasting, or even foresight. The futures studies of different countries are coloured by cultural and environmental differences, yet some researchers think that they are similar, but are used under different time periods or in different countries. For example, Inayatullah (2010) argued that different theories and methodologies have their own purpose and applications, and hence it is not necessary to be either for or against a specific term. Godet (2010) claimed that despite cultural differences, the concepts of la prospective and strategic foresight are very similar. Linstone (2010) considered that the debate on the terminology is a rather jejune pursuit. The maturity of information technology has triggered the convergence of the relevant terminologies.

Many researchers have conducted reviews on a specific term of broad foresight. They separately have looked at the development of forecasting (Martino, 2003; Meade and Islam 2006), foresight (Martin 2010; Miles 2010), and futures studies (Kuosa 2011). Martino (2003) reviewed the methods applied in technological forecasting and presented some advances in methodology. Meade and Islam (2006) examined the modelling development on forecasting innovation diffusion and found that the main applications are on consumer durables and telecommunications. Martin (2010) provided an insider's perspective on the origins of the concept of foresight. He adopted a case study to examine the uses of the concept of 'foresight' in the U.S. and Canada, as well as a similar concept of 'la prospective' in France to understand the origins and early evolution of technology foresight. Miles (2010) indicated that technology foresight took off in the 1990s and is far more officially acceptable and legitimate now. Kuosa (2011) discussed the evolution of futures studies and identified two existing paradigms and the emergence of a new one. While these researchers have all offered valuable concepts of broad foresight from different perspectives, there is still no article in the literature, up to now, that has reviewed 'broad foresight' together, thus potentially missing some important insights among them. This study puts all the relevant terms together to probe for some insights into broad foresight.

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http://dx.doi.org/10.1016/j.techfore.2016.07.040
0040-1625/

This study targets to answer the following questions. What is the development trajectory of 'broad foresight'? What are the major research themes of 'broad foresight'? What are the relationships or linkages among the major research groups of 'broad foresight'?

2. Methodologies

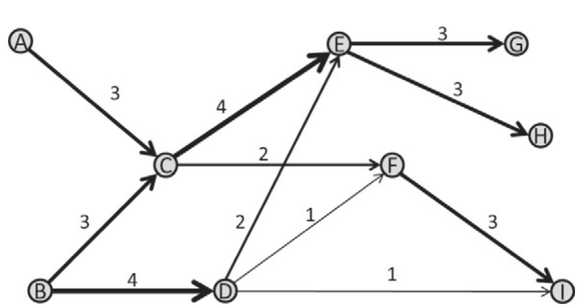
This study employs an integrated methodology, combining the edge-betweenness clustering technique and main path analysis, by retrieving the relevant papers and constructing the citation network among them. First, we use edge-betweenness clustering (Girvan and Newman 2002; Newman 2006) to the citation network in order to identify the major research groups and the citation linkage among them. Second, we apply the key-route main path analysis (Liu and Lu 2012) to explore the overall knowledge diffusion trajectory of the broad foresight literature and exhibit the relationship among the research groups. Third, we utilize the global main path analysis on the three medium-sized research groups to identify their development trajectories. We briefly describe the concept of main path analysis and edge-betweenness clustering below.

2.1. Main path analysis

Hummon and Doreian (1989) introduced main path analysis by proposing a procedure to identify the major development trajectory of a specific scientific field. The procedure for main path analysis is as follows. First, it constructs the citation network among the relevant papers of a scientific field. Second, it calculates the 'traversal count' for each link of the citation network. Third, it searches the main path according to the traversal counts. Many researchers have applied main path analysis to bibliographic citation data or patent citation data to explore the scientific or technological development trajectories (Lucio-Arias and Leydesdorff 2008; Moore et al. 2006).

Fig. 1 illustrates a simple example of a citation network to describe the concept of main path analysis. Each node represents a paper, and the link between two nodes indicates the citation relationship. A source node is a node that is cited but does not cite any other node in the network. A sink node is a node that cites other node(s) but is not cited. When one exhausts all the searches from all the source nodes to all the sink nodes, the search path count (SPC) of each link is defined as the total number of times the link is traversed.

The traditional main path is a 'local search', because it begins the search from all the source nodes and selects the link(s) with the largest SPC value for the next search until a sink node is reached. In Fig. 1, link B–D is selected first and then D–E, E–G, and E–H are chosen sequentially. The local main paths are B–D–E–G and B–D–E–H. One can find that the accumulated SPC value of the local main paths is 9 and is lower than that of paths A–C–E–G, A–C–E–H, B–C–E–G, and B–C–E–H. The accumulated SPC value of the latter ones is 10. It means that the traditional main path analysis has the shortcoming of missing some significant paths. Liu and Lu (2012) supplemented this by proposing several new types of main paths, including global and key-route main paths. The global main path is defined as the path with the largest accumulated SPC value. Here, A–C–E–G, A–C–E–H, B–C–E–G, and B–C–E–H are the global main paths generated under the definition.



Note: The thicker the line is, the higher the SPC index.

Fig. 1. A simple citation network with the SPC index.

Neither the local main path nor the global main paths include all the links with the largest SPC. The key-route main path is introduced to overcome this issue. The key-route main path is formed as follows: identify the links with the largest SPC as the key-route(s); trace backward from the start node of the key-route and forward from the end node of the key-route until a source or a sink node is reached; combine all the key-route(s), the generated forward searching paths, and the backward searching paths to compose the key-route main path. In Fig. 1, the key-route main paths are A–C–E–G, A–C–E–H, B–C–E–G, B–C–E–H, B–D–E–G, and B–D–E–H.

Combining the local, global, and key-route main path analyses, one can view the development trajectories from different perspectives. These new types of main paths have been applied to various fields and are demonstrated to be quite useful in understanding the whole picture of a theoretical or technological development (Liu et al. 2013a, 2013b; Lu and Liu 2013). Among these main paths, the key-route main path is able to exhibit the convergence and divergence phenomenon of a scientific development and is so far the most widely adopted main path.

2.2. Edge-betweenness clustering

Girvan and Newman (2002) proposed an edge-betweenness clustering technique to group networks. The betweenness of an edge is the number of the shortest paths between pairs of vertices that run along it. Edge-betweenness can be used to split a citation network into several groups. Fig. 2 illustrates the concept of edge-betweenness clustering. When links a, b, c, and d are removed, three groups are clearly identified. In a network, two nodes can be considered similar, or structurally equivalent, if they have identical links with all the other nodes. Under the context of this study, that means two articles pursue similar topics if they not only cite the same set of literature, but also are cited by another identical set of literature. Based on this assumption, Newman and Girvan (2004) demonstrated that edge-betweenness clustering is a feasible and useful approach to group a large-scale citation network (Newman 2004).

Newman (2006) further recommended the concept of modularity to decide the optimal structure of a network. The modularity is defined as 'the number of edges (links) falling within groups minus the expected number in an equivalent network with edges placed at random'. The optimal division of a network is the one with the largest network modularity. The procedure of edge-betweenness clustering is as follows. First, calculate the betweenness for all links of the citation network.

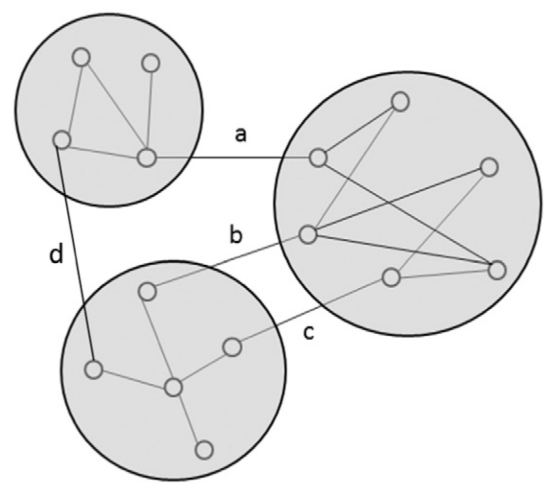


Fig. 2. Illustration of edge-betweenness clustering.

Second, remove the link with the highest betweenness. Third, recalculate the betweenness for all links affected by the removal. Repeat the second and third steps until two groups are divided, and then calculate and record the modularity. The above steps are repeated until all the links are removed. Finally, select the network division with the largest modularity as the optimal result.

In the broad foresight field, many papers may simultaneously discuss all three topics of foresight, forecasting, and futures studies. Moreover, a term (method) may belong to more than one topic - for instance, the method 'scenario analysis' is used in both foresight and forecasting. Therefore, it is difficult to cluster papers according to keywords. The edge-betweenness clustering is a citation-based approach to divide the citation network into groups within which the network connections are dense, but between which the network connections are sparse. A citation-based clustering is more appropriate for grouping the broad foresight literature than a keyword-based one.

3. Data

We collected the keywords from some review papers and their references (Martin 2010; Miles 2010) and then consulted with experts in this field to make the set of keywords as complete as possible. The final set of keywords includes 'anticipatory intelligence', 'emerging generic technology', 'futures studies', 'futures research', 'futuristics', 'futurology', 'la prospective', 'project foresight', 'research foresight', 'technological forecasting', 'technology forecasting', 'technological foresight', 'technology foresight', 'technology anticipation', 'technological prediction', 'technology prediction', 'future-oriented technology analysis', 'foresight support system', and 'ICT foresight'. We use the set of keywords to retrieve the relevant papers from the databases of ISI Web of Science (WOS) in November 2015.

The basic search on title, abstract, author keywords, and KeyWords Plus is used. The time span of data retrieval ranges from 1977 to 2015, bringing for a total of 1439 related articles. We remove those articles from anonymous sources and run a proprietary main path analysis to build the citation network. The data in the fields of authors, publication name, cited references, year published, volume, beginning page, and digital object identifier are used to construct the citation network. Only 785 out of the 1439 articles construct the citation network. In the end, we keep these 785 articles as the final dataset for further main path analysis, because this study uses citation-based methodologies.

3.1. Journal statistics

We find that there are 11 journals that have published more than 10 foresight-related papers. Table 1 lists the data for total number of papers published, g-index, h-index, citations per paper, active year, and journal title. We follow WOS' document type to classify the category of a paper into article, bibliography, book review, editorial material, note, and review. We present these data in the parenthesis of the column for the total number of papers published. The h-index and g-index do not exclude self-citation and co-authorship.

The two journals *Futures* and *Technological Forecasting and Social Change* are the most active in this field. They have respectively published 312 and 223 broad foresight-related papers over the past 39 years. Other journals have published less than 30 papers.

3.2. Growth curve of journal and author

Fig. 3 shows the curves of the accumulated number of researchers who have published broad foresight-related papers and the accumulated number of papers that have been published. In general, the numbers of both researchers and papers exhibit a growing trend over the past 39 years. The research community is in the growing stage now.

4. Results

We first apply edge-betweenness clustering to identify the major research groups in this field and provide basic information for each group. We next adopt two types of main path methods, key-route and global, to explore the development trajectory of the broad foresight. Key-route main path analysis is applied to depict the picture of the overall knowledge diffusion trajectory, because the key-route main path can identify the divergence-convergence phenomenon of the overall development in a targeted field. The global main path is used to probe the major papers contributing to the development in each group.

4.1. Major research themes

We use the edge-betweenness clustering technique to identify the research themes of the broad foresight literature. The result consists of six groups with the number of papers from 22 to 177 along with many small groups that published less than 20 papers. After clustering into groups, we apply a word cloud technique on the titles, author keywords, and abstracts of all the papers in each group to identify the major keywords and label each group accordingly. A word cloud is a visual representation of text data. The larger the typeface size is, the higher the appearance of the keywords. The keywords in each group are listed in the order of the number of appearances. Table 2 shows the theme, the number of papers, keywords, and growth curve of these six groups.

After analysing the keywords, we select the highest appearance keyword(s) in each group to name the first three major groups as 'technology foresight', 'futures studies', and 'technology forecasting'. The other three medium-sized groups also discuss similar themes, but further focus on specific topics under these themes. When labelling these three medium-sized groups, we neglect the same keywords that appear in the three major groups and name them as 'scenario analysis', 'FTA' (future-oriented technology analysis), and 'TFDEA' (technology

Table 1
Journals that published more than 10 papers.

Total papers[a]	g-Index	h-Index	Citations/paper	Active years[b]	Journal
312 (242/5/18/41/2/4)	33	17	5.92	1977–2015	Futures
223 (193/1/18/7/1/4)	43	28	11.91	1977–2015	Technological Forecasting and Social Change
27 (23/0/0/3/0/1)	16	8	10.56	1995–2015	Technology Analysis & Strategic Management
23 (22/0/0/1/0/0)	5	4	2.13	1998–2015	American Behavioral Scientist
19 (18/0/0/0/0/1)	9	6	6.16	1996–2011	International Journal of Technology Management
18 (11/0/7/0/0/0)	9	4	5.5	1977–1997	Long Range Planning
12 (10/0/2/0/0/0)	10	6	9.33	1979–2012	R & D Management
11 (9/0/1/1/0/0)	11	8	19	1982–2003	Journal of Forecasting
11 (10/0/0/0/0/1)	10	8	9.82	2002–2015	Technovation
11 (2/0/3/5/1/0)	2	2	0.55	1993–2014	Futurist
11 (11/0/0/0/0/0)	2	2	0.73	1978–2015	Journal of Scientific & Industrial Research

[a] Article/bibliography/book review/editorial material/note/review.
[b] Only the volumes indexed in the WOS.

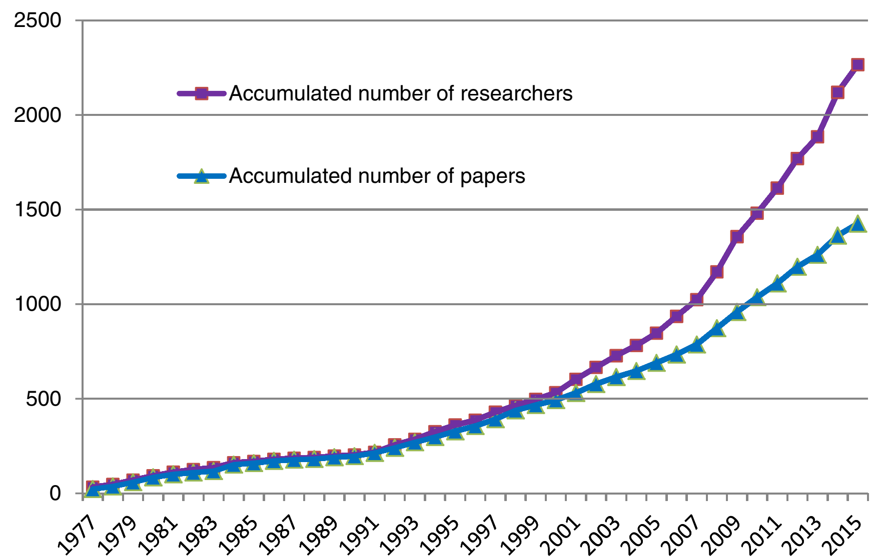


Fig. 3. The growth curve of the numbers of researchers and papers.

forecasting using data envelopment analysis). From the growth curve we see that three medium-sized groups are emerging research themes, because researchers did not put more efforts on them until the year 2000.

The power of information technology (IT) has increased the data analysis capability in technology forecasting and foresight, inducing a convergence phenomenon among different kinds of futures research. Although the six research groups are identified and named independently, there are some linkages among these research groups. Fig. 4 exhibits the citation linkage among them. One can see that the linkage between group 'technology foresight' and 'technology forecasting' is intensive, while a similar situation exists between the group 'futures studies' and 'scenario analysis' as well as between 'technology foresight' and 'futures studies'. Fig. 4 demonstrates the phenomenon of cross-citing. The contents of Table 2 and Fig. 4 support that the concept of 'broad foresight' is on the right track.

4.2. Overall knowledge diffusion trajectory

Fig. 5 shows the key-route main path of the broad foresight literature with the number of key-routes set at being 10. We see two major streams in the key-route main path. Papers in the left part discuss the issues of technology forecasting and foresight, while papers in the right part mainly investigate the topics of futures studies. We briefly discuss them below. In Fig. 5 to Fig. 8, the nodes in green, red, and blue colors indicate the source, intermediate, and sink nodes, respectively.

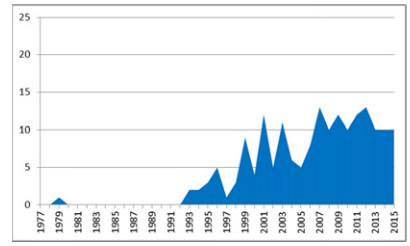
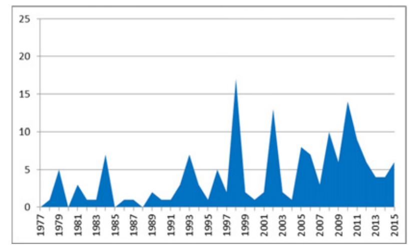
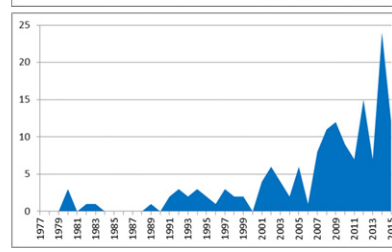
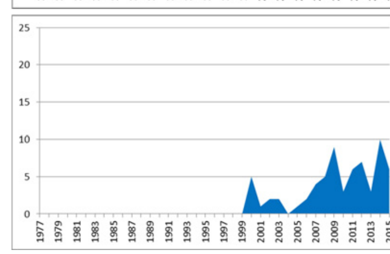
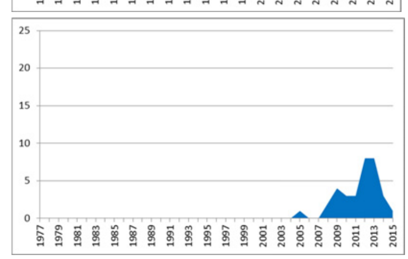
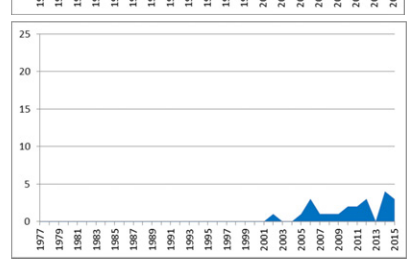
In the upper middle part, researchers investigated the issues of technology forecasting, with some examining the activities of technology forecasting in different countries. Balachandra (1980) argued that more companies in the U.S. industry employ technological forecasting than in the past and greatly perceive its importance. Ayres (1989) reported that managers in U.S. firms face very critical decisions on the timing of technological switching and raised some issues of forecasting. Bowonder and Miyake (1993) described the status of technological forecasting in Japan and related that the foci of technological superiority are in photonics, nanotechnology, lasers, robots, and fuzzy logic. Some researchers focused on an examination at the industry and corporate levels. Hauptman and Pope (1992) studied the executive analysis, anticipation, and planning process of the die magnetic resonance imaging industry and proposed a normative typology of executive decision-making in technological forecasting. Van Wyk (1997) proposed a process for strategic technology scanning that emphasizes the involvement of all levels of the corporate hierarchy. Several researchers have devoted efforts at strengthening the theories and methodologies. Du Preez and Pistorius (1999) presented the concept of technological threat and opportunity assessment for anticipating technological change. Coates et al. (2001) suggested a new tool of technological forecasting that borrows the theories from computer science, innovation management, political science, and scientometrics.

In the upper left part, researchers mostly focused on the studies of technology foresight at the country or industry level. Godet (1986) introduced 7 key ideas and one scenario method of 'la prospective' and described a new structural analysis approach and its application. Martin (1995) analysed the foresight experiences of Australia, Germany, Japan, New Zealand, the Netherlands, the UK, and the U.S. and answered why some foresight exercises are more successful than others. Blind et al. (1999) presented the status of foresight activities in Central Europe. Van der Meulen et al. (2003) reviewed the foresight program of agriculture in the Netherlands and indicated that it improves the strategic thinking in that nation's agricultural sector. Cuhls (2003) described that, in the 1990s, the wording changed from forecasting to foresight and reported the foresight process in Germany. Konnola et al. (2009) developed a collaborative foresight method and demonstrated its usefulness in the foresight process in Finland.

In the lower left part, the emerging topic of 'future-oriented technology analysis' is popularly discussed. The powerful capabilities provided by information technology induce the rejuvenation and growth of FTA. Holopainen and Toivonen (2012) examined Ansoff's (1975) concept of weak signals and argued that the concept is applicable for futures research. Tuomi (2012) argued that policy, strategy, and future-oriented analyses need to move beyond evidence-based approaches. Haegeman et al. (2013) suggested that integration between quantitative and qualitative methods in FTA is helpful for its future development. Cagnin et al. (2013) concluded that combining qualitative and quantitative approaches of FTA is a feasible way to deal with disruptive changes and grand challenges. Georghiou and Harper (2013) described that the practice of FTA can deal with disruptive transformation. Carabias-Hutter and Haegeman (2013) showed that many institutionalized forms of FTA have been proposed and that the exploitation of FTA networks provides agile and strategic support for decision-making.

For the literature of futures studies, researchers discussed the topics of programs, methodologies, and taxonomy. Masini and Gillwald (1990) investigated the situations of futures studies conducted in West Germany and the U.S. Sardar (1993) revealed that futures research is becoming a tool for the marginalization of non-Western

Table 2
Themes, number of papers, keywords, and growth curve of each group.

Group	Theme	No. of papers	Keywords	Growth curve
1	Technology foresight	177	Foresight Technology Future Research Development Delphi	
2	Futures studies	160	Futures Studies Future Research Foresight	
3	Technology forecasting	157	Technology Forecasting Patent Analysis Technological	
4	Scenario analysis	66	Scenario Futures Studies Planning Foresight Analysis	
5	FTA	33	FTA Technology Analysis Future-Oriented Future	
6	TFDEA	22	Technology Forecasting TFDEA Technological DEA	

cultures and women from the future. Inayatullah (1998) argued that causal layered analysis is a new method for futures research and is useful not only in predicting the future, but also in creating transformative spaces for the future. Slaughter (2002) suggested going beyond the mundane and reconciling depth and breadth in futures studies. Slaughter (2008) concluded that 'integral futures' is a productive approach to understand futures studies and provided some suggestions for the field. Inayatullah (2010) argued that it is not necessary to be either for or against integral futures or causal layered analysis. Different theories and methodologies have their own purpose and usefulness.

In 2010 researchers debated the terminologies used in 'futures studies'. Some argued that these terms are similar, while others insisted that they are different. Sardar (2010) contended that 'futures studies' is better than 'futurology' and 'foresight' for naming the study of the future

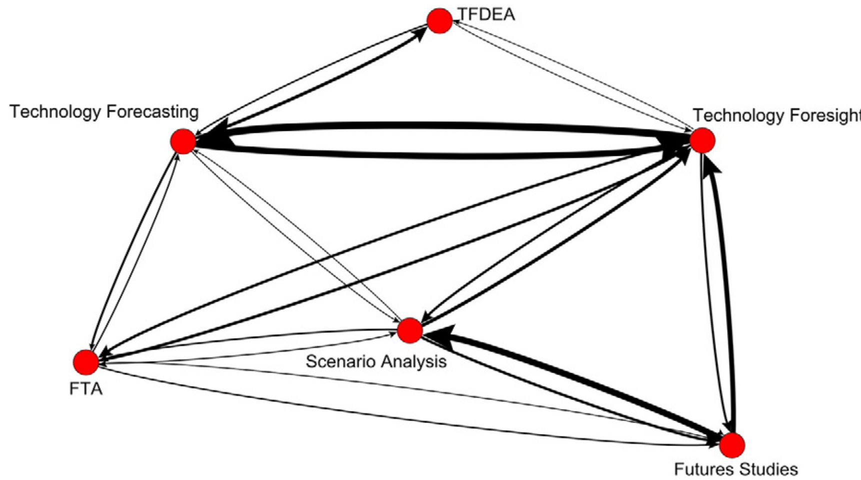


Fig. 4. Citation linkage among six research groups.

and presented four laws of futures studies: wicked, mutually assured diversity, sceptical, and futureless. Marien (2010) revisited the taxonomy of 12 types of futurists in response to Sardar's (2010) 'the namesake' viewpoint. Martin (2010) described the origins of the concept of 'foresight' in science and technology and highlighted that foresight is similar to the approach of 'la prospective' developed in France. Miles (2010) reviewed the development of technology foresight. Magruk (2011) presented and classified a collection of foresight methods. Wysokinska et al. (2013) reported an empirical foresight project in the textile industry in Poland.

When viewing the trajectory from a timeline perspective, it exhibits that futures studies, technology forecasting, and technology foresight are simultaneously investigated by the research community from the broad foresight. Foresight and forecasting converged around 2000.

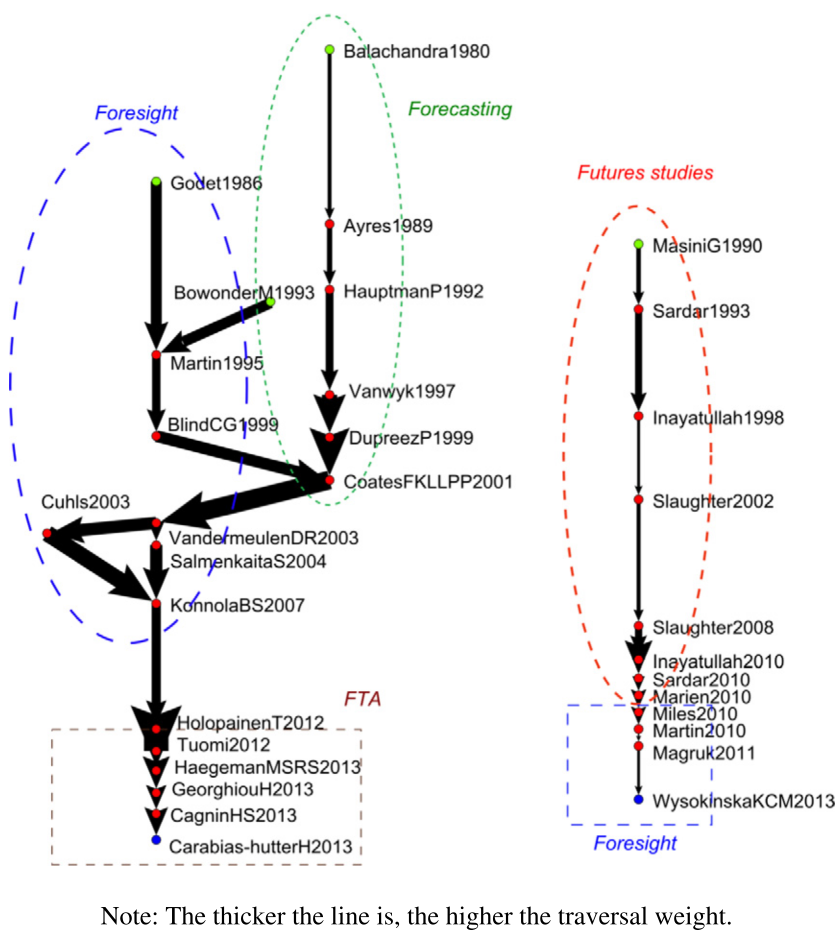


Fig. 5. Overall knowledge diffusion trajectory.

Foresight has gained more attention since 2010, and FTA is recently becoming an emerging research theme. In the main path analysis, review papers gain an advantage over non-review papers, because the former in general attract more citations than the latter.

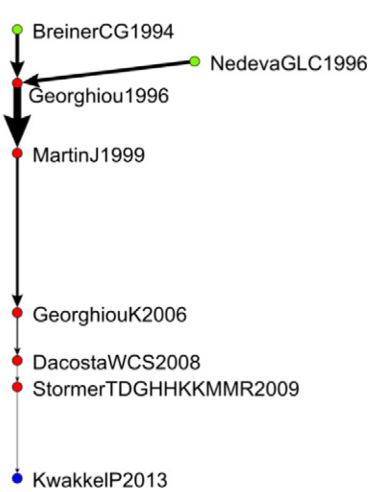
4.3. Global main paths of three major groups

One can understand the divergence and convergence phenomenon of the broad foresight development from the key-route main path. One may further want to know the development in each group. Below we apply the global main path analysis to identify the major papers that participate in the development.

4.3.1. Group 1: technology foresight

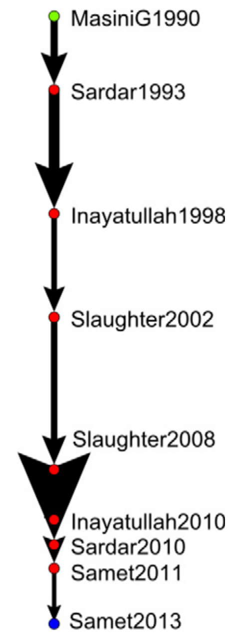
Papers in this group are the research studies of technology foresight, including technology foresight activities applied in different countries and industries, as well as the methods used in technology foresight. Fig. 6 shows the papers in the global main path of the group technology foresight.

Breiner et al. (1994) compared similar technology foresight projects, through a Delphi survey conducted in Japan and Germany, to understand the cultural influences on technology assessment. Georghiou (1996) examined the UK Technology Foresight Programme, and Nedeva et al. (1996) reported the detailed process of the co-nomination that is used in this technology foresight project. Martin and Johnston (1999) compared the approaches of technology foresight conducted in the United Kingdom, Australia, and New Zealand to identify the strengths and weaknesses of each approach. They proposed a new method for wiring up the national innovation system. Georghiou and Keenan (2006) evaluated the foresight programs in the United Kingdom, Germany, and Hungary and concluded that there is no 'one-size-fits-all' approach. Da Costa et al. (2008) elaborated upon six functions of foresight for policy-making from the FORLEARN project in Europe and presented guidelines for improving foresight practice. To address the trade-offs related to value conflicts, context uncertainties, and sustainability deficits, Stormer et al. (2009) introduced the method of 'Regional Infrastructural Foresight' and reported its application to strategic planning in Switzerland. Kwakkel and Pruyt (2013) investigated the Exploratory Modelling and Analysis (EMA) approach and concluded that EMA is useful for generating foresights.



Note: The thicker the line is, the higher the SPC value.

Fig. 6. Global main path of the group technology foresight.



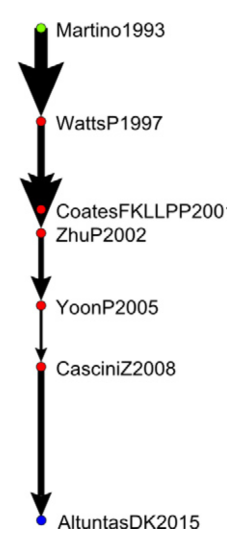
Note: The thicker the line is, the higher the SPC value.

Fig. 7. Global main path of the group futures studies.

4.3.2. Group 2: futures studies

Fig. 7 shows the global main path for the group of futures studies. The papers in the global main path discuss the concepts and methodologies of futures studies, futures research in different disciplines, and the future of futures studies.

The papers before year 2010 have been described in Section 4.2, and we only report the rest below. Samet (2011) disclosed five major schools of futures studies and outlined complexity science applications for each of the schools. Samet (2013) claimed that the emergence of 'science of cities' provides the bases for long range futures research and the



Note: The thicker the line is, the higher the SPC value.

Fig. 8. Global main path of the group technology forecasting.

features of a complexity theory of cities involved in multiple scientific disciplines.

4.3.3. Group 3: technology forecasting

Fig. 8 shows the global main path of group technology forecasting. The major topics of the papers in this main path focus on the methodologies and models used in technology forecasting, as well as the applications of technology forecasting in different fields.

Martino (1993) argued that there are only four basic methods of forecasting: extrapolation, leading indicators, causal methods, and probabilistic methods. Technological forecasters use variations and combinations of all four. Watts and Porter (1997) offered a concept of 'innovation forecasting' that combines technological trends, mapping of technological interdependence, and competitive intelligence. Coates et al. (2001) claimed that promising new tools are anticipated via borrowing various concepts from other fields. Zhu and Porter (2002) reported that automated extraction and visualization of information are helpful for generating technological intelligence and forecasting. Yoon and Park (2005) proposed a keyword-based morphology analysis method for identifying technology opportunities. Cascini and Zini (2008) introduced a patent comparison algorithm to measure patent similarity and applied it in the field of electric current circuit breakers. Altuntas et al. (2015) proposed a method for forecasting technology success based on patent data and demonstrated its applications on three technologies.

4.4. Influential papers in other groups

The number of papers in the three medium-sized research groups is not appropriate for conducting main path analysis. We briefly describe some influential papers in each group below.

In the group 'scenario analysis', researchers contributed to methodology development and applications. Bradfield et al. (2005) traced the origins and growth of scenarios and probed three main schools of methodology. Borjeson et al. (2006) developed the typology for scenario practices and techniques. Hojer et al. (2008) identified the connections between different types of scenarios and the tools used in environmental systems analysis. Coreau et al. (2009) suggested that ecological futures research should rebalance scenarios and predictive models. Moriarty (2012) applied scenario analysis in tourism planning and policymaking.

The powerful capabilities provided by information technology have advanced the process of FTA. Some special issues published in Technology Forecasting and Social Change reported the activities and papers presented in related conferences. The 2004 EU-US seminar on 'New Technology Foresight, Forecasting and Assessment Methods' presented the rejuvenation and growth of FTA (Scapolo 2005), with methodologies and tales from the frontier discussed at this seminar. The Second International Seville Seminar on FTA focused on the impacts of FTA on policy and decision-making (Harper et al. 2008; Scapolo et al. 2008). The third conference for FTA emphasized the impacts and implications for policy and decision-making (Konnola et al. 2009). Saritas and Burmaoglu (2015) adopted a scientometric analysis to the publications of the major FTA journals to examine the evolution of foresight methods.

In TFDEA, Anderson and colleagues introduced the concept of TFDEA and applied it to various technologies. Anderson et al. (2002) employed data envelopment analysis (DEA) to examine Moore's law and to measure the progress of a technology. Inman et al. (2006) demonstrated that TFDEA is a powerful technique for predicting complex technological trends and time to market. Anderson et al. (2008) used the TFDEA technique to predict the future of wireless communications technologies. Lamb et al. (2012) proved that TFDEA is also useful for setting R&D targets. Lim et al. (2014) argued that a secondary objective function can solve the multiple optima problem generated by traditional TFDEA.

5. Conclusion

This paper's clustering technique reveals three major and three medium-sized research groups within the broad foresight literature, providing some related data for each group. The research themes and growth curve disclose information as to the active topics and hint at topics for future research. The overall development trajectory depicts the historical evolution and clearly shows the relationship among all the research themes of broad foresight by time, by school, and by research theme. We believe that the results depicted in this study offer a valuable reference for those interested in the broad foresight literature and help fill the gap in the literature review of the foresight field.

This study has demonstrated that the methodology applied is a feasible and practical approach to exploring the overall development trajectories and in identifying the major research themes in the foresight literature. This approach is also applicable to other academic fields. Furthermore, the results of this study help us gain several insights which are supported with real data. First, the convergence among foresight, forecasting, and futures studies have occurred gradually in recent years, as the power of IT has blurred the lines among different futures research methods. This makes any debate on which method is suitable for what situation somewhat unnecessary. Figs. 4 and 5 provide evidence of the convergence and intersection. Second, several emerging research themes are gradually attracting researchers' interest at putting more efforts on them. Examples are scenario analysis, FTA, and TFDEA. The growth curves in Table 2 clearly reveal the phenomenon. While other developing themes such as 'foresight support system' and 'ICT foresight' are promising (Keller et al. 2015; Von der Gracht et al. 2015), they are not exhibited in the clustering results, because they have yet to form a significant cluster. We believe that the research on these themes will grow gradually in the near future. If one narrows down the time span of data retrieval to a certain level, then the newly developing themes can be exhibited more clearly. Third, the overall knowledge diffusion trajectory exhibits a dynamic evolution in the broad foresight field. The results indicate that various methods are being increasingly used in broad foresight research activities and reconfirm Saritas and Burmaoglu's (2015) observation.

The approach adopted in this study can also be applied to any technological field. For example, one can select a target technology (e.g. RFID), retrieve relevant patent data from the USPTO database (or other patent databases), and then apply the key-route main path analysis and edge-betweenness clustering method to the citation network established from the patent citation data. The technological development trajectories and major research themes of the target technology can thus be identified. Any researcher who is interested in analysing a specific technology can adopt a similar approach to gain a full picture of that technology.

We need to highlight that the clustering technique used in this study is citation-based instead of keyword-based. A group may consist of papers discussing different research topics as long as these papers cross-cite each other. Hence, a research group may include different foresight terminologies. Moreover, the analyses of this study are based on the publications from WOS. As such, the results concluded may miss some foresight activities that are not listed in the WOS database.

Acknowledgments

The authors thank the partial financial support from the National Science Council Taiwan grants NSC 102-2636-H-155-001-MY3, 102-2410-H-155-021-MY3 and 102-2410-H-011-008-MY3.

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