A survey of bibliometric tools and techniques and their applications for technology forecasting

John R Taylor

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Department of Information Studies

Aberystwyth University

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Abstract

The following study set out to examine the bibliometric tools and techniques required to inform a technology forecast. The principal aims were to establish the ability of bibliometric analysis to provide a technology forecast and indicate which tools and techniques would be best suited for this task.

The research was undertaken in two parts, literature review and practical case methodology. The literature review was complemented with a review of suitable software. A selection of software packages were reviewed to both provide an overview of the available tools and to select a tool with which to carry out the practical case study.

The range of tools and techniques noted by the literature and software reviews were an indication of the significance of bibliometric analysis for technology forecasting and this was supported by the findings of the practical case study. The case study also highlighted the limitations of some bibliometric techniques and illustrated the ultimate need for statistical analysis to inform the final forecast.

It is recommended that any similar study should be carried out on a larger dataset and that subject matter expert opinion should be sought to provide qualitative analysis. Further study of new database sources, especially non-subscription sources would also be a useful adjunct to this study.

It is concluded that bibliometric analysis is a fundamental tool for technology forecasting and is an excellent method for technology assessment given the available sources and the development of increasingly sophisticated techniques. It is also noted that some techniques are limited in their use for technology forecasting and that no single software currently supplies a complete solution to the problems of technology forecasting - the ultimate forecast remains dependent on further statistical analysis.

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Abbrevations

DII	Derwent Innovations Index
HTML	HyperText Markup Language
ICT	Information and Communication Technologies
MEMS	Micro-Electrical-Mechanical Systems
NLP	Natural Language Processing
JACS	Journal of the American Chemistry Society
JASIST	Journal of American Society for Information Science & Technology
JPEG	Joint Photographic Experts Group
PNG	Portable Network Graphics
RFID	Radio-frequency Identification
RIS	Research Information Systems
SCI	Science Citation Index
SSCI	Social Sciences Citation Index
TFIDF	Term Frequency Inverse Document Frequency
USPTO	United States Patent Office

CHAPTER ONE - INTRODUCTION

Background

Both bibliometrics and technology forecasting are relatively modern social science disciplines. Although bibliometrics can lay some claim to a tangible history, having its roots in early works such as the Gross and Gross (1927) citation study of the Journal of the American Chemical Society (JACS) and subsequently hardening into an academic discipline during the 1970s and 80s, technology forecasting only truly emerges after the Second World War. The development of both disciplines has benefitted immensely from the information technology boom of the 1990s. The availability of online citation databases coupled with cheaper, more powerful personal computing has vastly expanded the horizons of technology forecasting and bibliometrics.

Analytical tools and techniques for citation databases have been developed since the 1960s following Garfield and Sher's (1963) early work on citation indexing and more recently with the development of online bibliometric analytical tools such as the suite of tools developed by Leydesdorff (2013) and commercially or freely available bespoke bibliometric software such as CiteSpace and VantagePoint.

Bibliometrics is defined by the Karolinska Institutet Bibliometrics Project Group as "the application of mathematical and statistical methods to publications" and they also note that it is "often used to assess scientific research through quantitative studies on research publications" (Bibliometrics: Publication Analysis as a Tool for Science Mapping and Research Assessment, 2008, p. 2). Bibliometrics assumes that scientific research is published and peer reviewed. It is also assumed that the citations are made available through citation databases. Building on these assumptions technology forecasters have come to view bibliometrics as one of the principal building blocks for any piece of technology forecasting research and it is the primary method used to "capture some of the information inherent in the content and patterning of the literature" (Watts & Porter, 1997, p.27).

The following research is intended to highlight how bibliometric methods can be used to analyse data for technology forecasts and to suggest which tools might be most useful to researchers. In support of this intention a review of bibliometric techniques and tools most applicable to technology forecasting is provided along with a review of available software packages suitable for the task and the reviews are used to develop a methodology for a practical case study. The practical study examines the technology of electrophoretic ink and compares suggested bibliometric techniques to provide information for the technology forecast. The study also examines how a combination of bibliometric and statistical techniques can be used to produce a final technology forecast.

Issue

The main issue addressed by this research is to identify the possible applications of bibliometrics for technology forecasting. The study also discusses the limitations of bibliometrics and considers to what degree bibliometric techniques alone are sufficient to inform technology forecasts. The study discusses which bibliometric techniques should be used and which other research methods could be combined with bibliometrics. The tools (software etc.) required for technology forecasting are discussed and several candidate software packages were reviewed. The software review was specifically tailored to identify a package robust enough to provide the range of statistical interpretations required by a technology forecaster.

Aims and structure

The research aims to identify specific bibliometric tools and techniques that can provide suitable forms of analysis for technology forecasts. The research examines how different methods and different blends of methods may be employed. The research also makes reference to some of the alternative non-bibliometric techniques employed by technology forecasting researchers and how these methods may be used in tandem with bibliometric techniques.

The initial hypothesis of the study was that in the 'Information Age' bibliometric techniques are an important, possibly the most important tools used by technology forecasters. The study also hypothesised that the available software and tools available to be researchers might be enough to produce technology forecasts without the addition of other research methods. The research was designed to examine these tools and techniques and conclude on the relative usefulness of individual pieces of software and highlight the most important techniques to use.

The following study was conducted through a combination of literature review, software review and practical technology forecasting case study. All elements of the study are intended to highlight the importance of bibliometrics as tool for technology forecasting.

The study begins with a broad introduction to bibliometrics, including a short history of the discipline. A similar introduction to technology forecasting is provided including a brief history and an introduction to the basic principles of this relatively youthful discipline.

The study is principally guided by the results of the initial literature review and a comprehensive literature review is provided. The review was designed to retrieve a broad spectrum of publications covering the application of bibliometrics within technological forecasting. The results of the review are presented thematically. Discussion is provided on the themes of technology forecasting, including some background on the development of the discipline; general bibliometric techniques and specific bibliometric techniques for technology forecasting with some reference to other applicable social science research methods being made. The bibliometric methods employed in the practical section of the research were those indicated in the literature review as being the most appropriate for technology forecasting.

A review of bibliometric software tools is also provided. The tools review makes recommendations as to which software packages are adequate for technology forecasting. The review also functioned as a method of selecting the appropriate software for the practical research element of this dissertation. The candidate technology for research, in this case electrophoretic ink, is introduced with an outline history of the subject and the reasons for its selection are presented. The remainder of the study discusses the results of the research and conclusions are drawn from these results.

Bibliometrics

The first formal definitions appear to have been coined as follows: Pritchard (1969, p. 348) defines bibliometrics as "the application of mathematical and statistical methods to books and other media of communication"; Nalimov and Mulchenko (1969) cited by Braun, Glänzel and Schubert (1985, p. 5) define scientometrics as "the application of those quantitative methods which are dealing with the analysis of science as viewed as an information process". As these first formal definitions appeared almost simultaneously, bibliometrics and scientometrics can be regarded as synonomous terms. Bibliometrics has been retained as the preferred term throughout this study.

Various claimants to the first bibliometric study can be found in the literature of the discipline. Sengupta (1992, p. 75) champions Campbell's (1896) study as the first of its kind. Lawani (1981, p. 296) makes a similar claim for Cole and Eales (1917) and Glänzel and Hornbostel (2011, p. 6) cite the Gross and Gross (1927) study of JACS as the earliest known bibliometric survey, although they warn that this is "not a citation analysis in the sense of present day bibliometrics".

Up until the 1970s bibliometrics was primarily employed as a library retrieval tool rather than as a means of evaluating research. As a new science indicators movement grew in the US during the 1970s so the discipline was driven forward. During this period "bibliometrics evolved from an invisible college, from a sub-discipline of and information science to an instrument for evaluation and benchmarking" (Glänzel & Hornbostel, 2011, p. 18).

During the 1970s and 1980s bibliometrics made the transition to a formally institutionalised and established discipline, ultimately finding itself at the intersection of "information science, computer science and the sociology of science" (Glänzel & Hornbostel, 2011, p. 19). The information revolution of the 1990s drives forward the evolution of bibliometrics to the fully formed academic discipline of today.

Technology forecasting

Coates et al. (2001) provide a useful definition of technology forecasting proposing that it encompasses "all purposeful and systematic attempts to anticipate and understand the potential direction, rate, characteristics, and effects of technological change, especially invention, innovation, adoption, and use" (p. 1).

The origins of technology forecasting are traced back by Coates et al. (2001) to the New Deal's National Resource Commission (United States. US National Resources Committee, 1937) which researched the future of a number of important inventions. The discipline is shown to have developed alongside US science policy after World War II and continued to grow with the introduction of systems analysis during the Cold War. However development of the discipline appears to be largely uneventful up until the end of the 20th Century. The period from 1975 to the early 1990s is seen to be largely stagnant. This phase is followed by a more dynamic era, propelled by advances in computer processing power and the development of the World Wide Web.

The introduction has outlined the proposed structure of the dissertation and has discussed the background of bibliometrics and technology forecasting. To understand how the discipline of bibliometrics may be used to inform technology forecasting and what tools are available to practitioners the following chapter reviews both academic literature and the currently available software.

CHAPTER 2 - LITERATURE AND SOFTWARE REVIEW

Literature review

Introduction

The purpose of this review is to establish the broad range of bibliometric approaches available to researchers and provide details of the specific techniques used for technology forecasting. The review also seeks to understand some of the broad themes of technology forecasting such as innovation and invention. The review covers a comprehensive selection of bibliometric literature derived from a search of Web of Knowledge.

The databases provided by the Web of Knowledge (particularly the Web of Science) are highly rated as a source by scientometric practitioners, van Leeuwen considers the Web of Science to be “the most important source of data for bibliometric analysis in sciences” (2006, p.134) and is regarded by Okubo (1997, p.16) as covering all the “mainstream” scientific journals. The majority of published, peer-reviewed output concerned with bibliometrics and scientometrics can be found in a relatively small number of journals, Bar-Ilan's review suggests that the top two journals (Scientometrics and the Journal of American Society for Information Science & Technology (JASIST)) cover around 60% of the literature and the top ten journals cover around 85% of the literature (2008, p.5). On this basis, a well constructed search string should confidently return a comprehensive set of results.

The vocabulary of scientometrics is still evolving, at various points in its short history the main advocates of the discipline have viewed the terms of bibliometrics and scientometrics as being interchangeable (Glänzel, 2003, p.6). This was mitigated in the initial search by using all known high level terms in the broad search string. The review has adhered to the principle that the terms are synonymous.

Search details

The strategy was built using a combination of broad technology keywords, general predictive terms, and a mixture of general bibliometric terms and specific bibliometric technique keywords.

[1] Technology Broad Terms: (technolog* OR innovati*)
[2] Predictive Terms: (forecast* OR emerg* OR management OR intelligence OR trend* OR foresight OR roadmap* OR assessment* OR opportunit* OR converg* OR diffusion OR selection OR indicat* OR map*)
[3] Bibliometric: (bibliometr* OR scientometr* OR informetr* OR citation-impact* OR citation-analy* OR co-citation* OR cocitation* OR crosscitation* OR (impact-factor SAME journal*) OR coauthorship* OR co-authorship* OR publication-activity* OR research-

evaluation OR research-performance OR highly-cit* OR mapping-of-scien* OR collaboration-network* OR web$metr* OR h-index OR hirsch-index OR hirsch-type OR patent-citat*) NOT Sym-H index.

The string was constructed as [1] AND [2] AND [3] and was entered into Web of Knowledge on 07-04-2012 and produced 1566 hits. De-duplication and manual filtering reduced this number to 1014.

Technology forecasting

Background

Watts and Porter outline the importance of technological forecasting as follows,

> *"Technological forecasting purports to provide timely insight into the prospects for significant technological change. Such information should help management make better decisions with regard to strategic corporate planning, R&D management, product development, investment in new process technology, production and marketing, purchasing of new technology and so forth."* (1997, p. 25).

Development

Coates' et al. (2001) study reviews the future of technology forecasting and indicates that the different forms of technology forecasting should include "national foresight studies, roadmapping, and competitive technological intelligence" (p. 1). They also include the effects of "invention, innovation and evolution" (p. 1) as forms of technology assessment. Of these forms of assessment, technological innovation and invention are considered by this part of the review.

Technological innovation (innovations systems or systems of innovation) is a term used within the sphere of economic development to describe the full range of emerging scientific, technological and industry processes, institutions and structures (Uriona-Maldonado, dos Santos & Varvakis, 2012, p. 977-978). As a driving force technological innovation is of great importance to economic development and this importance leads it to be of great interest to technological forecasting researchers (van Looy, Debackere, Callaert, Tijssen & van Leeuwen, 2006, p. 298). The understanding of innovation can assist technology forecasting by defining the direction in which innovation in a particular field can go. Tseng (2009, pp.658-659) also notes that the relative innovation strengths of the countries can be mapped as a guide as to where innovation may succeed.

A number of studies were retrieved which specifically analysed the theme of inventors and inventions and this area should not be overlooked. Dahlin, Taylor and Fichman (2004) studied tennis racket inventions using patent citation data, looking to see if modern inventors can be considered as important as their historic counterparts. He and Fallah (2009) utilised US patent data to explore patent networks, similarly Schoenmakers and Duysters used patent data to trace the “origins of radical inventions” (2010, p. 1051). In fact all the examples retrieved related to invention used patent data as the means of analysis. Schoenmakers and Duysters concluding that “Patent data is the single most dominant indicator in invention studies” (p. 1051).

Bibliometric techniques

Background

Van Raan defines bibliometrics as the “quantitative study of the written output of science” (1997, p. 205). The discipline is built upon the publication of scientific research, “bibliometric assessments are based on the assumption that most scientific discoveries and research results eventually are published in international scientific journals where they can be read and cited by other researchers” (Glänzel, 2003, p. 2).

Limitations of the discipline

The foremost proponents of bibliometric techniques are largely content to note that bibliometric methods have a number of limitations, Glänzel concedes that the simplistic nature of basic bibliometric methods “can only supply a very limited picture of the research they are trying to describe” (2003, p. 4). These limitations become increasingly apparent when the discipline is faced with innovative research, Glänzel notes that “when publications containing very new or unconventional research results are included in the assessment, these will not yet have been cited, which means that any assessment based solely on bibliometric indicators will not discover the potential of the research groups in question” (Glänzel, 2003, p. 4).

These limitations are important to note as researchers have increasingly been required to understand and track innovative research, Van Raan predicted that “the 'tracing' of breakthrough-events in the interface of science and technology in order to improve our understanding of the genesis of innovations” would be of increasing importance (1997, p. 216) and suggested that bibliometric methods might be able to find patterns of innovation that had previously eluded researchers.

Balla, Gandini and Nicolini, note a number of disciplinary limitations such as, self-citation, multiple authorship, value of work and different patterns of citation in different subject areas (1989, p100-101). The latter theme of patterns of citation in different subject areas is also assessed by Glänzel and Schoepflin (1999). Jansz discusses the notion of the “citation gap” with specific reference to research policy and suggests that at present, “scientometrics cannot provide policy makers with a set of indicators, which would be sufficient to evaluate all scientific disciplines.” (2000, p. 263).

One possible approach to solving these problems would be to draw together a unified theory of citation, the lack of such a theory is discussed by Wouters (1999) and De Marchi and Rocchi (1999). Wouters work attempts to outline a general indicator theory and groups indicators into four clusters: "science of science"; "sociological"; "semiotic"; “information science" (1999, p. 573). De Marchi and Rocchi discuss a range of possible approaches to understanding science and technology indicators, and conclude that efforts to simplify a multitude of indicators “used to measure science and technology to lean patterns have so far proved unsuccessful.” due to the lack of an “all-comprehensive theory” (1999, p. 48).

Objectivity of the discipline

Wagner-Döbler (2005) argues that bibliometrics provides a more objective overview than might be obtained by discourse with subject matter experts through qualitative methods such as Delphi survey. However, Huang (2008) whilst recognising that “the publications and patents are the “fact” and “data” of objective attribute” (p.29) also notes that the actual bibliometric analysis of the data to forecast emerging technology “is an objective judgement approach” (p.29).

Pillania (2011, p. 1162) rightly guards against the level of subjectivity claimed by in bibliometric research, pointing to the initial subjective choice of keyterms. Pillania also highlights the assumption made by researchers about the data that firstly, innovators publish their research in scholarly publications and secondly, published research is based on previously published research (p. 1160). We are also reminded by the same author that although datasets are increasingly large they are not necessarily exhaustive (p. 1162).

Patents and patent citations

Patent information covers “every area of technology” (Blackman, 1995, p. 117) and is concentrated primarily on mainstream science and engineering. The breadth of coverage given by patent information leads it to be viewed as an “essential source of technical and commercial knowledge” (Lee, Cho, Seol & Park, 2012, p. 17). Patent citations are viewed as the link between bibliometric and patent data and therefore the link between scientific and technological information. Due to this direct linkage patent analysis can be considered as a primary tool for technology forecasting. Meyer (2000, p. 174) describes the relationship as that of dancing partners and in a later work warned that the relationship is not a straightforward linear model (2002, p. 197). Bar-Ilan is left only partly convinced by the usefulness of patents concluding that “At this point, it is not clear how to interpret references to patents in scientific publications.” (2008, p. 33).

As simple patent counts by nation, firm etc fail to measure the importance or links between individual patents then citation information can be used to enhance patent analysis. The patent citation count is attractive as it can be argued that it provides both a quantitative measure (the straight count or frequency) and a qualitative indication of the importance or impact of the patent (number of citations). This is not to say that patent citation analysis is without its limitations with regard to technology forecasting. Historical data may be flawed as it is reliant on previous simple citation counts and the chronological position of a citation is often overlooked.

Bibliometric techniques for technology forecasting

Background

Many technological forecasting and innovation studies rely on bibliometric methods as part of their analysis, if we understand the premise of scientific research to be the production or enhancement of knowledge then the literature of science can be seen to be the "manifestation of that knowledge" (Okubo, 1997, p. 8). The need to interrogate this knowledge via databases of citations is understandably critical to the process of technology forecasting. Wagner-Döbler suggests that bibliometrics is now a requirement to evaluate and monitor organisations "to improve future performance" (2005, p. 145) and that a high majority of organisations must carry out such evaluations. The scale of these evaluations requires the techniques of bibliometrics which Wagner-Döbler sees as providing "a service for science" (2005, p. 146). Huang defines the first function of bibliometrics in technology management to be forecasting and that the second function to be judgement, "The technology development life cycle and technology maturity can be judged by bibliometrics analysis" (2008, p. 30). Support to the use of bibliometric techniques for technology forecasting is provided by Su and Lee, who conclude from their research into the literature that "it was evident that bibliometric analysis was the methodology used for mapping the evolution of knowledge" (2012, p. 203). Must (2006) is also adamant that bibliometric techniques should be used for technological innovation research.

Indicators

The basic bibliometric indicators for technology forecasting are no different than indicators used for other forms of bibliometric research, numbers of publications and numbers of citations are again at the core of any study. Wagner-Döbler suggests that there is some advantage in grouping these indicators and proposes three groups: output indicators; input indicators; efficiency indicators (2005, p. 148).

Techniques

As the techniques of technology forecasting have developed alongside bibliometrics over the last thirty years there seems to be a general agreement over the use of combined models and techniques, Millet and Honton (1991) and Martino (1993) both write in favour of this type of method. Within much of the relevant literature analysed for this review (Behkami & Daim, 2012; Coates et al, 2001; Daim, Rueda & Martin, 2006; Dodgson & Hinze, 2000; Roessner

(2000); Warner, 2000; Watts & Porter, 1997), a strong preference for a mixed method approach to technology forecasting was noted. Watts and Porter, suggest that combining bibliometrics with other techniques can provide for "an enriched form of technological forecasting" that they label "innovation forecasting" (1997, p. 25). Coates et al. list a number of the benefits of bibliometric analysis, noting that such techniques can monitor and forecast innovation. Their study also indicates that linkages between technologies can be made by the analysis of large datasets (2001, p. 13). Behkami and Daim provide a detailed review of possible bibliometric techniques for technology forecasting including text mining and clustering, their example analyses include the examination of research literature in India and Mexico, science and technology core competencies in China and the detection of emerging research domains (2012, pp. 499-500).

Citation analysis

Although there is evidence that technology forecasting can be undertaken using citation analysis as a single method - González-Albo, Gorria and Bordons (2010) provide an example of a single method in a small scale bibliometric survey of Spanish literature in neutron scattering - the overall trend is for a combination of methods. Kajikawa and Takeda (2009) present a study of emerging research domains in the field of optics using citation network analysis and topological clustering. Similarly Kajikawa, Yoshikawa, Takeda, and Matsushima (2008) undertook a citation network analysis to track emerging research domains in energy research. Takeda, Mae, Kajikawa and Matsushima maintain that the quantitative method is more important than the qualitative when researching global trends, remarking that "a computer-assisted approach is more helpful" (2009, p. 24) than relying on road mapping by subject matter experts.

Of the innovation focused studies retrieved citation analysis methods were employed by Seol and Park (2008, p.3), who suggested that there has been little work carried out on innovation studies in developing countries, their work investigates Korean innovation studies using citation analysis. Similar methods were used by Toivanen and Ponomariov (2011), who processed citation data in VantagePoint, though not mixed data in this case, in a macro level study of research collaboration patterns in African regional innovation systems.

Patents and patent citation analysis

Patent bibliometric analysis is defined by Narin as "the use of patents and patent citations in the evaluation of technological activities" (1994, p.147). The case for using patents and patent citations in bibliometric studies was advocated in a number of articles retrieved in the course of this study. Van Raan (1993) describes in detail the methods of assessing research performance and scientific development. Grupp, Schmoch and Kuntze (1991) show how patent indicators can be used to evaluate research programmes and Narin, Smith, and Albert (1993, p.53) describe how patent citation analysis can provide indicators of which companies are key in a technology area. Chang, Wu and Leu, carried out a patent citation and patent network analysis to monitor the emerging technology of carbon nanotube field emission display concluding that “For the future research, combining patent bibliometric analysis with patent network analysis will offer a useful avenue to monitor the emerging technology.” (2010, p. 18). Another possible patent citation technique is proposed by Graf (2012), this study analyses the development of the German knowledge base using the patent co-classifications of German inventors.

Many of the retrieved studies favour a blend of patent and citation data as a means of technology forecasting, patent citations are routinely used due to the temporal proximity of patent applications to new technologies. Hossain, Moon, Kang, Lee and Choe (2012) and Huang, Chang, and Chen (2012) combine citation and patent data in their research, Hossain et al, (2012, p. 71) use citation data from the Science Citation Index (SCI) with patent data from the US Patent Office (USPTO). Huang et al (2012, p. 458) employ a mixed scheme which uses citation and patent data when tracing the possible reduction of the US research and development role. Vilanova and Leydesdorff's (2001), assessment of a Catalonian innovation system is based upon patent and citation data from Catalonian institutions. Tseng (2009) combines patent and citation data to produce a comparative study of technological innovation of information and communication technologies (ICT) in South Korea, Taiwan, Singapore, Hong Kong, China and India.

Aggregate analysis

Aggregate analyses combine analyses from multiple studies. Retrieved articles specifically aimed at technology forecasting using aggregate analysis with patent citation data include Li, Chen, Huang, and Roco (2007), who present an aggregate analysis of nanoscience and nanotechnology and similarly Finardi (2011, p.37) uses an aggregate analysis of nanoscience and nanotechnology patents to analyse the time required for scientific knowledge to appear as technological application. Leydesdorff and Zhou (2007) and Schultz and Joutz (2010) both use aggregates of USPTO data to perform bibliometric analyses.

Technology forecasting with bibliometrics and other methods

A number of other possible mixed methods for technology forecasting were assessed by this study. Abercrombie, Udoeyop and Schlicher (2012, pp. 6-7) use a range of data to track the development of an emerging technology. Their study not only combines patent data and citation data but also blends in web based news data sourced from Google News and web based business data sourced from Google Maps. Gerdsri and Daim's study of research development progress analyses patents, links and impacts with bibliometric tools and uses a time shifting method to align the different types of data (2008, p. 4). Miyazaki and Islam (2007) combined bibliometrics with text mining and quantitative study in a survey of nanotechnology and use VantagePoint software to carry out the analysis (p. 665). A broad range of bibliometric and network analyses combined with co-citation analysis were utilised by Avila-Robinson and Miyazaki (2011), in an attempt to characterise emerging technologies.

Watts and Porter suggest combining bibliometric methods with other analytical techniques (qualitative techniques such as Delphi survey are suggested) pointing to the weakness of citation counts and their lack of quality and lack of timeliness for research reports (1997, p. 27). Other proponents of the use of mixed methods were identified during the course of this survey. Zoss and Börner (2012) use an interesting and novel combination of bibliometric analysis of citation data along with content analysis of an online community list server. Their approach suggests a way of mapping a specific online community as opposed to the more traditional mapping of national and international collaboration.

Rueda and Kocaoglu (2008) use Delphi survey and bibliometric techniques to estimate the diffusion of emerging technologies. Shen, Chang, Lin and Yu (2010) combine Delphi survey and patent co-citation analysis to select key technology fields for study. Chao, Yang and Jen note the benefits of combining bibliometric techniques with historical review in a review of radio-frequency identification (RFID) technology, stating that, “The historical method proposes that historical phenomena can be rich and complex and that we can gain a better understanding by reviewing and investigating the time(s), place(s) and context(s) in which events occur and develop” (2007, p. 269). Chen, Chen and Lee used bibliometric and patent analysis with a logistical growth curve model (S-curve) to assess technological maturity within the hydrogen energy and fuel cell energy industries. Their model claims to be particularly applicable to “new clean technologies” (2011, p. 6957) and can be used to predict when a technology will reach a particular stage of development.

Bibliometrics and system dynamics

A recent advance has been the use of system dynamics combined with bibliometric data to inform technology forecasting studies. Daim, Rueda and Martin (2006, p. 981) outline a multiple method approach which utilises a blend of bibliometrics and system dynamics to compare two different technologies. They claim that this approach may be successfully used to forecast technologies from different areas, a particular failing of bibliometrics identified by Glänzel and Schoepflin (1999). Daim, Rueda, Martin and Gerdsri (2006, pp. 984-985), again use mixed methods for technology forecasting and discuss the usefulness of a systems dynamics approach. Bengisu and Nekhili (2006 p. 844), conclude that patent and citation databases can be used to forecast emerging technologies with the help of logistic curves. Their work uses patent and publication data to study twenty different technologies (including carbon nanotubes, Micro-Electrical-Mechanical Systems (MEMS), solar batteries etc) and uses patent trends to provide technology intelligence.

Software review

Introduction

It was proposed at an early part of the dissertation process that the literature review would be supplemented by a review of software suitable for performing the types of bibliometric analyses required for technology forecasts. Literature relating to bibliometric software was retrieved as part of the main literature review. Cobo, Lopez-Herrera, Herrera-Viedma and Herrera (2011, p. 1386) identify nine software tools that can be used for bibliometric analysis: Bibexcel; CiteSpace II; CoPalRed; IN-SPIRE; Leydesdorff's Software; Network Workbench Tool; Science of Science (Sci^2) Tool; VantagePoint; VOSViewer. In addition to the tools identified by Cobo et al, this review identified HistCite, Publish-or-Perish and SciMAT as being potentially suitable tools. Other generic database tools and scripts, such as those developed and discussed by Mallig (2010) and Neuhaus, Litscher,and Daniel (2007) are available and were also identified as being able to fulfil some of the bibliometric requirements.

Requirements for technology forecasting

The literature review has identified the principal requirements for technology forecasting are that the software should be able to:

- Handle both patent and citation data, ideally without any pre-processing of the files output from the relevant database sources.
- Have pre-processing tools built in to enable the cleansing and de-duplication of data from multiple databases. The tools should allow for the cleansing of elements such as institution names and authors.
- Perform the following types of bibliometric analyses: burst detection; geospatial; network; temporal.
- Produce visualisations of the data and bibliometric analysis.
- Export the data for further analysis in spreadsheets etc.

Of the available bibliometric tools identified in the introduction to the tools review section only four provide a broad enough range of analyses to fulfil the requirements, these four are CiteSpace II, SciMAT, Sci^2 Tool, and VantagePoint. These tools are reviewed in greater detail below.

CiteSpace II

CiteSpace II is an open-source bibliometric software tool developed by Drexel University and authored by Chaomei Chen. The software has been developed as a Java application and requires a computer capable of operating Java Runtime, this allows the software to be run on different operating platforms. A number of recent studies are identified as using CiteSpace II for bibliometric analysis (Chen, Hu, Liu, & Tseng, 2012; Niazi & Hussain, 2011; Zhao, Chen, Dang, Dang, & Zhang, 2012). Data for CiteSpace II can be imported from a number of sources including Web of Science, PubMed and Derwent Innovations Index. The software includes interfaces enabling the direct download of data from the named sources.

CiteSpace II can provide all the analysis types required for technology forecasting. Burst detection is offered using an adaptation of Kleinberg's algorithm (Kleinberg, 2003) and can detect bursts of single or multiple words. Geospatial analysis is made available through an overlay to Google Earth and network analysis is provided by clustering networks of co-cited articles. Temporal analysis is provided by a time-slicing feature, the time slices can be visualised as "citation tree-rings" (Chen, 2006, p. 365).

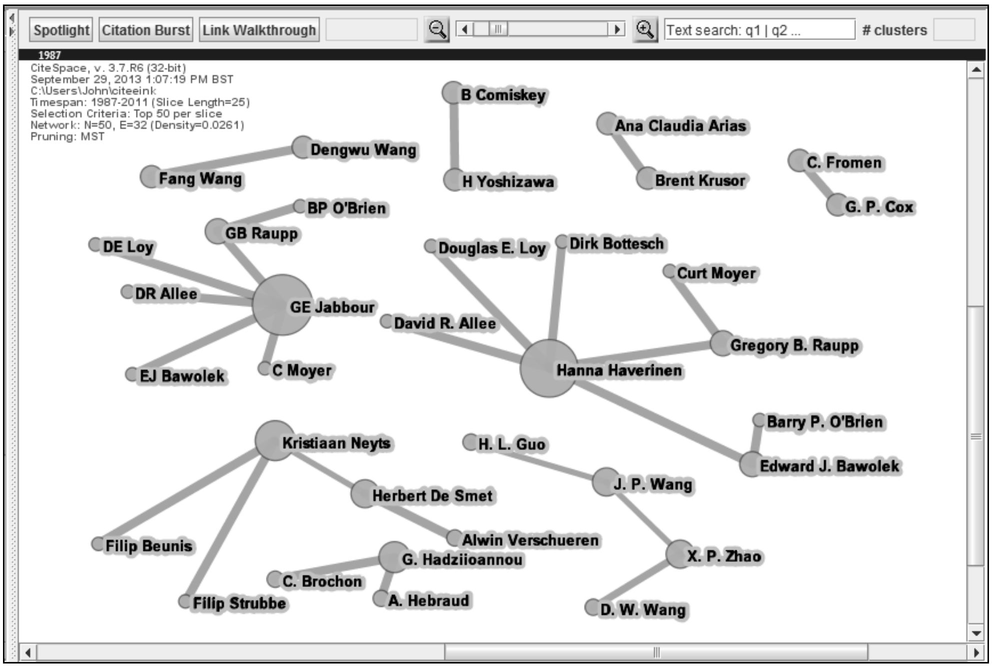


Figure 1: Author clusters visualised in CiteSpace II

The CiteSpace II interface gives a substantial amount of the control to the user thus mapping and visualisations can be adapted to meet the user requirement. Figure 1 shows a visualisation of author networks using the Citespace II visualisation tool.

CiteSpace II enables the researcher to build a wide range of bibliometric networks and offers all the relevant analyses required by those seeking to produce technology forecasts. The cited studies show that the software is a popular tool for technology forecasting and the platform flexibility is a strong point in its favour. The only obvious drawback of CiteSpace II is the lack of a de-duplication method as part of the pre-processing part of the package. This could be an issue to the researcher if multiple sources are being used to retrieve data.

SciMAT

SciMAT is the most recently published of the programs reviewed. It is described as a "science mapping software tool" (Cobo et al, 2012, p.1609) and aspires to reduce a researcher's dependence on third party software for the different stages of bibliometric research (pre-processing, bibliometric analysis, mapping and visualisation). The software is available to any user as open-source software and can be downloaded without charge. As with CiteSpace II and Sci^2 tool SciMAT has been programmed in Java and therefore will run on a wide range of operating platforms.

SciMAT is principally built around three modules: The 'Knowledge Base' where the data is imported and pre-processed (the Knowledge Base workspace is shown in Figure 2); the science mapping module where the data reduction, analyses and mapping is carried out and the visualisation module where data visualisation and interpretation are performed. The Knowledge Base Manager is used to build a new project or load an existing one. To add bibliographic details, SciMAT can read bibliographical information exported in Web of Knowledge format (ISI-CE) or Research Information Systems (RIS) format. Pre-processing tools are provided which allow for the de-duplication of items and the detection of spelling errors.

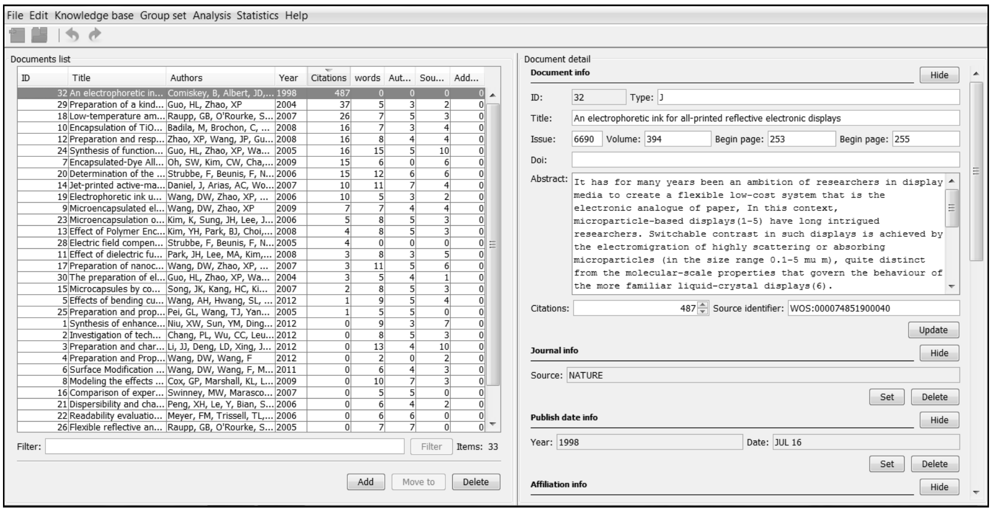


Figure 2: The SciMAT Knowledge Base manager window

The science mapping module provides the analysis tools, the range of tools provided are broad enough to cover the range of analyses required to construct a technology forecast. Bibliographic analysis can be carried using a number of methods (bibliographic couplings, co-citation and co-word analysis). Temporal analysis is enabled by SciMAt's facility to build an 'evolution map' which detects the evolving areas of a technology. This data can be further analysed to calculate "the 'evolution nexus' between the items of two consecutive periods." (Cobo et al, 2012, p. 1618). Geospatial analysis is not provided by the software and this omission has to be considered as a limitation.

Exporting of analysis is available as HyperText Markup Language (HTML) or LaTeX reports, the lack of options to export graphics as Joint Photographic Experts Group (JPEG) or

Portable Network Graphics (PNG) files might be considered another of the software's shortcomings. The interface is similar to the VantagePoint interface, list and detail windows are provided in the Knowledge base module and these can be supplemented with some basic statistical charts. Similar levels of detail can be accessed in the other modules.

SciMAT is undoubtedly a versatile tool for bibliometrics and appears to contain most of the requirements for technology forecasting. The relative youth of the software means that it has had a little time to build a reputation amongst researchers so a broad assessment of the tool is limited.

Science of Science (Sci^2 Tool)

The Science of Science (Sci^2) Tool developed by the Cyberinfrastructure for Network Science Center at Indiana University is a modular toolset providing analysis and visualisation tools designed to work with the academic output of science. The toolset claims to provide support at all levels (micro, meso, macro) for temporal, geospatial, topical, and network analysis. The toolset also provides a range of visualisation tools again operating at all levels.

The toolset requires Java SE 5 (version 1.5.0 or later) to run and registration is required before use. A user guide can be downloaded from the University website, (Sci^2 Tool: A Tool for Science of Science Research & Practice, 2010) alternatively a user guide wiki is available. Sci^2 can read data files from different databases such as Web of Science and Scopus and different export formats such as Bibtex and EndNote. Sci^2 can also import plain text exports direct from Web of Knowledge. The Sci^2 toolbar has a series of menu options for the different stages of processing data, arranged such that a workflow runs from left to right as follows File (Import and Export), Data Preparation, Preprocessing, Analysis, Modeling, Visualization, The pre-processing options are based around five submenus but are not as sophisticated as those offered by VantagePoint and are mainly focused on de-duplication.

The Analysis menu offers analysis options for each of the four domains; temporal, geospatial, topical, or network. The geospatial domain attempts to extract geographic coordinates from text in specified columns. The generic decoder can only take Countries, US States or US Zip codes. There is also a Yahoo decoder, which connects to Yahoo to obtain geographic coordinates from a wider range of input data. The temporal analysis features burst detection, which identifies sudden increases in the frequency of words. The user can choose to detect bursts related to author names, journal names, country names, references, Web of Science keywords, or terms used in the title and/or abstract of a paper. Topical analysis is delivered via co-word analysis, the importance of a word in the body of data is calculated using Salton's term frequency inverse document frequency (TFIDF).

Once the previous data steps are complete, the Sci^2 tool can visualise the results. Simple networks can be viewed using the GUESS toolkit, larger scale networks are better depicted using the DrL Large Network Layout tool. The toolset is expandable through plug-ins and supports plug-ins from other tools including Network Bench Tool and TEXtrend.

The range and depth of analysis features in Sci^2 make it a well featured package for bibliometric analysis and the software can easily carry out the required tasks required by technology forecasting. The lack of advanced pre-processing features was the only shortfall during the evaluation of the software.

VantagePoint

VantagePoint is a commercial software tool designed and developed by Search Technology Inc. (USA). to analyse primarily the output from patent and citation databases. The software is available under licence, full licence details and pricing arrangements are available from TheVantagePoint.com. A number of recent bibliometric studies have used VantagePoint software (Morel, Serruya, Penna and Guimarães, 2009; Porter and Youtie, 2009; Shapira, Youtie and Porter, 2010). VantagePoint will only run under Windows, the latest release, version 8, can be operated on Windows XP (SP2), Vista and Windows 7 platforms.

VantagePoint provides over 180 of its own import filters to enable researchers to import data without pre-processing from virtually all major citation sources, the one exception being Google Scholar. Bespoke import filters can be written by users, a working knowledge of regular expressions would be desirable if users wish to undertake this type of modification. Output can be presented in a number of ways, mapping and visualisation wizards are built in to the software and direct export of data to Excel is available. Plug-ins such as the Aduna visualisation plugin are available to enhance the software's capability.

VantagePoint handles both patent and citation data and provides the four analysis types required for technology forecasting. Burst detection is enabled by Natural Language Processing (NLP) features. Networks and clusters are easily identified in VantagePoint's matrix building features (Figure 4), the matrices can also be use to carry out geospatial analysis and this analysis can be visualised using the Aduna plugin (Figure 3). Temporal analysis can also be performed using VantagePoint matrices, publication years being combined with fields at different levels of aggregation.

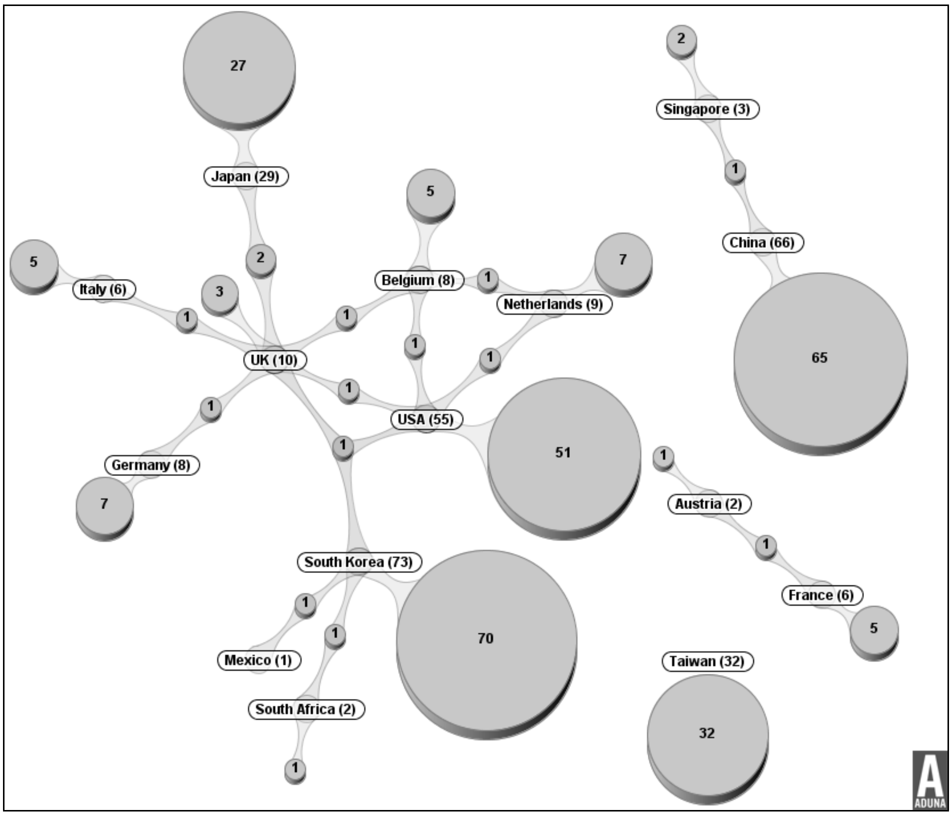


Figure 3: Country networks visualised in VantagePoint using the Aduna plugin

All changes made in VantagePoint, list cleanups etc. are overlain on the original data and produced as a new list. In this way the original data is not affected and can be recalled for analysis at any time. The VantagePoint user interface is simple to use and visually clear. Information is provided in three main views (Figure 4). The main workspace window presents a tabbed view of any lists, matrices or maps generated by the user for instant reference. Further detail from individual records can be added by opening the title and detail view windows.

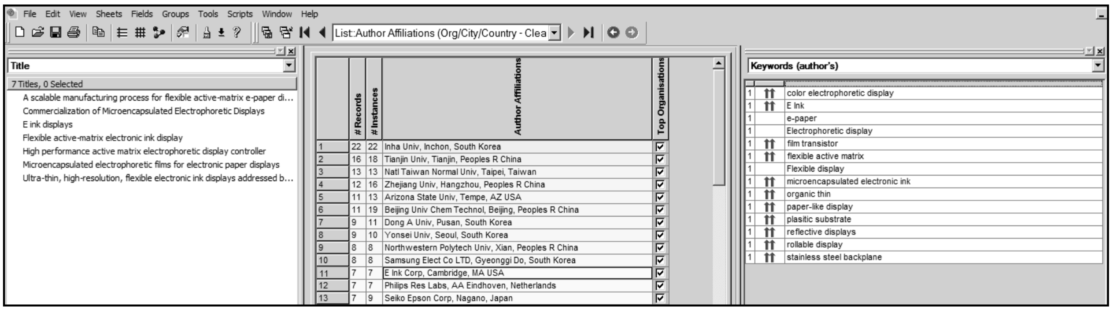


Figure 4: VantagePoint main workspace with title and detail windows

VantagePoint is a large, powerful tool which must come under serious consideration by any technology forecaster. The ability to process patent and citation data, the impressive range of filters and the presence of mapping and visualisation tools make it a solid candidate to undertake technology forecasting research.

Conclusions

This part of the study has shown that the most likely candidates for the software to be used for the research are CiteSpace, Sci^2 Tool, SciMAT and VantagePoint. For the purpose of technology forecasting all three packages will provide the baseline types of analysis, will handle the retrieved data sources and will perform the necessary visualisations to inform a technology forecast.

All four packages have minor drawbacks which would require the use of additional software to rectify. Results from Sci^2 Tool and VantagePoint can be enhanced with additional graphics or spreadsheet software. CiteSpace requires additional software at the pre-processing stage and SciMAT lacks any geospatial visualisations. The multi-platform usability of CiteSpace and Sci^2 Tool may find them favoured by some researchers, especially non-Windows users.

As all four packages can lay claim to being able to perform the bibliometrics required for technology forecasting without any major drawbacks, the decision ultimately comes down to the type of operating platform and subjective opinion over the ease of use. In the brief trials of the four software packages the author found the VantagePoint user interface in combination with the supplied help and guidance the most straightforward of the packages to work with. This ease of use combined with the powerful automated clean-up tools and the capacity of the software to perform analyses suitable for technology forecasting meant that VantagePoint was selected as the software to be used for the practical case study.

Summary

The literature review has discussed the bibliometric techniques available to researchers and has indicated the bibliometric methods considered most suitable for technology forecasting. The software review has discussed the range of software available for this kind of study to be undertaken and a single specific software package has been selected to be used to perform the case study. Both sections of the review chapter are used to inform the following methodology chapter, the literature review suggesting techniques and the software review helping to establish a practical approach to the study.

CHAPTER 3 - TECHNOLOGY FORECASTING METHODOLOGY AND SOURCES

Technology forecasting

The literature review has described the emphatic development of technology forecasting over the last fifteen years. Advances in personal computing have allowed in depth literature searching to be undertaken by a greater number of researchers. Technical advances in computing and increased processing power have enabled practical data mining and detailed analysis of databases using techniques such as phrase proximity. However, Martino warns that "The use of computers for text searching does not eliminate the need for expert analysis. It does, however, multiply the effort of the experts by searching documents for words and phrases that have been determined to be important." (2003, p.720).

A typical technology forecast should seek to establish a number of possible directions for a particular technology or, in some cases, set of technologies. The forecast should establish where (geographically) a particular technology is going to be adopted and establish the rate of that adoption. Similarly, the forecast should establish from which areas of research and design the technology has emerged (or is emerging) from. The forecast should also be used to predict who the likely leaders (countries, institutions, people) in the development of the technology will be. As the practical case study will be largely quantitative the advice regarding quantitative technology forecasting will be heeded. A quantitative technology forecast should seek to establish a projection of technological change based on patterns established in the "historic data related to changes in or adoption of that technology" (Walk, 2012, p.104).

Practical methodologies

Bibliometric methodology

There is evidence within the literature to suggest that the practical methodologies for technology forecasting with bibliometrics can be broken down into a number of steps, Watts and Porter (1997, p.31) provide a thirteen step sequence, Martino (2003, p. 720) maps these steps onto a series of technology life cycle indicators. The designers of SciMat provide a 'general workflow' (Cobo et al, 2012, p.1610) and the Vantage Point creators provide a step-by-step list of analysis questions (The VantagePoint, 2013). This is, perhaps, sufficient indication that the forecast should be approached as a logical sequence of steps.

The steps can be characterised as follows. An initial period of data retrieval and query refinement forms the information retrieval part of the process. This is followed by data analysis, modelling and visualisation, which forms the bibliometric analysis part of the process. Finally this is followed by forms of qualitative interpretive analysis, the subject matter analysis part of the process. Although bibliometric analysis is strictly speaking only undertaken as part of the second step, it needs to be understood in order to inform both the first step of data retrieval and the final conclusions of the qualitative analysis.

Data retrieval and query refinement

The data retrieval process starts with the formation of the search string and the string is used to download relevant technical information. Wide coverage should be sought and a number of databases should be used to ensure a sufficient breadth of information is retrieved. Watts and Porter (1997, p.31) suggest beginning with a search "on the basic topical term(s) in multiple databases". The examination of the more important fields returned in the initial search (titles, abstracts, authors, institutions, keywords etc.) should then inform further refined searches. These subsequent searches should then give preference to the most suitable databases. This examination should also enable the researcher to "gain fluency with related activities, applications, key players, dispersion" (Watts & Porter, 1997, p.31). Martino (2003, p. 720) suggests a method whereby the data is grouped as either relevant or non-relevant at this stage and the second search is then based on the relevant terms.

A baseline bibliometric methodology to retrieve and analyse the data has been suggested by the literature and software reviews. The method will follow the steps delineated above and will use a structured step-by-step method. The selected databases will be interrogated with a search string which will be refined until the results reach an acceptable balance between recall and precision. The data will be subsequently cleaned using the software's supplied thesaurus and data cleansing tools, this will ensure a clean reliable dataset to perform the rest of the analysis on.

Data analysis, modelling and visualisation

Data analysis techniques can be used to plot trends in overall activity, topic-specific activity, institution-specific activity, etc. Straight counts of articles, patents and news items can be provided and more sophisticated counts giving different weight to principal authors etc can be used if required. More complex analyses of co-citation and co-authorship (cross-correlation) can also be undertaken; this deeper analysis can be used to identify the diffusion or transfer of technology between individuals, institutions and countries. Figures will be produced at different levels of aggregation, either directly from the software or as a data export into a suitable tool with chart producing capabilities such as Microsoft Excel.

Technology forecasting models

Data modelling techniques such as logistic curves or exponential growth models can be employed to provide the forecasting element of the analysis. As indicated in the literature review the weight of opinion favours the use of mixed methods for technology forecasting, this remains true when employing models and forecasting experts (Martino, 1993; Millet & Honton, 1991) agree that models should be combined. Data from both patent and publications is required for this stage of the process to establish the development and maturity of the technology, the VantagePoint guide suggests that to provide a clear enough pattern of development this data should cover a period of over fifteen years.

As it is beyond the scope of this study to discuss all the possible mathematical and statistical techniques, two forecasting methods have been identified. Firstly a simple linear trendline will be plotted where an acceptable fit can be found; secondly following Martino's advice that "the two growth curves most commonly used by technological forecasters are the logistic or Pearl and the Gompertz" (2003, p.724) a logistic curve will be plotted. In addition to these statistical forecasting methods a method of presenting normalised data, introduced by Abercrombie, Udoeyop and Schlicher (2012, p. 336), will be used to highlight the transition of the technology through different life-cycles.

Qualitative analysis

Bibliometric analysis of citations (either publication or patent) can be undertaken to provide a qualitative element to the research. This kind of qualitative analysis can be derived from citation counts in the form of the h-index and its numerous derivatives. The h-index (Hirsch index) is a measure of 'citedness' that can be applied at any level of aggregation. The basic h-index considers both the number of publications (output) and the number of citations per publication (impact). The final numeric value of the h-index is arrived at as follows, "A scientist has an index h if h of his/her N_p papers have at least h citations each, and the other $(N_p – h)$ papers have $\leq h$-citations each" (Hirsch, 2005, p.16569). A depiction of this method is shown below in Table 1, which shows the h-index for Peter Jacsó based on a search of Web of Science using the broad bibliometric search terms from the literature review search strategy. This level of analysis is perhaps the most controversial, other forecasters preferring to use more established methods of qualitative analysis such as Delphi to provide the 'expert opinion' element of the research. A limited form of qualitative analysis will be provided in the case study by the examination of citation metrics. The h-index method will be used as an indicator of the importance of a contributor to the technology at an appropriate level of aggregation.

Jacsó notes that at Country level "results are reassuring about the viability of using the h-index for purposes of measuring and ranking the scientific performance of countries" (2009, p.835). This study acknowledges that the use of the h-index and its derivatives is still regarded with some scepticism and that other qualitative methods remain favoured, Martino states that "Delphi remains one of the most popular methods for technological forecasting. For large scale national or industry forecasts it is probably the only method." (2003, p.724).

Rank	Title	Citations
1	Testing the calculation of a realistic h-index in Google Scholar, Scopus, and Web of Science for F. W. Lancaster	35
2	The pros and cons of computing the h-index using Google Scholar	35
3	A deficiency in the algorithm for calculating the impact factor of scholarly journals: The journal impact factor	33
4	The plausibility of computing the h-index of scholarly productivity and impact using reference-enhanced databases	30

5	Metadata mega mess in Google Scholar	22
6	The pros and cons of computing the h-index using Web of Science	22
7	The pros and cons of computing the h-index using Scopus	21
8	Analyzing the journal coverage of abstracting/indexing databases at variable aggregate and analytic levels	16
9	Errors of omission and their implications for computing scientometric measures in evaluating the publishing productivity and impact of countries	14
10	Five-year impact factor data in the Journal Citation Reports	14
11	**Database source coverage: hypes, vital signs and reality checks**	**11**
12	Calculating the h-index and other bibliometric and scientometric indicators from Google Scholar with the Publish or Perish software	11

Table 1: h-index table for Jacsó, P.

As the study is concerned primarily with the understanding of bibliometric techniques weight is given to the use of these techniques. The importance of enhancing technology forecasts with other methods has been highlighted by the literature review and cannot be totally ignored. The methodology proposed for the case study therefore whilst largely dependent on bibliometric techniques also contains some element of statistical forecasting techniques to provide an illustrative technology forecast.

Bibliometric sources

Citation databases

Until relatively recently there has been only one all-inclusive database available to researchers, the Web of Science, which includes the Citation Indexes originally proposed by Eugene Garfield in the 1950s. The Web of Science is currently available through subscription as part of the Web of Knowledge. The two more recent citation databases reviewed Google Scholar and Scopus were made available in 2004 and thus have had a little under a decade to develop a reputation amongst researchers. Academic citations are available from Scopus via Science Direct, which also hosts open access content. Google Scholar is freely available on the internet and delivers both academic and patent citations.

Web of Science has a long established reputation in the world of citation databases. As well as providing downloadable bibliographic references suitable for direct import imported into bibliometric software the Web of Science website provides its own citation analysis tools. Scopus provides journal access via the Science Direct platform. Science Direct provides a searchable database of academic output in a similar manner to Web of Science, citations again being made available for direct import into bibliographic and bibliometric software.

Initial academic evaluations of Google Scholar seem largely sceptical, Norris and Oppenheim declaring that it “cannot be seriously thought of as a database from which metrics could be used to measure scholarly activity” (2007, p.168). Jacsó’s (2008) discussion of Google Scholar repeats this scepticism. However this does not mean that it has been dismissed out of hand. Harzing and Van Der Wal presented a more enthusiastic view of Google Scholar, noting that its open accessibility provides a “democratization of citation analysis” (2007, p.1). Bar-Ilan’s review suggests an increase in performance by Google Scholar but also notes that it still lacks user-friendliness (2010, p.495). Harzing subsequently developed the Publish-or-Perish software specifically for analysing Google Scholar data (Harzing, 2010).

The relative usefulness of the databases is likely to depend on the type of study being carried out and the subject area of the study. This particular study will draw conclusions on the databases value for technology forecasting, claims regarding the value of the database for the chosen technology are of lesser importance. Lasda Bergman concludes that “*Google Scholar* may not be as reliable as either *Scopus* or *Web of Science* as a stand-alone source for citation data. Nonetheless, to obtain the most comprehensive citation count, one must use all three resources” (2012, p. 378). The concept of using all three databases is attractive but it may not be, in all cases, practical. The ability of the chosen software to handle data obtained from the selected databases was also of importance and the preference would be for data that did not require substantial pre-processing.

Patent databases

The research into patent databases suggested that World, US and European patents should be given priority and patents should be investigated as part of a technological forecasting project. Coverage of these patent citations is available through Derwent Innovations Index (DII) which provides information from European, Patent Cooperation Treaty (‘World’), US, German, British and Japanese patenting authorities. Coverage in DII was redesigned in 1997 and should be consistent from this point forward. Although patent information can also be retrieved from Google Scholar the quality of patent and patent citation data available from DII precluded the requirement for a comparative study of the sources.

News item databases

Google News and EBSCO Discovery were advocated as possible sources for news items, EBSCO Discovery provides output in a form readable by the bibliometric software with only minor processing required. Final selection of the news database would be dependent on the number and quality of hits returned from the initial search.

Initial research

Criteria for candidate technology

The choice of a candidate technology was limited by a series of criteria, some self-imposed and some imposed by the nature of the research. The preference was for the technology to have some relevance to the general subject area of library and information studies. Larger scale research areas were initially considered, for instance, a number of technology forecasting articles referred to nanotechnology and although this type of large subject area looked attractive it was dismissed on the grounds of relevance and the likely production of a dataset of over 60’000 citations.

The technology also needed to be sufficiently mature to provide a dataset substantial enough to make the study worthwhile, references were required from a period of at least fifteen years. The time requirement precluded very recent advances such as Google Glass, conversely overly-mature technologies such as RFID were rejected as candidates on the same grounds as nanotechnology as the datasets were expected to be excessive. A compromise solution was found in the selection of electrophoretic ink (e-ink), the technology that supports modern e-reading devices.

Electrophoretic ink

Electrophoresis was first observed by a German professor, Ferdinand Reuss in 1809 as part of a series of experiments into electrokinetic phenomena (Reuss, 1809). Reuss's experiments noted the movement of clay particles in sand and water during the application of an electric current. In this experiment the charged clay particles rose from the sand layer in a movement towards the positive charge. The science became widely applied in chromatography and electrophotography. The 1970s saw increased interest in the application of electrophoresis to display devices (Dalisa, 1977; Ota, Ohnishi & Yoshiyama, 1973). This initial research paved the way for the development of a lightweight electrophoretic display in the late 1990s (Comiskey, Albert, Yoshizawa & Jacobson, 1998). This breakthrough was the first time an electrophoretic solution had been found to the problem of emulating ink on paper electronically and can be considered to be the first instance of 'electronic ink'. This paradigm has enabled the increasingly commonplace adoption of commercial e-ink and e-reading technologies such as the Amazon Kindle.

The science, therefore, is a little over 200 years old, the theoretical application of the science is around forty years old and the practical application of the science as e-ink is around fifteen years old. This makes the technology a useful fit for the criteria suggested for this study since there has been enough practical development to enable the tracking of the technology and enough references can be retrieved to make some informed predictions as to how the technology may evolve.

Background research

Based on the advice recovered, notably Watts and Porter (1997) and Martino (1993, 2003) during the literature review and the practical solutions offered by the help guides and literature associated with the reviewed software (Cobo et al, 2012; SciMAT: Science Mapping Analysis Tool, 2013; Sci^2 Tool: A Tool for Science of Science Research & Practice, 2010; The VantagePoint, 2013,) a step-by-step approach was taken to the background data retrieval for e ink technologies. The first step is included here in the Background Research section, the subsequent steps are recorded and discussed in the following Results and Discussion chapters.

The initial step was to conduct a citation search on the basic topical terms in a range of suitable databases. The initial searches were carried out between 11/04/2013 – 15/04/2013 using the terms “e-ink” OR “electronic ink”, and the results for each database are discussed below.

Academic citation databases

Web of Science was expected to give the highest number of results due to its broad coverage and the range of databases Science Citation Index (SCI), Social Sciences Citation Index (SSCI) etc included within it. The search terms were entered into Web of Science as a ‘Topic’ search. The Web of Science Topic search interrogates the following fields – Title, Abstract, Author Keywords Keywords Plus – this covers all fields where the subject terms would be expected. The Web of Science Topic search produced 165 hits.

Science Direct provides coverage of over 2500 journals and although not expected to return higher numbers of science articles to those retrieved by Web of Science a reasonable return was expected. The same search string was entered and the Title, Abstract and Keywords fields were searched. The search produced 31 articles, this relative lack of information meant that this database could be discounted for the study.

Although the debate in the database sources section on the use of Google Scholar as a citation database source was not conclusive the database was used in the initial search on grounds of completeness. The search was altered to “electronic ink” for simplicity and the search retrieved over 2000 hits. Whilst the number of hits were encouraging the probable pre-processing time required to cleanse the data and lack of simple data download led to this source being disregarded for the case study.

Patent databases

As a single source of patent data DII was expected to provide all the relevant details for a technology forecasting study. Coverage is excellent and the metadata quality is consistent from 1997 onwards. DII also has the advantage of providing citation figures for the patents. Therefore DII was selected as the source of patent citation data for the study, on these grounds the selected software would have to be capable of dealing with the output from DII. The initial search in DII returned 2091 hits.

News item databases

EBSCO Discovery is a federated search tool covering a wide range of news and citation sources. The search was primarily required to retrieve news items, the subscription version of EBSCO Discovery also retrieves from Science Direct and Web of Science but these results would obviously duplicate the previous results. The News, Magazine Articles and Trade Journal fields were employed in the EBSCO Discovery search. The search produced 2357 results with the search time-limited to 1998-2012.

For completeness a similar search was undertaken in Google News, the search again being simplified to "electronic ink". The search returned similar results to EBSCO Discovery, a total of 2451 hits were retrieved.

Although both sources returned similar numbers of hits EBSCO Discovery provides more sophisticated search options and offers downloads in RIS format, this additional capability led to its selection as the news source database for the study.

Summary

The methodology chapter has provided justifications for the type of technology to be investigated by case study along with bibliometric methods employed to undertake the study. The reasons for the selection of the various sources have been discussed, along with an indication of the likely scale of the search results. The following chapters present the results of the case study in detail, with accompanying figures and provide a detailed discussion of the findings. The final chapter draws together the conclusions of all the research including the literature and software reviews as well as commenting on the quality of the data and methodology of the case study.

CHAPTER 4 - RESULTS

Description

The results are presented in two sections. The first section briefly outlines and reiterates the findings of the literature and software reviews, the second section discusses the results of the bibliometric case study of electrophoretic ink technology.

Literature and software reviews

The literature review has established that bibliometric study is an effective and valuable technique for technology forecasting but should probably not be used as the sole instrument for producing the forecast. A broad body of academic opinion (Behkami & Daim, 2012; Martino, 1993; Watts & Porter, 1997) supports the use of mixed methods for producing forecasts. It was also noted that a single bibliometric solution is unlikely to be applicable to all technologies and some degree of technique to topic-matching would be required (Mishra, Deshmukh & Vrat, 2002, pp. 5-6).

The principal function of the software review was to establish a suitable software for this type of bibliometric task and to select a specific software to undertake the bibliometric case study. The requirements of the case study were informed by the literature review and VantagePoint software was selected on the basis of its compatibility with the study requirements.

Search strategy and results

The final search string used was as follows:
(“electrophoretic ink” OR “e ink” OR “e-ink” OR “electrophoretic display”) OR (“electronic ink” NOT (“liquid electronic ink” OR “electronic ink pen”))
The topic field was searched in Web of Science and DII. The search in EBSCO Discovery was conducted in the Title, Abstract and Keyword fields and was limited to News Items only. The results from each selected database are recorded in the table below (Table 2)

Database	Number of hits	Coverage
Web of Science	355	1987 - 2013
Derwent Innovations Index	4773	1995 - 2013
EBSCO Discovery	1913	1986 - 2013

Table 2: Total hits returned from database sources using final search string

Data retrieval and cleansing

The datasets were downloaded from the sources discussed in Chapter 3; Academic Articles - Web of Science; Patents - Derwent Innovations Index; News Items - EBSCO Discovery. In all cases the data was downloaded as a tagged text file to allow import into the VantagePoint bibliometric software. The text files were then imported into VantagePoint using the supplied import filters for Web of Science and Derwent Innovations Index, a bespoke filter was created to import the EBSCO Discovery data.

The datasets (patent and academic) were cleansed using VantagePoint's List Cleanup feature. The List Cleanup matches data using a selected fuzzy logic files (several are provided and the level of aggression can be manipulated by the user). The List Cleanup provided results of approximately 80% accuracy for the Author Affiliation fields in the Web of Science and DII datasets, the rest of the data cleansing for these fields being carried out manually. Where inconsistency or uncertainty remained in the cleansing of the Affiliation fields the data was cross-referenced with information from company or institution websites. This final check eliminated any remaining inconsistencies in affiliation address details. Despite the need for manual intervention the software makes this process straightforward for a relatively new user.

The process was repeated on the Author field in the Web of Science data and the Assignee field in the DII data. In both cases the List Cleanup feature automatically corrected around 80% of the data without manual intervention. This kind of cleansing was not required for the EBSCO Discovery data, the small number of fields allowed the dataset to be refined by manual checking only.

EBSCO News sources were used to retrieve news data using the EBSCO Discovery federated search tool, the same string was used in this tool as that used for the academic and patent data. EBSCO data can be exported in a range of formats (HTML, Bibtex, Plain text etc.), the most useful format for the purpose of this study was the Plain text format. This format allowed for a straightforward import into VantagePoint using an adapted version of the software's own RIS format filter.

Some restrictions on the downloading of news items were apparent during the course of the study. The EBSCO Discovery platform allows hits to be downloaded one page at a time for export and each page contains thirty hits. The download times for a substantial number of hits would therefore become cumbersome and this should be noted as a limitation of the tool.

A further drawback for a technology forecasting study is the unreliability of the geospatial data provided by EBSCO Discovery. The data is referenced geospatially relating to the publication place of the news story rather than the provenance of the subject being discussed, thus a US invention reported by a UK newspaper would be indexed as a UK reference. There were also inconsistencies in the formatting of the publication dates so temporal information could be misleading if it was being analysed in any greater depth than by year. The news data, therefore, can only be accurately analysed on an annual temporal basis. It was also noted that the news sources are heavily biased towards US sources so some degree of national partiality can be expected in these results.

Results in detail

The results of the case study are presented with accompanying figures in the following section. The results are organised by levels of aggregation; country level information is presented first followed by institution level information and author level information. The forecasting element of the study is presented in the subsequent Findings chapter, which also includes figures presenting normalised data from the different datasets.

The bibliometric analysis was performed in VantagePoint, the limitations of VantagePoint's visualisation tools resulted in data being output to Excel (VantagePoint provides a direct export for this) in order to use Excel's chart and statistical functions. The following figures therefore have been predominantly produced in Excel, figures produced directly from VantagePoint are annotated to indicate their origin.

Country level data

The following pie chart (Figure 5) shows the overall breakdown of academic output between 1998 and 2012. South Korea, China and the USA are responsible for the majority of output with Taiwan and Japan the other notable contributors. This matches a generally recognised historic trend for electronic innovation in the USA and the Far East. A small and even spread across a number of, primarily northern, European nations is noted.

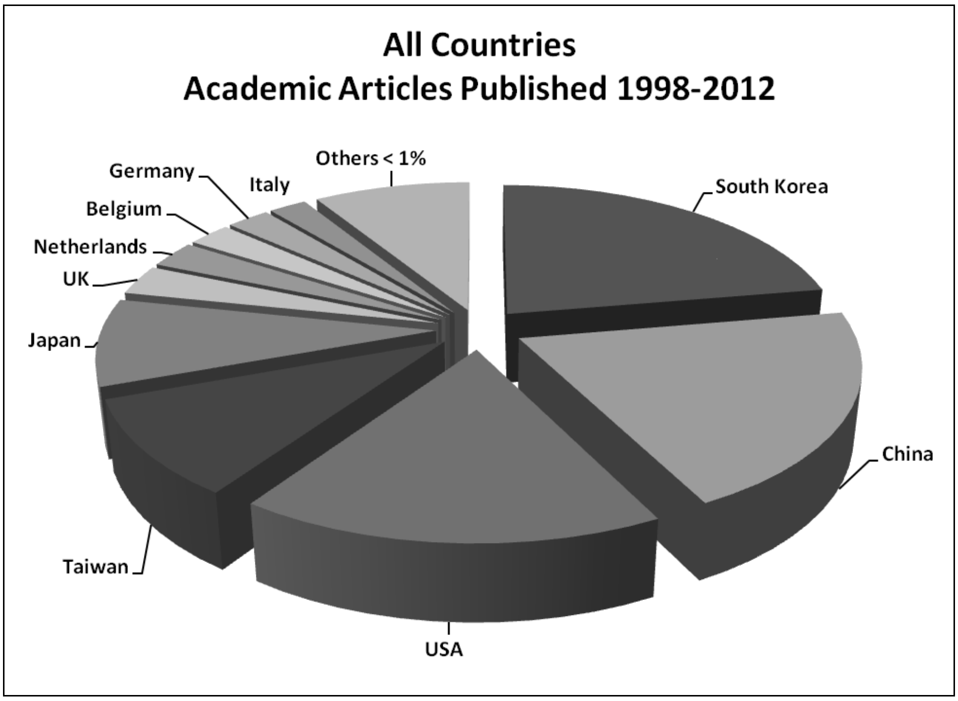
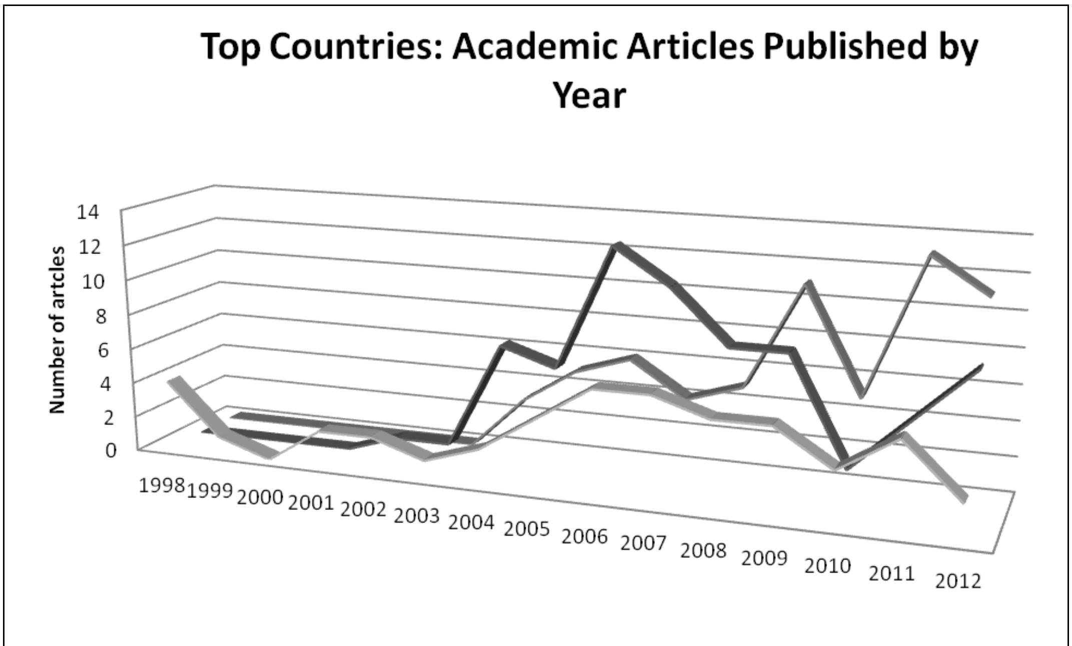


Figure 5: Share of academic articles by country 1998-2012

The following graph (Figure 6) indicates the relatively recent growth of South Korea and China in comparison to the initial development of the technology in the USA. The chart shows how the technology has spread geographically and also indicates an unusual worldwide slump in interest around 2010.



	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
USA	4	1	0	2	2	1	2	4	6	6	5	5	3	5	2
South Korea	0	0	0	0	1	1	7	6	13	11	8	8	2	5	8
China	0	0	0	0	0	0	3	5	6	4	5	11	5	13	11

Figure 6: Temporal projection showing development in top countries since 1998

The reason for the global slump is not immediately obvious; this may be attributable to a) a change in terminology relating to the introduction of the Amazon Kindle b) an unidentified technological challenge to electrophoretic ink. The dip in figures for China and South Korea in 2012 is likely to be caused by the incompleteness of Web of Science data for this year.
South Korean dominance is established around 2004 after the early breakthroughs were made in the USA (Comiskey et al, 1998). A more recent surge has been noted from China though this may represent the more recent accessibility of Chinese academic reports.

Institution level data

The top fifteen institutions associated with electropheric ink technology by citation count are shown in Figure 7. The institutional data could reasonably be

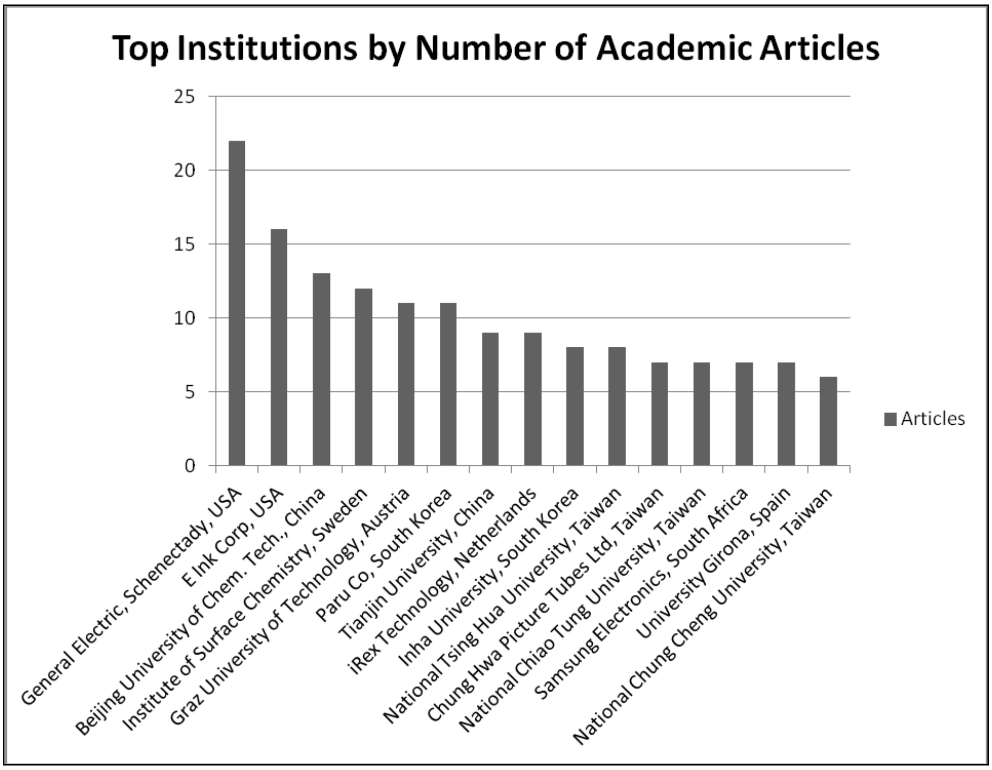


Figure 7: Top institutions by number of academic articles retrieved from Web of Science

expected to mirror the country data and it is not surprising to see two USA institutions at the head of the table. China, South Korea and Taiwan are all well represented, one possible surprise is the appearance of The University of Girona in Spain. This level of analysis contributes to the knowledge of both where the technology is being developed and who is responsible for the development.

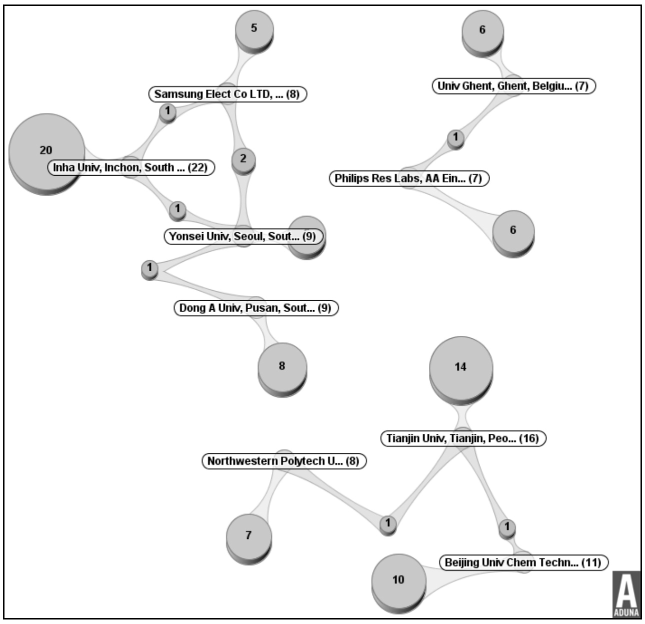


Figure 8: Collaboration between top institutions (VantagePoint)

Bibliometric study can be used to identify collaborations or networks at different levels of aggregation. The following figure (Figure 8) depicts collaborations at an institutional level.

The figure, produced using VantagePoint's Aduna plugin, depicts collaborations between the most prolific institutions in terms of academic output. Amongst the notable exclusions is E Ink Corp who have no collaborations with other high ranking institutions. The figure highlights that these institutions have been collaborating within their own countries and would suggest that there has been little technology transfer between institutions of different nations.

Author level data

All the above methods can be applied if required to individual level data, qualitative assessment can be provided by use of the h-index as shown in the following tables.

Authors	**Records**	**h-index**	**Citations**
Choi, H.J.	17	7	197
Li, X.G.	14	3	42
Chen, H.Z.	13	4	69
Kao, W.C.	12	4	37
Wu,G.	12	4	69

Table 3: Top authors by record count ranked by h-index

The first table (Table 3) shows the most prolific authors ranked by h-index, the second table (Table 4) shows the most cited authors also ranked by h-index.

Authors	**Records**	**h-index**	**Citations**
Choi, H.J.	17	7	197
Chen, H.Z.	13	4	69
Wu, G.	12	4	69
Chen, Y.	3	2	219
Comiskey, B.	1	1	505

Table 4: Top authors by citation number ranked by h-index

The difference between the two tables illustrates one of the drawbacks of the h-index as a method of qualitative assessment. Comiskey, in particular, is an influential figure within the technology – indicated by the high citation score yet would be found at the bottom of h-index rankings due to his limited publication history. The conclusion drawn from this particular study is that subject matter expert opinion may have been a more useful tool for qualitative assessment.

Findings

Specific bibliometric techniques for technology forecasting have been indicated by the findings of the literature review and their applicability to technology forecasting using a selected bibliometric software package is demonstrated in the case study. Significantly the reviews have identified the need to combine methods when producing a technology forecast, as a result of this understanding the case study was designed to include an additional statistical element to be illustrate a final forecast.

The figures included in this chapter illustrate some of the suggested forecasting methods described within the literature review. At the most basic level linear trendlines are provided showing the linear trend of the technology over a period of time. Logistic curves are also plotted, this method should provide a better fit for the data and is a classic statistical forecasting technique. The final normalised figure shows ‘normalised’ data which follows a method proposed by Abercrombie, Udoeyop and Schlicher (2012).

The following figures show the development of electrophoretic ink based on the academic and news sources identified for bibliometric analysis, in both cases the basic counts have been subjected to transformations by logistic curve techniques. A linear trendline is also superimposed with the relevant R^2 value shown. The R^2 value gives an indication of how well the linear trendline fits the data, a figure of 0.80 can be viewed as giving an acceptable fit.

It is important to note that the logistic curve lines have been calculated using a bespoke formula. The saturation figure for the curve is an estimate by the researcher, this figure should normally be established by subject matter experts. The saturation figure in the following figures is generally at the point of peak hits, this is a purely qualitative estimate. The formulae used for both the logistic curve and the linear trendline are provided in the appendix.

Academic articles

The first figure (Figure 9) shows the numbers of academic articles published between 1995-2012. Linear trend lines and logistic curves are estimated out to 2014 in order to indicate forecast. In this case the R^2 value is calculated as 0.76, this is on the borderline of an acceptable fit. The logistic curve suggests that growth in this area is close to its peak and that this curve can be expected to plateau in the near future.

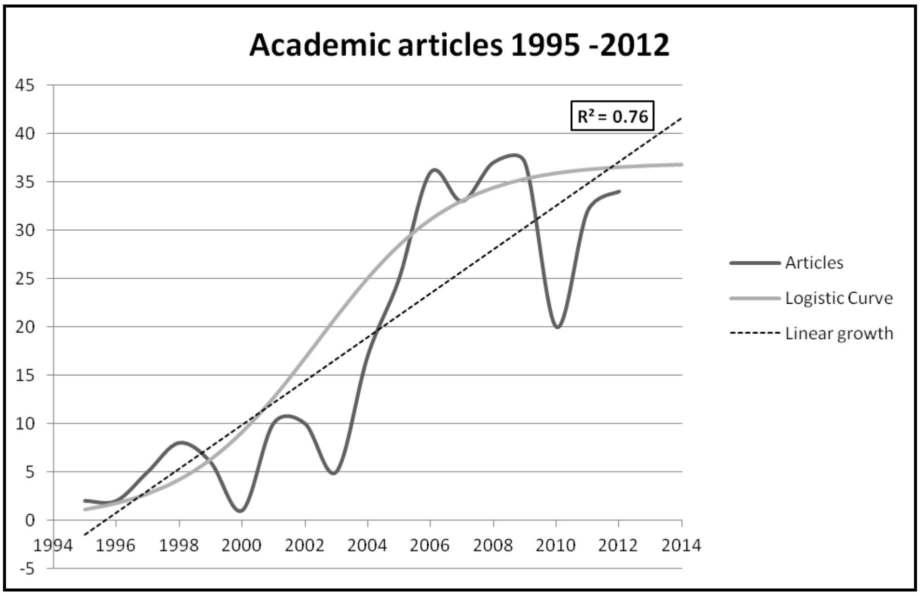


Figure 9: Academic articles 1995-2012: Linear trendline ("linear growth") and logistic curves shown to 2014 to indicate growth forecasts

News items

A similar graphic (Figure 10) is provided for News articles, in this case the data is more difficult to interpret and forecast. The reduction in News Items after 2008 could have several causes; lack of collection on the part of the source database; lack of 'newsworthiness' on the part of the subject matter; deficiencies in the search query and the possibility of neologisms describing the technology. The volatility of the data means that the linear trendline is a poor fit and should be disregarded in this case for forecasting. The logistic growth curve indicates a peak of just over 500 items per year, however no clear forecast can be assumed from the data.

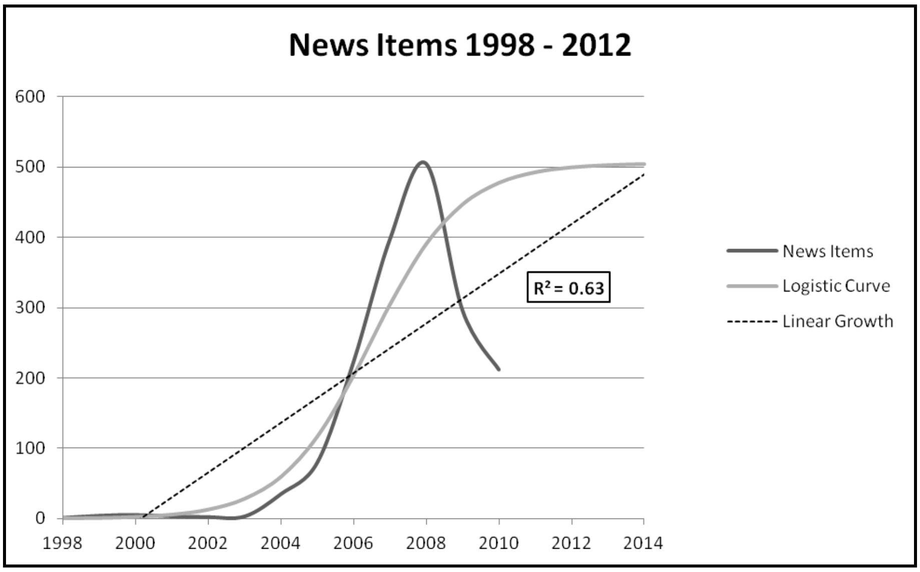


Figure 10: News Items 1998-2012: Linear trendline ("linear growth") and logistic curves shown to 2014 to indicate growth forecasts.

Normalised data

Abercrombie and Udoeyop discuss the use of 'normalised' data as a means of identifying emerging technologies and addressing "the relationships among *multiple disparate* sources of information" (2011, p. 2).

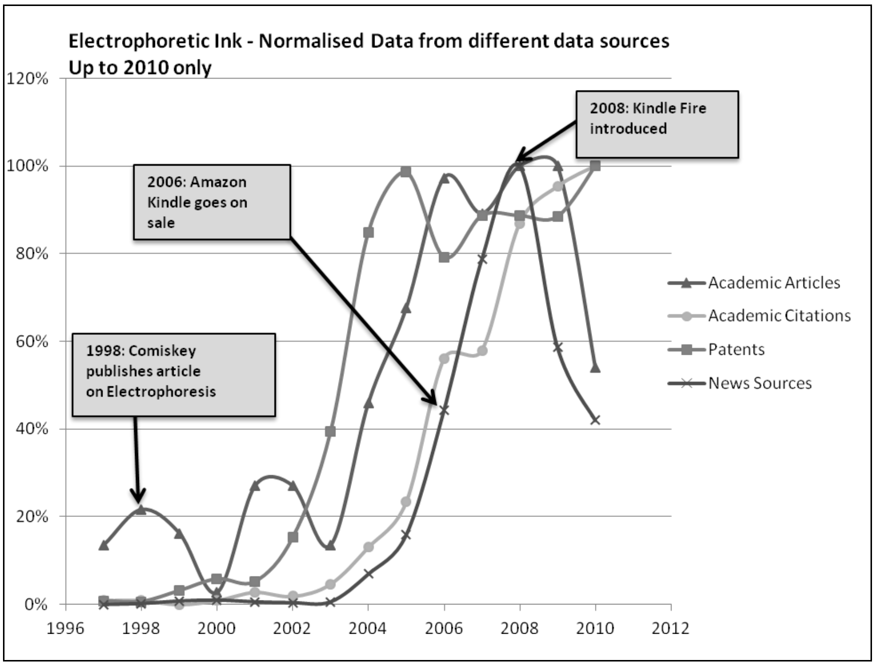


Figure 11: Normalised data from different data sources

Their "empirical trending approach is made possible by normalizing the data within each distinct datasource (i.e. each yearly point is transformed to its respective percentage of the maximum data point within the dataset)." (2011, p. 8). Their method allows the sources to be compared directly and with immediate visual impact. The following figure (Figure 11) is provided using this kind of analysis.

Figure 11 shows the combination of all data sources presented on a single chart. The correlation of the lines indicates the development of the technology. The early period of the technology's development is marked by academic discussion and publication, this begins to be overtaken by patent citations after around five years. Growth in academic articles is mirrored by a growth in numbers of academic citations which follow roughly three years behind and finally the development of the technology begins to be recognised in the news media. The chart is annotated with three key historic incidents in the history of the technology; the introduction of the technology by Comiskey et al in 1998, the initial sale of the Amazon Kindle in 2006 and the introduction of the Kindle Fire in 2008.

The requirement for additional statistical analysis and combining methods is illustrated by the findings of the case study. The strong case for the use of bibliometrics as a tool for technology is laid out in both the reviews and the case study of electrophoretic ink. The case study has shown how a technology can be tracked and subsequently forecast using a combination of bibliometric techniques and statistical analysis.

CHAPTER 5 - DISCUSSION

Background

The main issue addressed by this research is the demonstration of the applications of bibliometrics to technology forecasting. The study also discusses the some of the limitations of bibliometrics and considers to what degree bibliometric techniques alone are sufficient to inform technology forecasts. The study discusses which bibliometric techniques should be used; which other research methods could be combined with bibliometrics and which software based tools are able to process data in the manner required by a technology forecaster. Whilst the research as a whole is heavily dependent on both the literature and software reviews a case study has been presented to illustrate both the bibliometric techniques and statistical interpretations employed by a technology forecast.

Results

The subject area of bibliometrics is well served by academic literature; the initial broad literature search returned a substantial body of information. The subsequent narrowing of the search produced more articles than could be reasonably read within the given time-frame and resulted in further judicious and subjective selection. To bring some order to the literature review the results were initially grouped into two themes; broad bibliometric information and technology forecasting related studies. The technology forecasting theme was narrowed further by the inclusion of articles from a limited number of sources, a broader search of the technology forecasting subject area being impractical for the purposes of this particular piece of work.

The availability of several software packages specifically designed to provide the tools needed for bibliometrics analysis and specifically the kind of bibliometrics analysis required for technology forecasting further supported the likelihood that bibliometrics would be a useful technique for producing a technology forecast. The range of tools available was eventually reduced to four options and the software review indicated that any of these options would have produced results suitable for technology forecasting.

Case study

The study has underlined the value of bibliometrics as a tool for technology assessment and technology mapping but has indicated that its methods have some limitations when it is extended to actual forecasting. The predictive element of the forecast must be carried out by mathematical or statistical modelling. The bibliometric element of the case study has been able to identify the emergence of the technology and its development through life cycles from basic research to implementation and commercial acceptance. The bibliometric study also shows the geographic development of the technology and has illustrated who the major institutional and organisational actors are. The basic temporal and geographic projections supplied by the bibliometric analysis have then been enhanced with simple statistical forecasting methods to produce an indication of the likely development of the technology.

The initial hypothesis of the study was that in the 'Information Age' bibliometric techniques are an important, possibly the most important tool, available to technology forecasters. The study also hypothesised that the available software and tools available to be researchers might be enough to produce technology forecasts without the addition of other research methods. The research was designed to examine these tools and techniques in depth and conclude on the relative usefulness of individual pieces of software and highlight the most important techniques to use.

The results of the case study to a certain extent followed a predictable pattern. The technology life cycle was produced as expected and the overall development of the technology did not appear to be unusual.

Previous research

Previous research (Daim, Rueda & Martin, 2006; Martino, 1993, 2003; Watts & Porter, 1997) has indicated clearly the importance of bibliometrics as a tool for technology forecasting. The general weight of argument is that bibliometrics provides a thorough method for assessing and mapping the historic and current state of a technology. Based on the results of the literature review, many academic writers can be named as stating the importance of bibliometrics for technology forecasting, though there do not appear to be any claimants for it to be used as an exclusive method for technology forecasting.

The study began on the premise that bibliometrics formed a fundamental part of the process of technology forecasting and an expectation that such forecasts might be feasible using bibliometrics alone. The research has indicated that the latter assumption is unlikely – a much larger scale study undertaken over a longer time period would be required to provide a definitive answer to this.

Recommendations

Perhaps the greatest limitation of the study is the lack of subject matter expert input guiding the development of the search string. The technology chosen for the case study is not overly complex but a fuller understanding of the technology and some of its broader applications would greatly inform a similar study. Most certainly expert knowledge of the e-ink market would give much greater credence to the ultimate forecasting results.

The relatively small number of hits for each area (academia, patents, news) impinge on the overall integrity of the statistical analysis and therefore the statistical conclusions are of only minor importance to the study. The amount of data though is felt to be sufficient to apply the different example techniques to and was a comfortable amount of data to both download and work with in the bibliometric software. An argument against using a much larger dataset would have been that the cleansing of data would have been too time-consuming given the limited ambition of the actual case study. The degree of manual data-cleansing, particularly of the author and author affiliation from Web of Science is approximated at c.5% of the overall time allocated to the bibliometric study. As with all similar studies such time scales are dictated by the degree of precision required from the results.

The case study is limited to research in a relatively small area of technology and it should be understood that the results are not indicative of larger scale technologies. Results from a larger scale technology would perhaps require different techniques and again would benefit from the participation of subject matter experts.

This discussion of the study results is followed by the final conclusions; the conclusions will further expand on the issues identified by the study and provide some recommendations for further study.

CHAPTER 6 - CONCLUSIONS

Introduction

The introduction to this dissertation noted the relative modernity of bibliometrics as a scientific discipline and the how it has developed alongside modern advances in personal computing and the development of large scale, accessible online databases. Early theoretical advances regarding the study of scientific literature such as those espoused by de Solla Price (1965) were followed by the development of analytical tools led initially by Garfield's establishment of the Science Citation Index.

The principal aim of the research was to identify the possible applications of bibliometric techniques and tools for technology forecasting. A further concern was the possible limitations of bibliometrics as a single method for technology forecasting and therefore the study reviewed which methods might be used in combination with bibliometrics.

Literature review

The literature review was undertaken to enable an understanding of the range of bibliometric approaches available and provide some detail of the techniques used for technology forecasting. The review set out to look at a broad range of bibliometric techniques and assess which might be most commonly used for technology forecasting. The review also aimed to identify technology forecasting papers which relied predominantly on bibliometric techniques for their results. The technology forecasting section of the review also noted a number of possible statistical methods for producing a final predictive element of the forecast, though this was not an explicit aim of the original dissertation this element of the work was included to produce an illustrative forecast. The literature review shows that bibliometrics is widely used as a technique by technology forecasters and provides the backbone of many such studies. The literature review illuminated one unexpected point that bibliometric techniques alone are unlikely to produce adequate results to produce a technology forecast and that a number of techniques should be ideally combined to have confidence in the predictions.

Software review

A review of bibliometric software accompanies the literature review. It was necessary to review a number of software options as increasing numbers have become available to researchers in recent years. The different software packages were reviewed with a view to their specific ability to perform the types of bibliometric analysis recommended for technology forecasting. In some cases the software producers provided explicit instructions for producing a technology forecast, indeed VantagePoint goes as far as providing a step-by-step list of instructions for the budding forecaster.

Methodology

The methodology for the practical study was informed by the results of the literature and software reviews and the following elements were selected: a candidate technology of sufficient scope and maturity; database sources providing academic, patent and news information; bibliometric methods for studying technologies; statistical forecasting methods; software to undertake the study. The methodology and research design were drawn up to reflect the overarching aim of identifying bibliometric techniques and tools.

Results

The results of the practical study outlined the development of e-ink technology from its introduction in the 1990s to the present day. The limitations of each dataset were outlined, in some cases more recent results had to be ignored as these years were incomplete in the datasets.

The results painted the following picture of the development of the technology. An initial US discovery was further developed in the US and then subsequently overtaken by advanced development in the Far East. The bibliometric analysis shows current leadership in the market by South Korea, China and Taiwan.

The bibliometric study tracks the emergence of the technology and satisfactorily outlines the geographical diffusion of the technology. The technology 'life-cycles' are indicated by the different datasets: basic and applied research identified by the academic articles; commercial development by patents; commercial application by news items.

The forecasting element is shown through linear trendlines, logistic growth curves with the development of the technology been depicted by a sequence of normalised datasets. In all cases this is intended to be illustrative rather than depict a definitive forecast and no assumptions about the technology should be drawn from these forecasts.

Discussion

The evidence of the literature review and the results of the practical study both indicated that the original premise that bibliometrics could be used alone as method of technology forecasting was not feasible, though it could not be completely dismissed without further study.

The limitations of the practical part of the study have been identified, the lack of subject matter expert input being the largest concern alongside the scale of statistical data used for the study have been identified.

Further research

Further research in a number of areas could be undertaken to enhance this study. Further studies of software, especially more recent releases, might discover a more suitable bibliometric software with a greater emphasis on technology forecasting. The bibliometric techniques outlined could also be studied in greater depth particularly the more sophisticated techniques such as network analysis. The study could also be replicated on a technology returning a much larger dataset and any further study might consider if professional and academic attitudes towards newer sources such as Science Direct and Google Scholar are changing.

Conclusions

The work set out to discuss bibliometric techniques for forecasting and review both literature and software as a means of determining which techniques and tools could be used for such forecasting. An assumption at the outset of the work was that bibliometric techniques might be able to provide a full enough analysis to provide a technology forecast without recourse to additional analytical methods. The results of both the literature and software reviews have indicated that this was a largely impractical assumption. Bibliometric analysis can, however, provide a rich technology assessment as it can draw on sources from research through to application and implementation of a technology.

A further assumption was that a skilled enough researcher might be able to produce a forecast without the intervention of subject matter experts. Whilst this may, in exceptional cases, be possible the likelihood is that for the forecast to have any real authority the engagement of expert opinion is required.

The research has shown that bibliometrics techniques richly inform the process of technology forecasting and the use of such techniques is widely accepted. The discipline is well serviced by software developments and the refinement of new packages may allow for more sophisticated bibliometric analysis. Bibliometric analysis provides a widely accessible and powerful means of assessing technology but must be combined with other analytical techniques to produce a technology forecast.

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Appendix

Linear trendline

The linear trendlines were calculated in Excel. The linear trendline uses the following equation “to calculate the least squares fit for the line:
$\gamma = mx + b$

where *m* is the slope and *b* is the intercept” (Add, change, or remove a trendline in a chart, 2013).

Logistic growth model

The logistic curve results presented in the Results chapter were based on a bespoke Excel function developed by Professor Stephen R. Lawrence, University of Colorado (Lawrence, n.d.). The theory provided in the worksheet is quoted in full below.

> ***The Logistic Curve***. *The logistic curve (or Pearl curve) is represented by the function*
>
> $$y = L/[1+ a*\exp(-bt)]$$
>
> *By defining*
>
> $$Y = ln(L/y - 1)$$
>
> $$\alpha = ln(a) \qquad \text{so that } a = \exp(\alpha)$$
>
> $$\beta = -b \qquad \text{and } b = -\beta$$
>
> *the non-linear logistic function is transformed to the linear function*
>
> $$Y = \alpha + \beta t$$
>
> *Given a dataset of y's and t's the y-values are transformed into Y-values, and standard linear regression is used to estimate α or β for a given L, from which a and b are calculated*
>
> ***Estimating and forecasting.*** *For estimated values of a, b, and L, forecasts for y at time l are obtained by using the logistic equation defined above.*
>
> ***Scale Parameter L.*** *Note that L is a “scale” parameter which scales the logistic function “up and down” Scale parameter L must be specified*