Technological innovation in libraries

Pei-Chun Lee
Graduate Institute of Library, Information and Archival Studies, National Chengchi University, Taipei City, Taiwan

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Abstract

Purpose – The purpose of this study was to identify technological innovation in libraries and further examine the knowledge source and their effects during the technology life cycle (TLC).

Design/methodology/approach – This paper discusses the technological innovation taking place in libraries. Patent citation analysis was used to capture the trend of technological innovation associated with libraries.

Findings – The findings are as follows: (1) library technologies are now in the ascent phase of their life cycles; (2) private companies from the United States, Germany, France, Japan and the United Kingdom are the top-five owners of intellectual property rights associated with library technology and (3) patent data along with knowledge and technology indicators can be interpreted in the light of library development. The knowledge source with the highest degree of scientific and technological orientation was identified as basic material chemistry. The major technological categories that have received the greatest knowledge effect from library-associated technological innovation are chemistry, electrical engineering, instruments, mechanical engineering, with other fields (civil engineering and furniture, games) being subject to less effect.

Research limitations/implications – There are two research limitations in this study. First, the results use single informants, patents retrieved from United States Patent and Trademark Office, as the source of data. Second, this study uses patent citation measures for exploring the knowledge source and effect of technological innovation, these measures are only subjective for those new invention highly based technological advances. This study concludes that technological innovation for libraries will be characterized by an increasing role for science-intensive and interdisciplinary areas. This study also suggests that organizational learning facilitates innovation. Therefore, a library hoping to co-evolve with dynamic environment through technological innovation should improve its organizational learning processes.

Practical implications – Theories of technology-push and demand-pull were examined in relation to technological innovation taking place in libraries. The TLC analysis indicated that library technology is mainly in the ascent stage, suggesting that libraries have not achieved the strongest technological transformation. The findings suggest that the importance of demand-pull and technology-push vary over the TLC of libraries.

Social implications – To survive in a dynamic environment library must be able to cope with increasing complexity and high-speed technological change. It is pivotal to integrate the views of users (as customers), software houses or design companies (as suppliers) as well as other libraries (as communities) into the sustainable development strategy of a library. In these contexts, libraries with the capacity to innovate will be able to respond to new demands faster and to invent and provide new services better than noninnovative libraries.

Originality/value – Analysis based on the technological innovation perspective to identify the future development of libraries is still lacking. This paper seeks to identify the technological innovation employed in libraries to accommodate the 21st century model of information-seeking behavior. This study identifies a variety of factors that have influenced the transformation of library services, and these include technology developments and new demands from library users. To illustrate the driving forces of technology-push in libraries, this paper examines holistic-patented technologies invented for libraries.

Keywords Technological innovation, Library, Patent citation analysis

Paper type Research paper

1. Research background

The term “innovation in libraries” refers to the process by which library services evolve to be calibrated to the changing needs of users, such as by offering new or revamped services

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incorporating new digital technologies, and by supporting for new paradigms of information-seeking behavior by users (Yeh and Walter, 2017). Innovation in libraries has been broadly defined to consist of changes in existing library services to keep up with the changing needs and information-seeking behaviors of users. Service innovation driven by new digital technologies further supports new paradigms of teaching and research (Walter and Lankes, 2015). Rapid evolution of technology and the digital era have enabled faster and more convenient access to knowledge and information resources, and the role of the traditional librarian is changing. Because the main mission of most libraries is to offer equal access to information, libraries have become trendsetters in the use of digital platforms and implementing innovative technologies and services. Due to rapid changes in the collective information landscape, the information-seeking behavior of library users and the nature of library operations, usage patterns of library resources have steadily evolved from being library-centric to involving reciprocal interaction between the library and users (O'Connor *et al.*, 2007). This trend has caused a paradigm shift in the role and function of libraries in the 21st century. Major advancements include the emergence of digital technologies, changes in how library users seek and use information, and the new demands and expectations that these users have of libraries, prompting libraries to transform the delivery of user services.

A number of forces have driven the recent transformation of libraries, including the digitization of content; the development of print repositories, e-readers and print-on-demand publishing; the growth of open access; challenges to established academic publishing organizations; and the growth of new forms of scholarship based on openness and social productivity. The ubiquitous and interconnected communication network that predominantly makes information resources easily and freely available requires a synchronous transformation of library practice (Lewis, 2013; Lynch, 1993). Therefore, libraries now can play a role in organizing citizenship and offer playgrounds and makerspaces, social services and much more. The growing maker movement within communities and libraries is due to the many advocates promoting its value. The makerspaces are designed to fabricate things, and consist of digital equipment for designing products and the digitally driven tools to create them (Burke, 2014). One significant characteristic of the maker movement, which distinguishes it from previous versions of people simply making things, is the impact of community-building and the collaboration of people working to make things within a single space (Abram, 2015). Makerspaces not only take advantage of such openness to create opportunities for partnership, collaboration and creation but also becoming a means of future-proofing libraries to ensure that the library evolves along with advances in technology and changes in users' needs (Slatter and Howard, 2013) (Moorefield-Lang, 2015). Therefore, flexibility, vision and open-mindedness in the design and architectural planning process are essential to facilitating the transformation of libraries. It has been suggested to librarians that they embrace new technologies to keep abreast of new trends. Their role has been depicted as that of agents of change through whom new technologies are made available to users (Callahan, 1991). There are several obvious applications of new technologies with great potential for library services. For instance, the storage and analysis of large datasets can be a major advantage for librarians because they have the skills and knowledge to make the most effective use of these massive sources of information. Moreover, big data can improve a library's overall activity by enabling it to gain access to more insights into the users' minds using various applications of artificial intelligence focused on delivering information to the users. Adding an intelligent dimension to all applications at libraries is also a useful approach to understanding the patterns in user behavior and adapting to users' needs. Furthermore, blockchain technology also provides an opportunity to build an enhanced metadata system for libraries to keep track of digital-first sales rights and ownership, to connect networks of libraries and universities, or even to support community-based borrowing and skill-sharing programs. The Internet of Things has received considerable attention since its first deployment in the library context, which has entailed tracking room usage and program attendance and monitoring humidity levels for special collections. Regarding the design thinking of the user-interface, personalized interaction between the system and users and the digital interface of collections represent the future perspectives of library services. Through the use of these new technologies, libraries can offer improved user experiences by enriching their services and collections.

Overall, prominent transformations have taken place in libraries. Since 1939, the American Library Association and the International Federation of Library Associations have maintained a code of professional ethics that librarians and other information professionals reference regarding social challenges such as copyrights, censorship and freedom of information (Shachaf, 2005). Ethical issues raised in the early years dealt primarily with librarians' responsibilities. Librarians tend to view social responsibility as a part of their profession. Additionally, library professionals pursue excellence, integrity, collaboration and transparency in the workplace. Therefore, librarians must make patrons feel comfortable accessing information in an environment that does not safeguard their personal data. According to the Family Educational and Privacy Rights Act and the Protection of Pupils Amendment, firms are free to collect data in academic settings, creating an ethical dilemma for library professionals (Williams, 2009). In response, librarians have advocated for free and unrestricted learning access to information by patrons (Dole *et al.*, 2000).

Libraries have been expected to answer the call to enter the digital age. Research has examined how libraries are evolving in response to the digital revolution (Lougee, 2002; Ochs and Saylor, 2004; Lynch, 2003; Calhoun, 2014). As libraries have started digital transformation, big data and analytics can play key roles in the success of this digital transformation. Prior study predicted that the total volume of digital information will expand from 130 to 40,000 exabytes (Guo, 2014). Under this trend, the field of predictive analytics is going to become increasingly popular due to the massive amount of user data generated by social media. By analyzing the big data from social media, libraries will be able to identify the hallmarks of users. Consequently, libraries need professionals who can conduct research, analyze data, solve problems, develop new solutions and improve library services through the use of new technologies. Furthermore, technology proponents have postulated the ideal and practices of digitization, which entails replacing tombs of hardbound and paperback stacks with open reading spaces populated by electronic retrieval and reading devices. Digitization is the process by which materials are converted from hard copies to electronic copies. The main purposes of digitization are to enhance access and improve the preservation of library materials. A number of challenges are encountered in the process of digitizing library materials. These challenges include human and technical problems, which have implications for transforming and developing libraries. Currently, libraries are working on reallocating their functional spaces as well as providing users with diversified resources and activities, such as the expansion of makerspaces where users gather to learn, create, invent and develop skills that are impractical to learn online. The first public library with a makerspace was the Fayetteville Free Library in New York State, which best exemplifies the continued focus of the library on learning (Willett, 2016).

Innovation taking place in libraries has been discussed through an organizational and librarian development lens. However, analysis based on a technological innovation perspective is still lacking. This paper fills the research gap concerning the technological innovation perspective in the library transformation literature. The sources of innovation can be purely external or internally generated competencies that enable a library to integrate external knowledge within its boundaries. It is suggested that the transition toward a library that meets the needs of the future requires integrated efforts that evolve with users' information-seeking behavior over time and are designed to increase collaboration between the libraries and users.

Libraries have introduced various information and communication technologies as a means of expanding and strengthening user services, but not much attention has been paid to the social, organizational and librarian-related aspects, despite being pivotal to the implementation of technological innovation strategies in libraries (Katsirikou and Sefertzi, 2000; Jantz, 2012; Drake, 1979). Nonetheless, analysis based on the technological innovation perspective to identify the future development of libraries is still lacking. This paper seeks to identify the technological innovation for libraries to accommodate the 21st century model of information-seeking behavior. First, this study identifies factors that have influenced the transformation of library services, and these include technology developments and new demands from library users. To illustrate the driving forces of technology-push in libraries, it is necessary to examine holistic-patented technologies invented for libraries. The purposes of this paper are to present (1) a review of the literature dealing with technology-push and demand-pull driving forces for library transformation and (2) the trend of patented technological innovation associated with libraries. The remainder of this paper is organized as follows. Section 2 reviews the literature on technological innovation in libraries, with a special focus on technology-push and demand-pull. In Section 3, this paper justifies the use of patent analysis to meet the research objective and describes the research design. Section 4 discusses the trend of technological innovation for libraries in light of the research results. Section 5 discusses the main findings of this study and provides a comprehensive picture of the status as well as development suggestions for libraries in the future.

2. Literature review

The purpose of this paper is to integrate the implications from technology-push and demand-pull perspectives for the development of future libraries. This section discusses innovation and diffusion in libraries, technology-push and demand-pull in terms of critical factors that affect library operations and their relationship to innovation. Driven by technology-push and demand-pull, libraries have gone through socioeconomic development and technological advances over the past decades. A collaborative and user-centric model is now leading libraries into a new chapter. Moreover, the new era is being ushered in much faster than previous ones (Callahan, 1991). The technology-push perspective recognizes the key role that technology plays in developing technological innovations and adapting to the changing characteristics of the external environment. The demand-pull approach can identify a broader set of user information-seeking behavior, including characteristic patterns of interaction between digital technologies and users as a whole, which affects the development of libraries.

2.1 Innovation in libraries

There has been well-developed confirmation of the role of technology in generating innovation and increasing criticism of a pure demand-pull perspective. In particular, a number of theoretical and empirical concerns have been raised against demand-pull. For instance, given the interrelated nature of demand and supply curves, Mowery and Rosenberg (1979) argued that it is technically complicated to distinguish a demand-pull situation from a technology-push one. Studies of the demand-pull thread have failed to produce sufficient and convincing evidence that needs presented through market signaling are the main driving force of innovation (Dosi, 1982). Moreover, demand-pull does a better job of explaining incremental technological change than discontinuous change; thus, it is not responsible for the most critical innovations (Mowery and Rosenberg, 1979; Walsh, 1984).

Innovation studies reflect research threads from two major perspectives: economics and sociology–psychology (Fagerberg and Verspagen, 2009). Economics regards innovation as concerning the diffusion of technology, technology transfer, economic development and growth. The sociology–psychology perspective examines the processes of social change and cultural diffusion. The spread of an innovation in a market is termed "diffusion". Diffusion research seeks to understand the spread of innovations by modeling their entire life cycle from the perspective of communications and consumer interactions (Mahajan *et al.*, 2000) (Krishnan and Suman, 2009) (Peres *et al.*, 2010). Diffusion processes of innovations have become increasingly complex and multifaceted in recent years. Users today are exposed to a wide range of influences that include word-of-mouth communications, network externalities and social signals (Peres *et al.*, 2010). Technology-based innovation developed for libraries comes either from user needs (demand-pull), leading to the discovery of new innovation technology to help meet those needs, or from new inventions that are later adopted by the users (technology-push) and become useful to meet new needs. Accelerated progress in information technology and telecommunications systems has created a dilemma for libraries. Technological advances have provided opportunities for skilled librarians to reshape internal operations and their interaction with users. Yet, the shorter life cycle of computer hardware platforms and systems software has made it increasingly difficult for librarians and information technology system designers to keep abreast of the latest developments. Technological uncertainty may arise from complexity or the need for knowledge to be able to successfully implement novel technologies. Technological innovation for libraries is not a single event but is rather a process of knowledge accumulation and professional expansion. Therefore, technological innovation, regarded as the extent of librarian professional development, affects innovation adoption.

The lack of a general theory of innovation prevents any definitive statements regarding the future course of innovation in libraries. It is useful, however, to review expert opinion regarding the probable course of innovation in the publishing, communications, and information industries and to note current trends. Building on these contributions, this study argues that the trend of technological innovation can be better understood through the critical driving forces for future libraries. The key idea presented is that the two driving forces, technology-push and demand-pull, continually influence each other over time and also affect the development of libraries. To illustrate this, this study considers the holistic overview of technological innovation for libraries as one of the best projections for us to capture the future of libraries.

2.2 Technology-push

Given its importance for economic progress and welfare, studies have long been interested in exploring the drivers of technological change. In this context, studies have revealed that technological change is driven by two main factors, namely, (1) technology-push – factors that increase the supply of technological options by directly fostering advances in science and technology and (2) demand-pull – factors that stimulate the demand for specific technologies. Technology-push refers to research and development (R&D) in new technology, which drives the development of new products or services. The core concept of technology-push is that advances in technological development determine the rate and direction of innovation (Nemet, 2009). Technology-push development is based on the notion that the product supplier recognizes the users' needs even before the users do (Dixon, 2001). However, the unidirectional development within the stages of the innovation process might be incompatible with coordinated sets of subsequent factors, such as feedback, interactions and networks. Another research thread has raised issues of the interrelatedness of the technological system (Frankel, 1955) as well as the importance of flows of knowledge between different disciplines (Rosenberg and Nathan, 1994).

Scholars have contended that four main library revolutions have occurred: Library 0.0, Library 1.0, Library 2.0, Library 3.0 and Library 4.0 (Bingsi and Xiaojing, 2006; Mason, 2010; Noh, 2015). None of the library models has entirely replaced prior ones. They have instead complemented and absorbed elements of each other. The use of version numbers to represent perceived improvements in library services is currently highly related to the application of the corresponding labels to refer to the development of the World Wide Web. Thus, Library 1.0 is analogically associated with Web 1.0 in the same manner as Library 2.0, 3.0 and 4.0 are linked to their corresponding versions of the World Wide Web. However, the sequence of developments and its embedded logic are controversial and subject to ongoing debate (Kwanya *et al.*, 2013, p. 0). Library 0.0 is mainly site-based, and all the users' information needs are supposed to be contained within the library. Access to the services and products can only be accomplished by visiting the physical library. The core concept of Library 1.0 represents the conservative traditional library in which the users are passive recipients of knowledge. Library 2.0 focuses on the participation of users and entails the dilution, to some degree, of the role of librarians. Library 3.0 is a hybrid model of Library 1.0 and Library 2.0 and reaffirms the role of librarians in the information value chain as apomediaries. From the Industrial Age into the Information Age, wider accessibility has driven Library 2.0 toward the borderless library of Library 3.0, which exists independent of physical location (Peltier-Davis, 2009; Casey, 2006). Since 2006, Library 3.0 has been encouraged by the technological adoption of artificial intelligence, evident in the application of the semantic web, cloud computing and mobile devices, to offer information services based on users' implicit rather than explicit needs (Balaji *et al.*, 2018; Kwanya *et al.*, 2013). Therefore, both the role and function of librarians have to be calibrated to the specific information needs of users; for instance, librarians should have the ability to annotate and compare books and other information sources from a variety of perspectives instead of just to organize the library collections and resources from the linear perspective of supply and demand. To promote and ensure the seamless accessibility, searchability, availability and usability of library collections, the application of tools, such as federated search systems, can facilitate the development, organization and sharing of user-generated content through seamless collaboration between users, experts and librarians (Belling *et al.*, 2011). As a virtual complement to the physical library space, Library 3.0 is expected to function seamlessly within established library systems, services and collections. It transforms unorganized web content into a systematic and organized body of knowledge by establishing a semantic relationship between all available web content. Therefore, the key performance indicator has shifted from conveying the right information to the right user at the right time to the optimization of speed, accuracy, precision and systematic organization of information available on the library website (Chauhan, 2009). The creation of a compelling experience defined by an environment that is authentic, humane, experiential, passionate, relevant and participatory has become a pivotal task for user engagement. Library 3.0 can be regarded as presenting the opportunity to make use of age-old library tools such as standardized thesauri, terminologies and classifications to facilitate effective information retrieval from a complex variety of sources and formats (Robu, 2008). It is consistent with the argument of Giustini (2007) that Library 3.0 will lead to the reappearance of the principles of librarianship. Library 4.0, or "the aesthetic library," is a further horizon of libraries. The features of Library 4.0 and the development direction of Library 4.0 entail intelligence-based service, massive data, augmented reality, context awareness, cutting-edge displays and infinite creative space (Noh, 2015).

2.3 Demand-pull

The argument of demand-pull can be traced back to the 1950s and 1960s. Scholars claimed that demand drives the rate and direction of innovation. Demand drives firms to work on certain problems. Market changes create opportunities for firms to invest in innovation to satisfy unmet needs (Rosenberg, 1969). Therefore, demand-pull refers to a scenario in which users demand a product (or service) type or define a problem, and libraries respond by delivering that product or service. It has been argued that technology alone will not sufficiently solve library operational problems. There is a great need to understand more fully the fundamentals of library service and the nature of users' needs. Therefore, librarians will have to become more knowledgeable and competent in dealing with user demand, the changing pattern of information-seeking behavior and the value of information to users. The design of demand-pull development needs to be adjusted over time to accommodate technological change (Nemet, 2009).

Regarding the development patterns of libraries, the library paradigm has shifted from a single library to a network of libraries, from one collection to distributed collections, from a catalog interface to multiple interfaces, and from books and journals to information fields and streams encompassing traditional and nontraditional forms of scholarly communication (Libner, 2003). This trend also indicates that the diverse forms of collections and resources in a full-text form within a fully integrated and comprehensive search environment can be accessible anytime and anywhere without limitation (Breeding, 2008). Innovation in libraries has been primarily focused on delivering improved services. There have been three major development trends: automation, low-cost rapid communications capability and demands for improved managerial performance, which have led to a broader concept of innovation centered on processes, functions and human behavior. On the basis of the existing studies, innovation leads to increased productivity as well as reduced cost. However, innovation is not necessarily synonymous with high technology or high-tech sectors; it is increasingly involved in equipment, materials, processes, software and methods. For instance, the library is among the most prominent entities that use innovation more than they produce it. Technological achievements and products are obtained from outside libraries, and so they become innovative in the range of processes (Katsirikou and Sefertzi, 2000). Innovation based on demand-pull can be developed by establishing social networks in response to an identified user need. For instance, libraries use social media to fulfill a range of objectives, with most focused on promotion (visibility for and usage of the library services and resources). Librarians share seminar, conference and workshop information on social media to raise awareness among library professionals and market library events on social media such as Facebook, Google+, Twitter and LinkedIn. The applications of novel technologies have changed how libraries connect and interact with the world, enabling library services to meet users' needs for information in a fast-paced society.

Skills, knowledge, abilities and attributes are core competencies that librarians are expected to possess to be able to contribute successfully in an innovation context. However, the extent of librarians' knowledge and capabilities have been questioned, with doubts expressed concerning (1) how effectively librarians can identify unrevealed needs from an almost infinite set of possible human needs, (2) the extent to which librarians in general have access to a large-enough stock of techniques to address the variety of needs that could be expected to emerge and (3) how far librarians might venture from existing routines to satisfy unmet demands. More specifically, librarians working in 3.0 environments are facing a role shift in which traditional competencies are becoming less prominent because of a greater focus on personal rather than technical competencies (Myburgh, 2003). In addition to the effective use of the Internet, practical software and hardware management, and database design skills, it has been suggested that librarians not depend entirely on technology but continue to advance services at a human level with a human touch. The competency index for a wide spectrum of librarianship covers five major dimensions that include library management, personal and interpersonal skills, public services, technical services and technology skills (WebJunction *et al.*, 2010). These five dimensions can be categorized into technology-push and demand-pull forces in libraries. The technology and technical competencies cover a wide range, including electronic communication, core hardware use, Internet use, core software use, core operating systems use, applications use, web design and development, enterprise computing, networking and security, server administration, technology project management, technology policy development, technology training, acquisition and processing, cataloging, collection management and preservation of information resources; these can be regarded as the most critical factors for absorbing technology-push in libraries (Junction, 2009). On the demand-pull side, the personal, interpersonal and public service competencies are the key factors for identifying and addressing the variety of needs that could be expected to emerge in future libraries. Therefore, communication, customer service, ethics, values, access services, specialized user (adult, youth and children) services, collection development and patron training are crucial for dealing with demand-pull in libraries (Junction, 2009). To sum up, technology-push and demand-pull are necessary but not sufficient for innovation to result; both may exist simultaneously (Mowery and Rosenberg, 1979). The sources of innovation can be purely external or internally generated competencies that enable the libraries to integrate external knowledge into their boundaries.

3. Research design

3.1 Data and method

Because patents can provide exclusive rights and legal protection for inventors, patents play a pivotal role in the development and diffusion of novel technologies. Patent analysis has been used to gain insights into various economic and social issues (Crosby, 2000; Jung and Imm, 2002; Marinova, 2001). To illustrate the technological innovation associated with libraries, patented technologies invented for libraries were analyzed in this study. Through the use of patent abstracts and titles, "library" was used as the keyword to retrieve 8,687 patents from the United States Patent and Trademark Office (USPTO). Concern that the term "library" has been interpreted in different ways by scholars from different fields, this study examined the details of patent data to verify whether patented technologies were invented for libraries. There is a total of 8,687 patents issued by the USPTO between 1976 and 2014 for technologies invented for libraries. In addition to descriptive statistics, this study assessed technological innovation in libraries from knowledge and organizational perspectives and examined indicators of knowledge sources, knowledge effects, knowledge diversification, and local and international collaborations to generate a comprehensive picture of the trend. This paper investigated the relative importance of technology-push in driving innovation, particularly for the development of libraries.

Several indicators have been applied to measure technological innovation as a function of patent quantity, quality or value. Some examples include patent citation indicators and logistic and regression models. Because the total number of patents over time for a technology has a saturation point, growth curves have been regarded as a useful approach by which to identify the current stage of the complete technology life cycle (TLC). Patent analysis has been shown to be valuable in planning technology development from an analysis of strategy at national, industry or organizational levels to predict the following development of specific emerging technologies (Ashton and Sen, 1989; Bengisu and Nekhili, 2006). Patents archived in most patent databases contain a variety of information such as the application and issue date, the assignees, the inventors, the patent and nonpatent references, and the international classification number. Much like text and journal information, few patents actually develop into something of commercial value; however, most are technically significant because they encourage or lead to follow-on developments in technologies or services (Ashton and Sen, 1989). Therefore, understanding the growth and direction of patented technologies according to knowledge and organizational perspectives can offer an illuminating overview of library development.

Inspired by a study in which patent citations appeared to be highly correlated with the value of innovations (Trajtenberg, 1990), this study applied two indicators, knowledge source and effect, to capture the origin and development of knowledge; this approach was adopted to achieve the research objectives. Patent citations that appear in a patent (as its backward citations) indicate the technological antecedents of the patented invention. A patent that contains many citations corresponds to an invention with many antecedents. It has been argued that inventions that are more basic are less incremental in nature and thus have fewer identifiable antecedents. In this sense, patents that are near the beginning of a trajectory are more basic and may be expected to generate fewer backward citations because of their shorter historical background. Furthermore, to analyze the degree of technological diversification, this study used International Patent Classification (IPC), which provides a hierarchical system of language-independent symbols for the classification of patents and utility models according to technological domain to which they pertain. This system reflects changes in technologies themselves, with new patent classes added and others being reclassified and discarded. Each patent is assigned to an original classification (class and subclass) as well as to any number of subsidiary classes and subclasses.

Patent trend analysis yields information on technology trends in the development of new or improved products or processes. Given that several technologies associated with libraries are still in the development stages, patent analysis can be used to measure the research interest for each technology. Patent activities can be used to interpret the stage of technological progress. The cumulative patent applications for a particular technology over time can be plotted as an S-shaped curve to represent its TLC (Ernst, 1997). Four stages are defined for the TLC: R&D, ascent, maturity and decline. Therefore, the United States patent database was selected as the source of data, and the cumulative number of patents granted by the United States can be plotted over time. In the analysis, the number of patents is used as an input for the determination of growth and substitution pattern of each storage technology by applying the TLC. The patent rate is then fit to a logistic curve as a baseline rate of patented technologies. It is used in the analysis of similar technologies to arrive at asymptote values for maximum market penetration. The S-shaped curve is generated by adding a control feedback loop that defines the maximum market penetration rate based on historical analogies of similar technologies. These methods can be used to forecast technological development. Although not applicable to every industry or research field, patent analysis is particularly effective in industries with a substantial volume of patented technologies, such as the telecommunication, information technology and automotive industries.

4. Results

4.1 Patented technologies for libraries

A total of 8,687 patents were issued by the USPTO between 1976 and 2014 for technologies invented for libraries. Usually, the number of patents in recent years exhibits considerable dropoff and is not representative of the trend in time-series analysis. Therefore, to avoid the problem resulting from the gap in the patent window, patents issued in the last five years were not included in this study. The number of patents is a better indicator of technological progress in pursuit of innovation than the actual amount of innovation (Narin *et al.*, 1987). Since 1995, there has been an obviously increasing trend in the number of patents issued for library-associated inventions, as shown in Figure 1. During these nearly four decades, the growth rate of patented technologies for libraries has fluctuated and peaked in 1996, as shown in Figure 2.

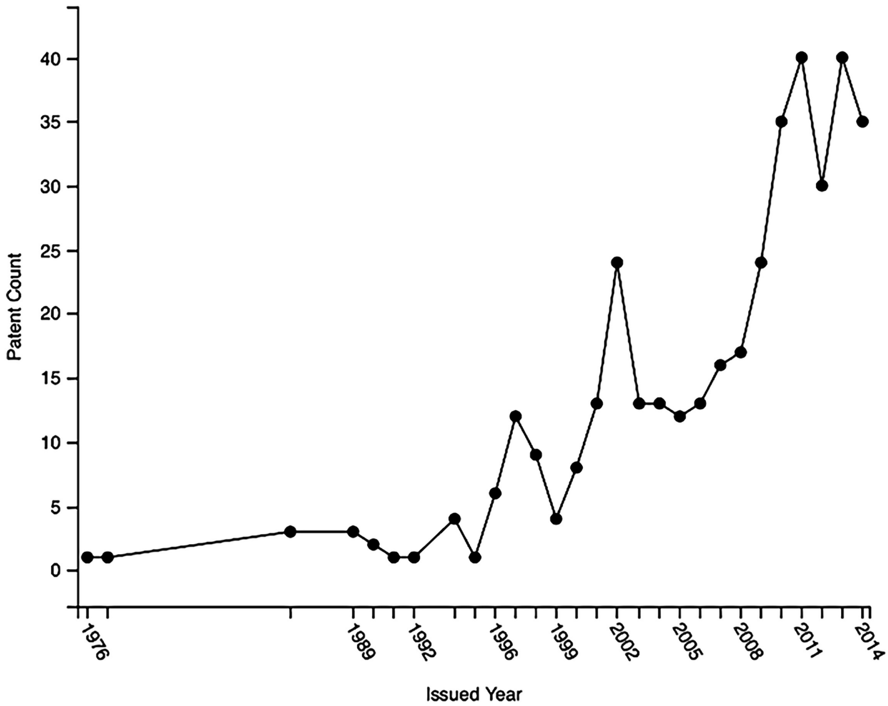

Figure 1.
Number of patents

Because assessment of the TLC seeks to predict the adoption, acceptance and eventual decline of new technological innovations, to estimate the future development of technologies for libraries and reach decisions whether to invest in them or not, one needs to know the current stage of their TLC. The dominant approach to analyzing TLC uses the S-curve to observe patent applications over time. Figure 5 and Figure 6 demonstrate the TLC of patented technologies invented for libraries according to the number of assignees and inventors, respectively. Both figures indicate that library technologies are now in the ascent phase of their life cycle. The growth stage is the period during which the technologies eventually and increasingly gain acceptance among users, the industry and the wider general public. During this stage, the technological innovation becomes widely accepted, and as a result, the rate of innovation adoption starts to increase. At the ascent phase, the goal is to see to the rapid growth and distribution of the novel technologies and leverage the advantage of having the newest and most effective library services. In the whole process of the TLC, the adoption of technologies also has a life cycle, with five chronological demographics: innovators, early adopters, early majority, late majority and laggards (Mattila *et al.*, 2003). "Innovators" refers to some libraries that are leading-edge-minded and have a higher propensity to apply new technologies. "Early adopters" refers to a larger but still relatively small demographic; these libraries are generally highly adaptable to new technologies. Early adopters follow the innovators in embracing a new approach to delivering library services. "Early majority" describes a much larger and more careful group than the previous two types of libraries; the early majority are usually open to new ideas but generally wait to see how they are received before adoption. Conversely, "late majority" libraries are usually slightly conservative and require convincing evidence before adopting novel technologies.

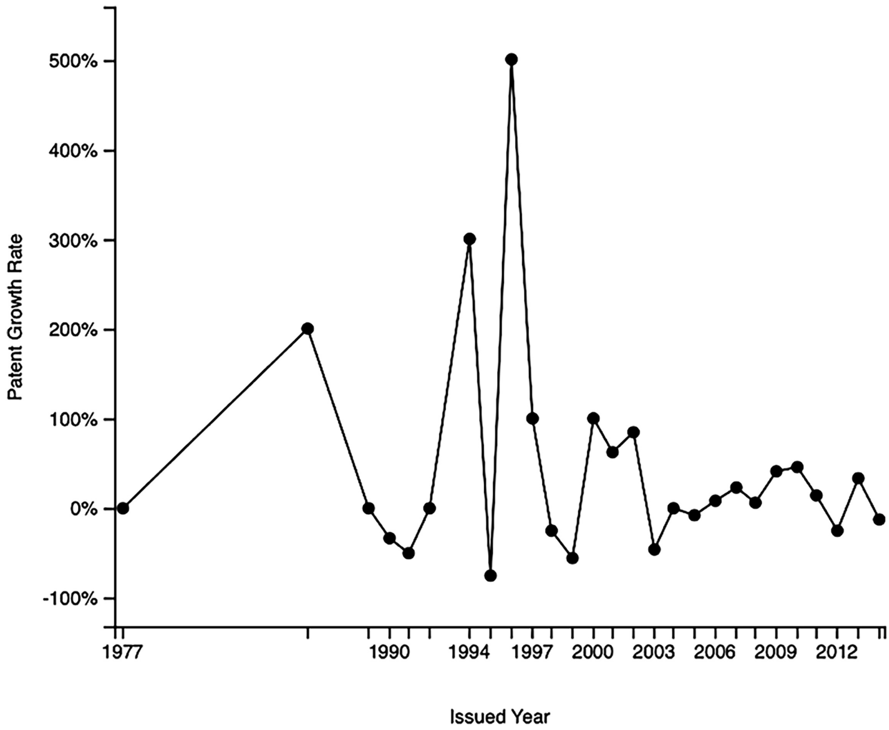

Figure 2.
Growth rate of number of patents

"Laggards" are frugal, conservative and often technology-averse and only adopt new technologies once they are already well-established (Lai, 2017) (see Figures 3 and 4).

Most assignees of patented technologies for libraries are companies, which indicates that most of the technological innovation is generated by the private sector, as shown in Figure 5. Universities and individuals are ranked as the second and the third assignee types, respectively. Figure 6 shows the top-20 assignees who own the most patented technologies.

The assignee with the most library patents is International Business Machines Corporation (IBM). IBM operates through five major segments: Cognitive Solutions, Global Business Services (GBS), Technology Services and Cloud Platforms, Systems and Global Financing. Furthermore, Figure 7 shows the top-20 most-cited assignees. Highly cited patents are regarded as high-impact or technologically important patents. To identify the origin of library technologies, this study also traced back to patents highly cited by library technologies. The identification of the top-20 most-cited assignees is shown in Figure 7.

The number of patents obtained by a country reveals the technological innovation performance of that country. "Patent counts by inventor country" refers to the number of patents assigned to the professional address of the inventor (i.e. the address of the lab in which the inventor works). "Patent counts by assignee country" refers to the number of patents owned by the assignee of each country. Regarding the ownership issue, different interpretations flow from the distinctions between patent counts by the inventor country and the assignee country. There has been a trend in which inventions created in country A increasingly count as being owned by a firm based in country B. Patent counts by the inventor country reflect the innovation performance of a given country's residents. Patent

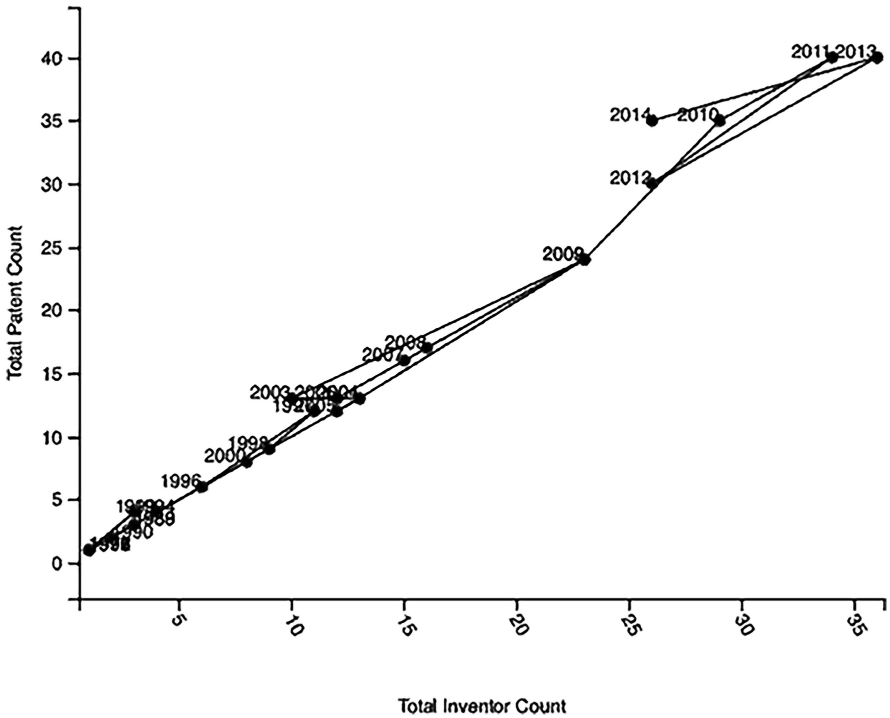

Figure 3.
Technology life cycle (by number of patents and assignees)

counts by assignee country reflect the intellectual property right to prevent others from freely applying the patented invention. Figure 8 shows the top-20 assignee countries that own the most patents for libraries. The United States, Germany, France, Japan and the United Kingdom are ranked as the top-5 assignee countries.

Furthermore, Figure 9 shows top-20 inventor countries that invent the most patented technologies for libraries. The United States, United Kingdom, Japan, France and Germany are also ranked as the top-five inventor countries. According to Figure 8 and Figure 9, these countries produce and own the most technological innovations invented for libraries.

To identify libraries' technological domains, the IPC codes listed in the patent records were identified and classified into technology fields to represent the libraries' major technological domains. A patent application in each field indicates an accumulation of knowledge and advancement in the technological trajectory. Patents can be classified according to the IPC schema. Each patent is assigned a classification code (class/subclass/groups/subgroups) based on the IPC. The classification code attached to a patent defines the technological class of the patent. The IPC divides patentable technology into eight major categories. The proxy for patent scope based on the IPC scheme has been widely accepted and applied. Therefore, mapping the patent activity of a country based on IPC is a useful method to measure the technological specialization and technological scope of the library patents through the distribution of its patents over various technological areas. Figure 10 shows the top-20 IPC categories of library patents. H01L refers to semiconductor devices, and electric solid-state devices are ranked as the top IPC category of library patents.

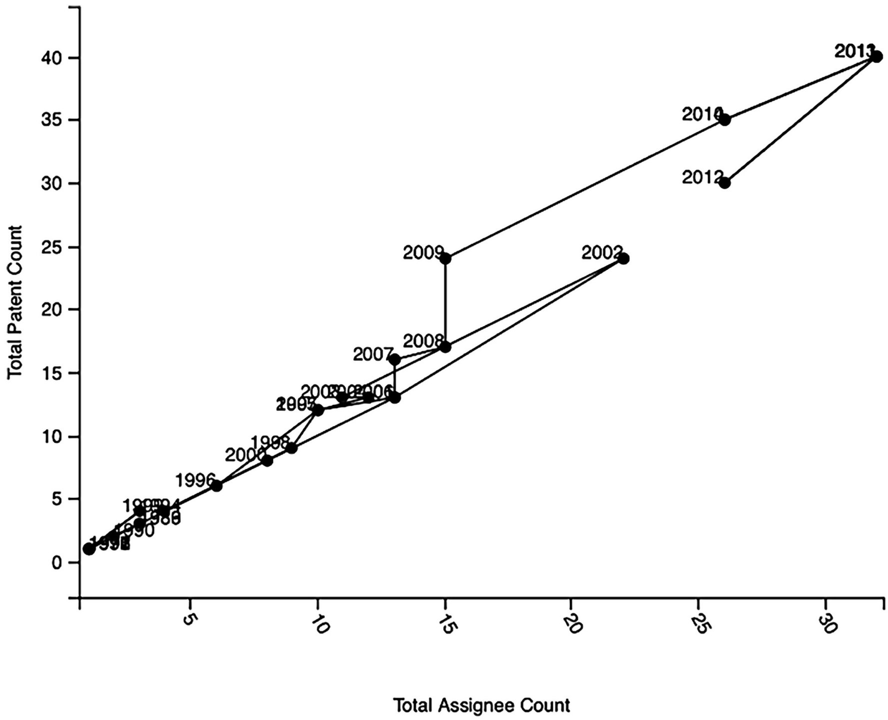

Figure 4.
Technology life cycle (by number of patents and inventors)

Figure 11 shows the allocation of IPC fields of library patents. Most library patents in the USPTO data are classified into four major technology fields: electrical engineering, chemistry, mechanical engineering and instruments.

Technological collaboration using the information of patent assignees and inventors can be categorized into three different types of collaboration, namely, local (same city), domestic (different cities of the same country) and international collaboration (Lei *et al.*, 2013). Figure 12 shows the degree of collaboration involved in library patents by average inventor count per patent and average assignee count per patent.

With a trend toward international R&D collaboration, the growth of interdisciplinarity and the globalization of technology, patent counts have been used as indicators for measuring technology output. An increasing share of patents has involved different technology fields, which reflects the interdisciplinarity of R&D activities among multinational firms or cooperation between industrial R&D laboratories located in different countries. Figure 13 shows the degree of international collaboration on library patents by average inventor country count per patent and average assignee country count per patent. Basic material chemistry, biotechnology, and materials and metallurgy are the three technological fields with the highest degree of international collaboration.

Technological innovation depends on knowledge developed by scientific research. Therefore, the number of patent citations given in the scientific literature has been suggested and widely accepted as an indicator of this process of transfer of technology knowledge from science to industry (Nomaler and Verspagen, 2008). Indicators based on nonpatent references are increasingly being used for measuring and assessing science–technology links or

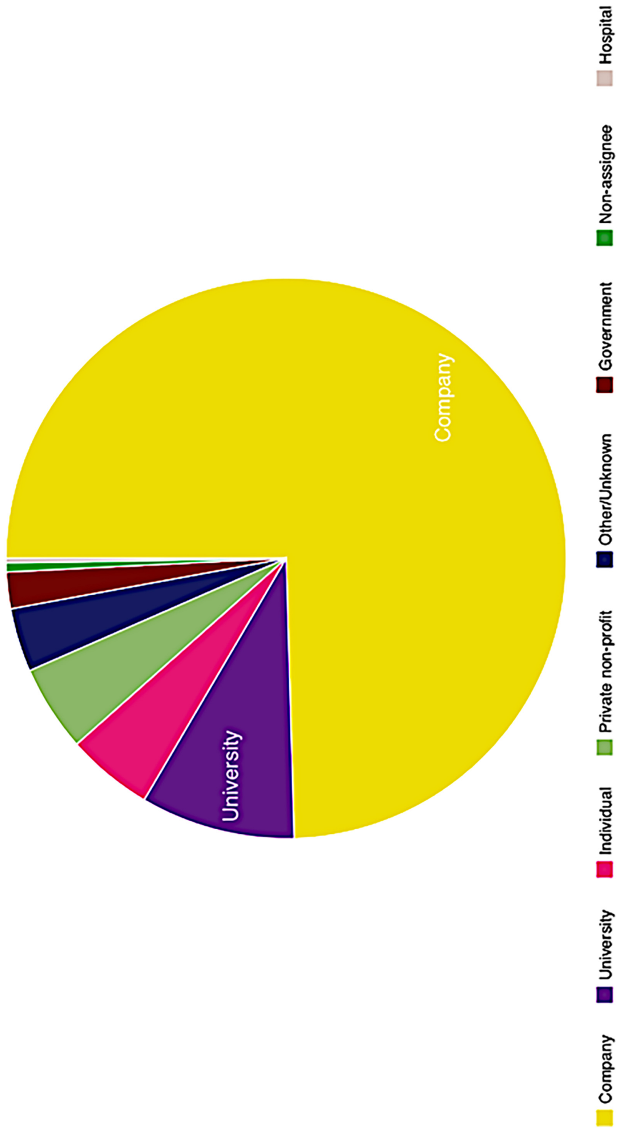

Figure 5.
First assignee type

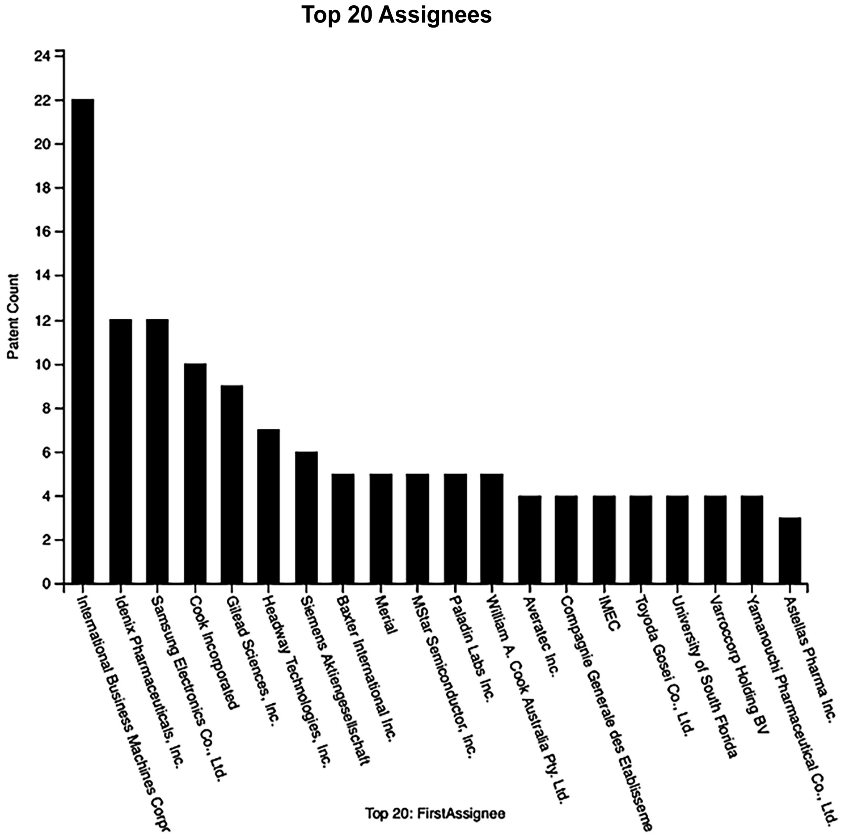

Figure 6.
Top-20 assignees

interactions (He and Deng, 2007). The more nonpatent references are listed in a patent document, the more science-oriented the patent is. Backward citations indicate how knowledge embedded in past inventions influences new inventions. Therefore, this study analyzed the scientific and technological knowledge sources of technological innovation in library based on backward citations listed in library patents. Figure 14 shows whether the knowledge source analyzed involved scientific (*Y* axis) or technological knowledge (*X* axis) sources, and the actor size is based on patent count. It illustrates that the knowledge source with the highest degree of scientific and technological orientation is basic material chemistry.

To capture the knowledge effect brought about by technological innovation in libraries, this study analyzed forward citations of library patents. Over the past three decades, proxies based on citation measures have become well-accepted. Citation linkages from one patent to another patent are believed to be useful and valuable. Studies have asserted that patents with higher forward citation counts have greater economic value than other patents (Brinn *et al.*, 2003). Figure 15 illustrates that the knowledge effect, according to forward citations with the highest degree of scientific and technological knowledge effect, includes the following categories: I2 control, M6 textiles, paper machines and other special machines. The major technological categories that have received the greatest knowledge effect from library-associated technological innovation are chemistry, electrical engineering, instruments, mechanical engineering and other fields (civil engineering and furniture, games).

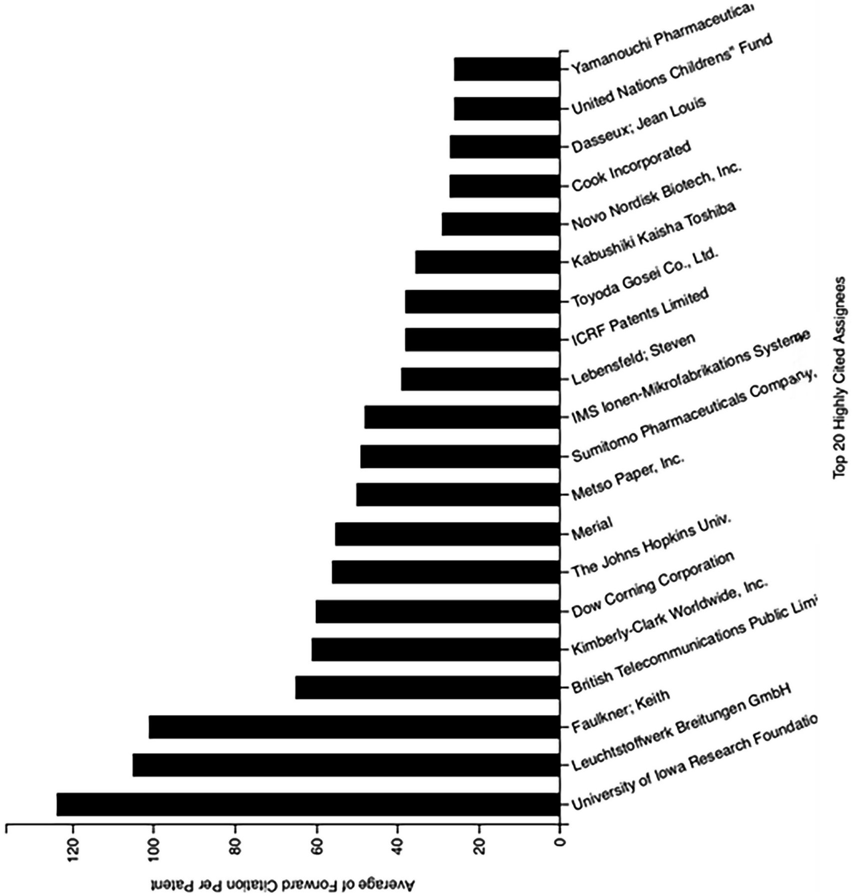

Figure 7.
Top-20 most-cited assignees

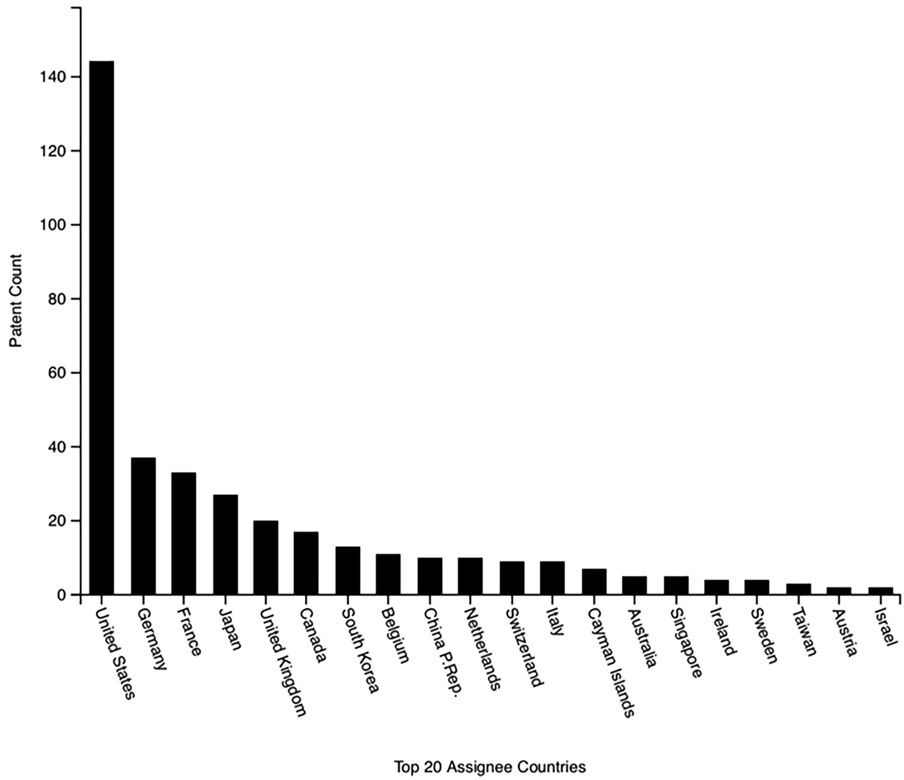

Figure 8.
Top-20 assignees countries

In addition to the knowledge sources and effect investigated to identify the origin and development of technological innovation in libraries, this study further tracked technology diversification based on the allocation technology fields to make a detailed examination of the incremental expansion in technological scope (Chen *et al.*, 2010). Libraries can expand their technological competencies to other technological fields to undertake technological diversification. This could expand a library's own knowledge and connect it with other knowledge contexts. Three benefits of technological diversification have been identified (Chen and Chang, 2012). First, technological diversification can reduce the average cost because of wider application in numerous fields. Therefore, multiple applications can improve technological knowledge through the experience curve and learning effect. Second, due to the cross-fertilization effect derived from technological diversification, new technological knowledge can be easily generated through the fusion of technology. Third, technological diversification can help libraries leverage the advantage of speed in R&D (Chen and Chang, 2012). Therefore, this study examined the extent to which library patent scale and scope components affect its diversity. Figure 16 presents the overview of technological diversification associated with library patents. Other special machines, analysis of biological materials, environmental technology and mechanical elements have been identified as the fields with the highest degrees of diversification.

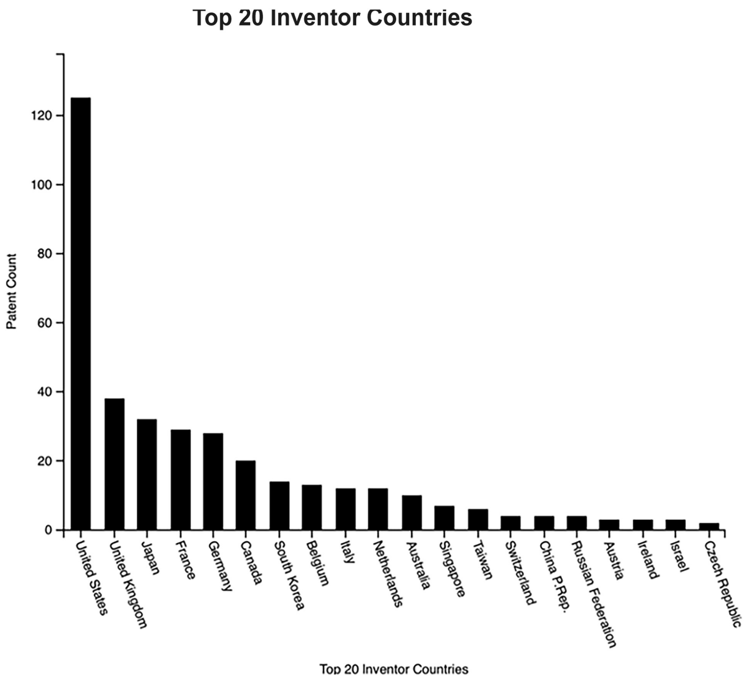

Figure 9.
Top-20 inventor countries

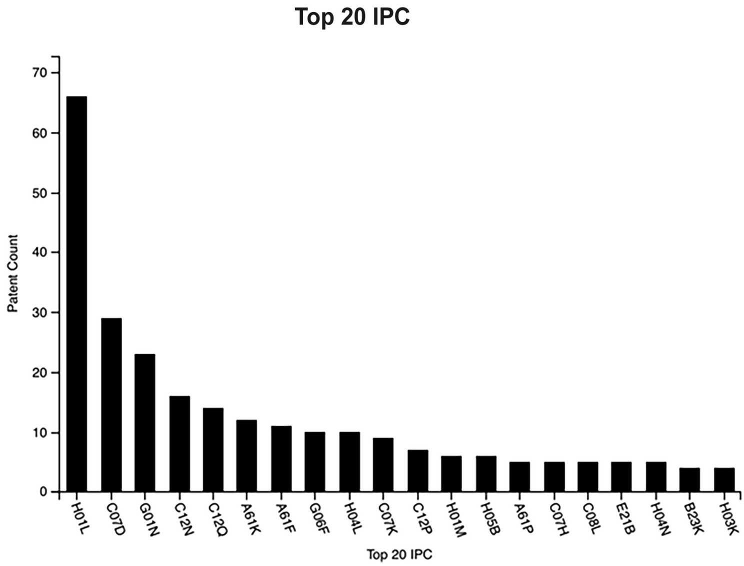

Figure 10.
Top-20 IPC categories

5. Discussion and conclusion

This paper aimed to discuss the development of technological innovation in libraries. Patent statistics were used as indicators of inventions intended for libraries. Patent analysis can be

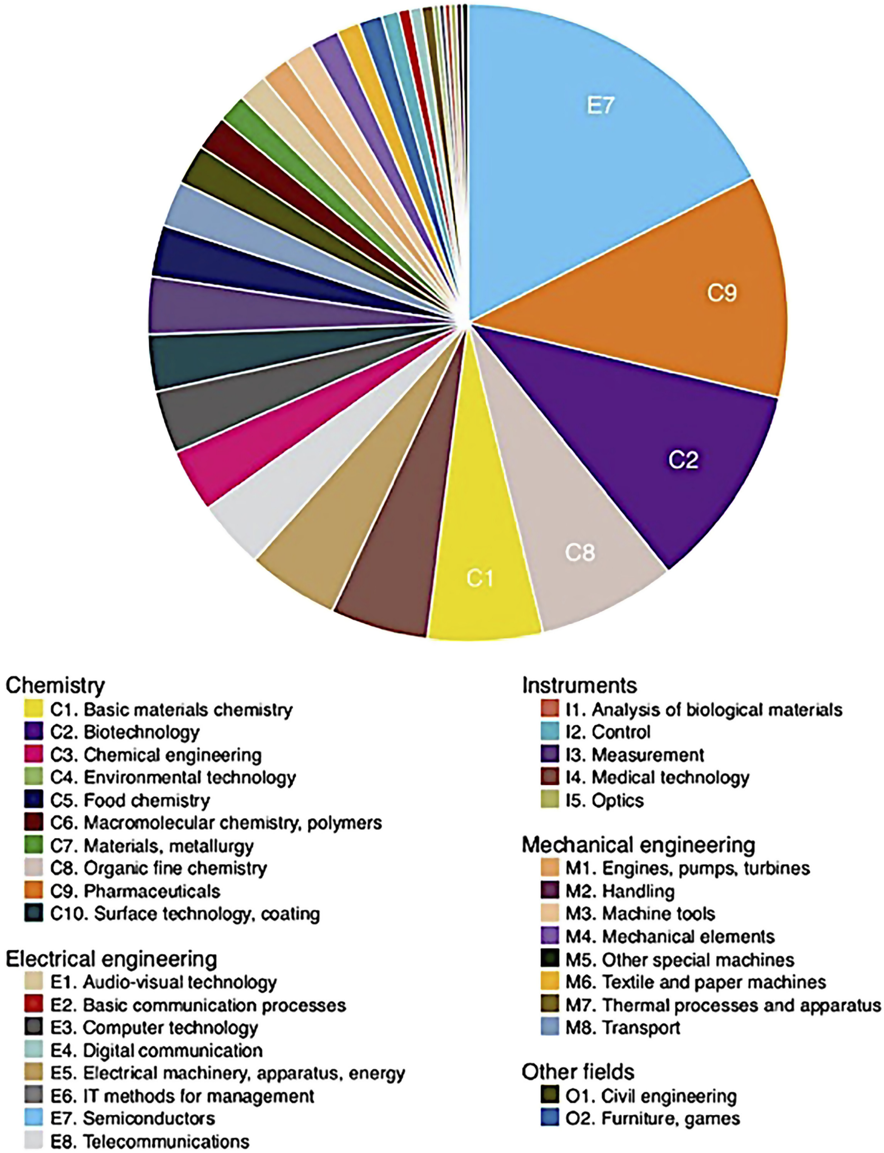

Figure 11.
Allocation of IPC fields

regarded as one of the most effective methods to remain current with technology trends. This paper has provided three major contributions. The first is the identification of the TLC of library technologies. Theories of technology-push and demand-pull were examined in relation to technological innovation taking place in libraries. The TLC analysis indicated that library technology is mainly in the ascent stage, suggesting that libraries have not achieved the strongest technological transformation. The findings suggest that the importance of demand-pull and technology-push vary over the TLC of libraries. The second contribution of

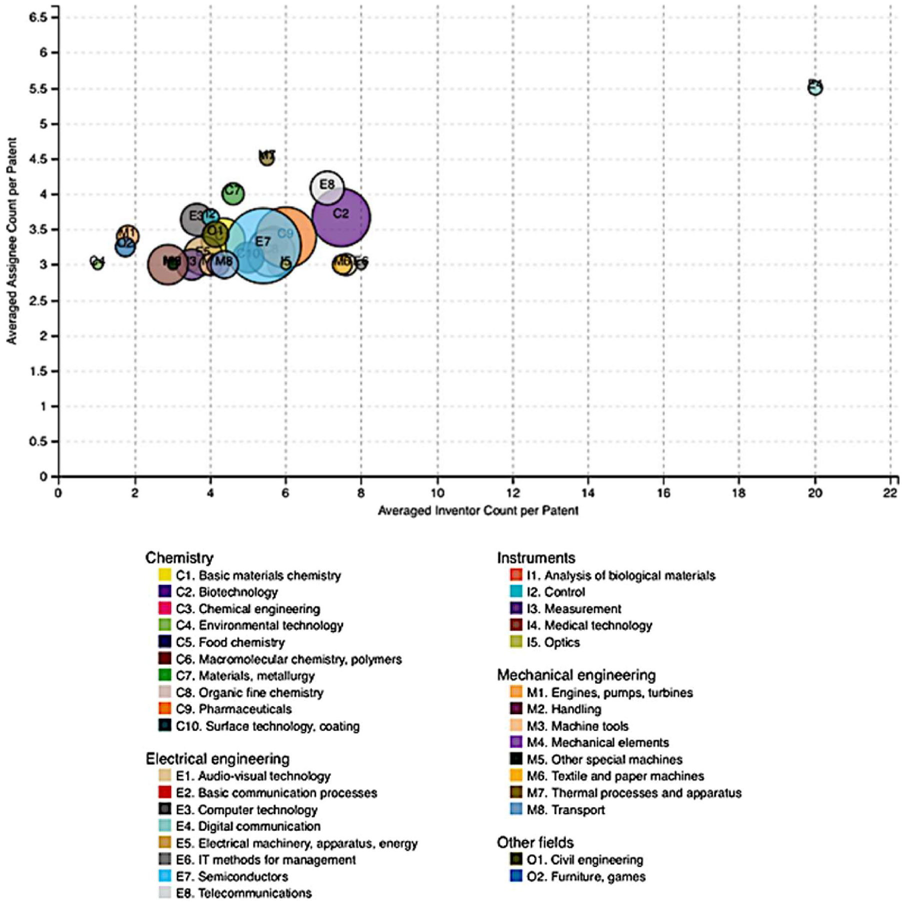

Figure 12.
Degree of collaboration (patent count as actor size)

this study was to present the complete picture of knowledge sources and the effect of technological innovation associated with libraries. Patents and forward citations were used to evaluate the knowledge effect of library transformation. The downside of using forward citations in evaluating technological diversification is that they are not available until a substantial period of time has passed after the granting of a patent because time is needed to accumulate substantial information about its citations. In practice, this means that the analysis is challenging with respect to the evaluation of current or very recent innovations. In comparison, backward citations provide comparable information about scientific and technological knowledge basis. The recognized trends regarding libraries indicate that key technological innovations are derived from chemistry, instruments, and mechanical and electrical engineering fields, which enable libraries to use technological developments in the future. Regarding the knowledge effect from library-associated technological innovation, instruments and mechanical engineering are two major fields receiving the greatest technological influences from library patents. The third contribution of this paper was to identify the allocation of inventions as well as ownership, which suggests the technological development of the future library. Differentiating between local and international

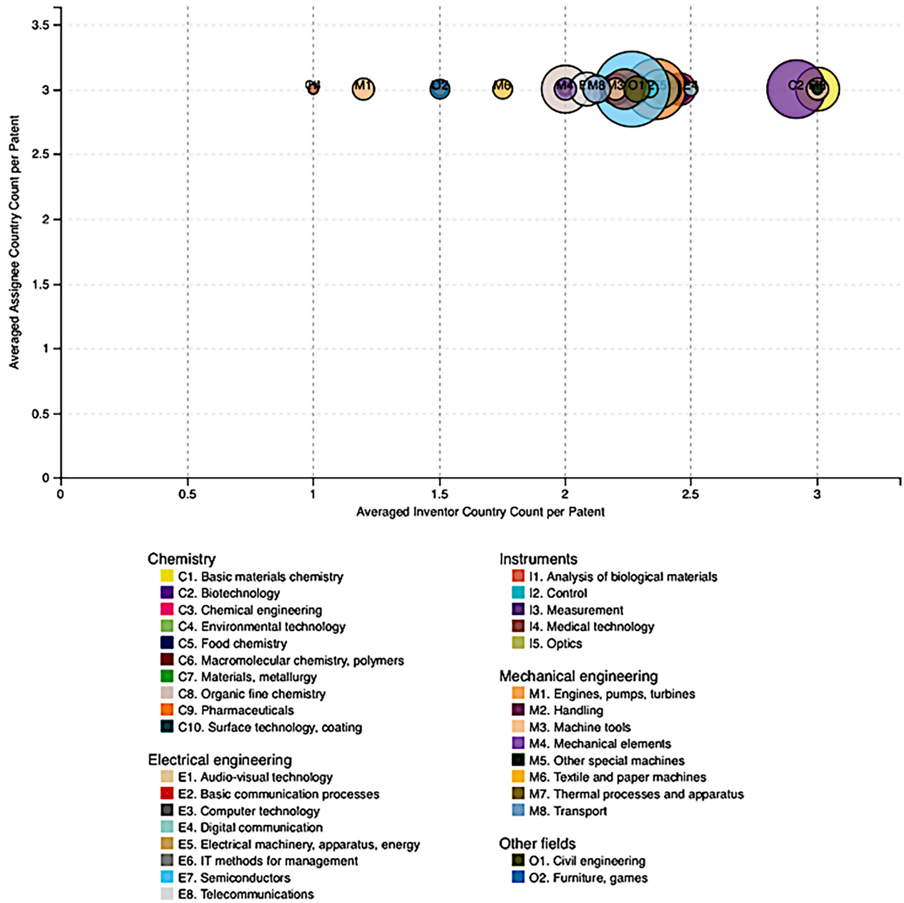

Figure 13.
Degree of international collaboration (patent count as actor size)

collaboration helps to provide a more comprehensive understanding of future library evolution. This study concludes that technological innovation for libraries will be characterized by an increasing role for science-intensive and interdisciplinary areas.

Regarding the general applicability of this study, since existing studies have tried to elaborate how technological innovations have led to the improved information management and library services (Kaur and Sharda, 2010). Librarians have been regarded as trendsetters in digital use and implement innovative technologies and services in libraries (Jharotia, n.d.). This study explores the knowledge sources and their effects of technological innovation in libraries to provide a holistic projection, both of technological and demand sides, for the future library evolution, which is also the novelty of this study. Technological innovation is the process where libraries embark in a journey where the importance of technological innovation as a driving force of transformation has been identified as a critical factor for sustainable development of libraries. A number of studies have tried to gain a better understanding of the factors that condition and enhance the organizational innovation and transformation (de Weerd-Nederhof *et al.*, 2002; Koberg *et al.*, 1996). Innovation helps libraries to deal with the turbulence of external environment and, therefore, is one of the key drivers of

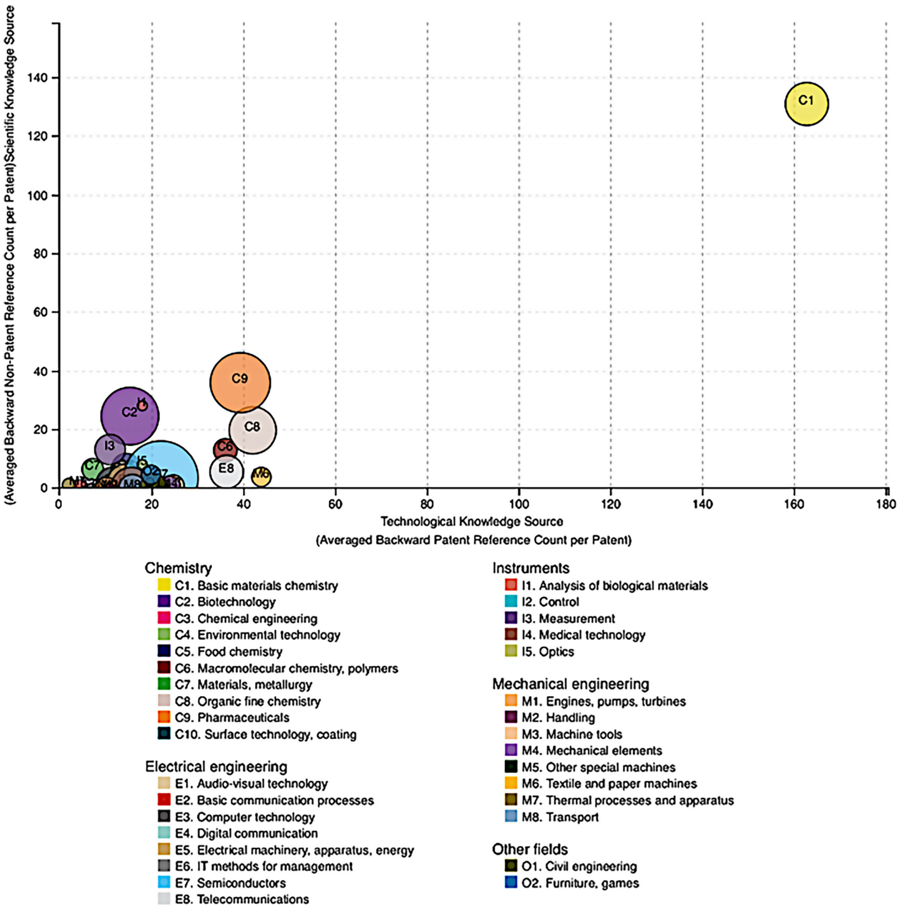

Figure 14.
Knowledge source (patent count as actor size)

transformation as well as sustainable development, particularly in dynamic environments. The results of this study underlie the ability of libraries to transform by continuous innovation and organizational learning. Regarding the research implications offered by this study, the potential increase in the value of the technological innovation is also synonymous of learning. Previous literature examines the relationship between innovation and performance and asserts a positive relationship between organizational learning and innovation (Darroch and McNaughton, 2002). Organizational learning and innovation relate positively to each other (Brockman and Morgan, 2003). With the advent of the knowledge society, the role of libraries is deeply changing toward digital libraries, special services and the provision of spaces (Henkel *et al.*, 2018). Organizational learning is the process by which the libraries develops new knowledge and insights from the common experiences, and has the potential to influence librarians' behaviors and improve the libraries' capabilities. During this organizational learning process, libraries acquire knowledge for obtaining new information and knowledge, distribute knowledge by which librarians share information within the library, interpret knowledge, which happens when individuals give meaning and transform

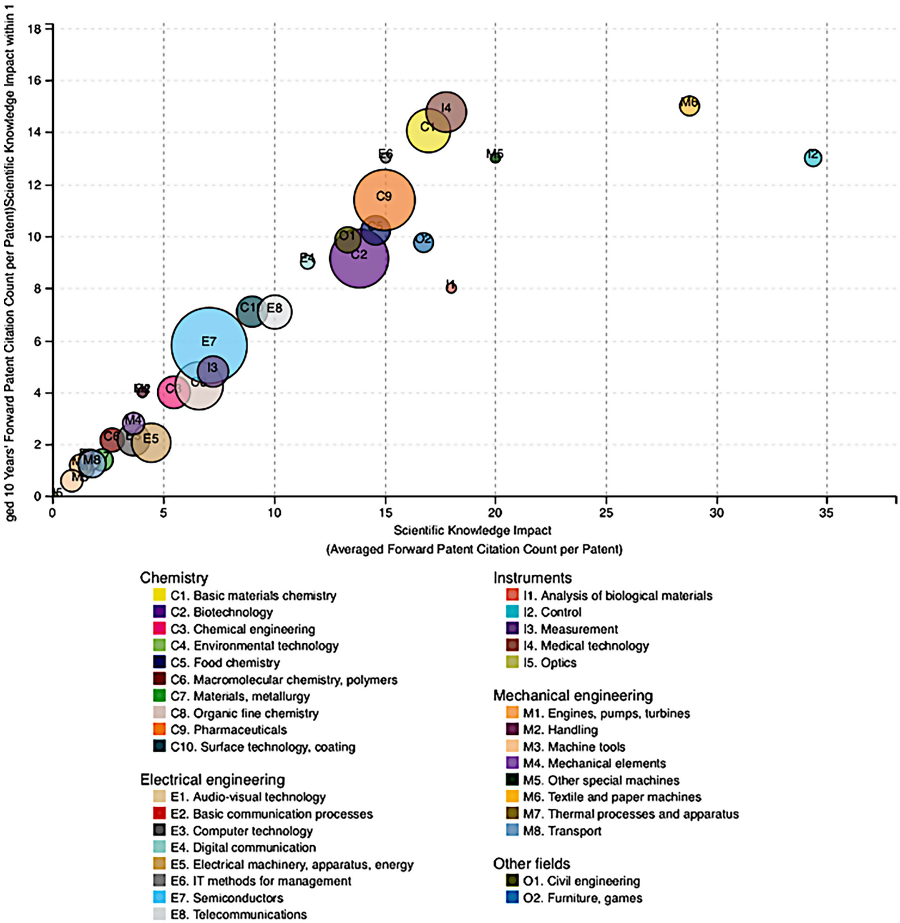

Figure 15.
Knowledge effect (patent count as actor size)

information into new common knowledge, and storing the information and knowledge for future use (Brockman and Morgan, 2003).

The findings of this study have implications for practitioners. To survive in a dynamic environment library must be able to cope with increasing complexity and high-speed technological change. It is pivotal to integrate the views of users (as customers), software houses or design companies (as suppliers) as well as other libraries (as communities) into the sustainable development strategy of a library. In these contexts, libraries with the capacity to innovate will be able to respond to new demands faster and to invent and provide new services better than noninnovative libraries. Although the idea that innovation influences transformation and sustainable development has gained recognition among practitioners, how to go about this process remained unclear. The present study suggests that organizational learning facilitates innovation. Therefore, a library hoping to co-evolve with dynamic environment through technological innovation should improve its organizational learning processes. This conclusion seems to be especially important for libraries operating in highly turbulent environments. Some recommendations in this line are the following.

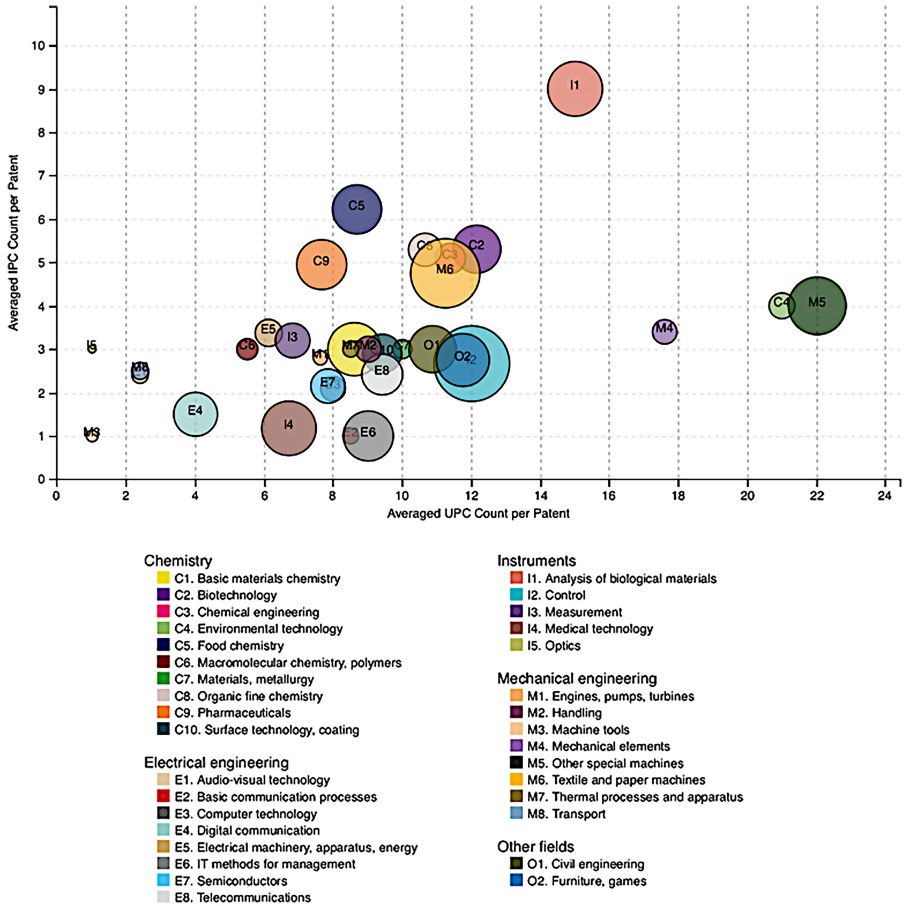

Figure 16.
Technology diversification (average forward citation count per patent as actor size)

First, libraries should promote the acquisition of new knowledge, for example by making librarians attend conferences and workshops regularly, consolidating their core value and fostering the development of new ideas and experimentation. Second, they should enhance the knowledge distribution and interpretation, for example by using formal and informal mechanisms to guarantee the sharing of best practice among librarian communities, making librarians talk to each other, using teamwork, collecting, assembling and distributing users' feedback and suggestions. Thirdly, libraries should try to keep opened for using the knowledge they create by updating databases, facilitating information governance and providing new services.

This study has some limitations that should be taken into account when interpreting its results. First, the results use single informants, patents retrieved from USPTO, as the source of data. Although the use of single informants remains the primary research design in most of similar studies, multiple informants would enhance the validity of the research findings. Second, this study uses patent citation measures for exploring the knowledge source and effect of technological innovation, these measures are only subjective for those new inventions highly based technological advances.

Future research is suggested to overcome the limitations of this research. One key point is to use diversified measure for investigating different types of innovation in libraries. This action could also help to overcome the limitation of using a single informant. Therefore, it is suggested to use multiple informants for enhancing the validity of the research findings. Some additional recommendations for future research are the following. One is to compare the effects between each phase of the organizational learning process and different types of innovation derived from libraries. Another suggestion is to examine whether the quality of the innovation, such as incremental or radical, has any influence on the results.

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Further reading

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Corresponding author

Pei-Chun Lee can be contacted at: pcleephd@gmail.com