This paper was presented at ISPIM Connects Bangkok – Partnering for an Innovative Community, Bangkok, Thailand on 1-4 March 2020.

Event Proceedings: LUT Scientific and Expertise Publications - ISBN 978-952-335-465-4

Foresight through Strategic Technology Intelligence for Collaboration and Innovation Pathways

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Abstract: Formulating a strategic direction for long-term growth is critical to address the challenges of technological competitiveness in the globalisation era. This article presents a case study of the technology of shelf life extension for agricultural foods. We propose strategic technology intelligence (STI) as an approach that combines quantitative tools with a qualitative technique using technological experts to judge and strengthen the findings. Cases from the patents database were extracted for analysis using the text mining software. The results illustrate that this particular technology has potential for growth and related research has been increasing. In addition, collaboration among researchers and organisations is essential to foster the speed of R&D and boost knowledge exchange. The findings can be useful for policymakers, managers, and researchers as a decision-making tool for further implementation and execution.

Keywords: Technological Opportunity; Technology Foresight; Innovation Management; Research Collaboration; Agriculture; Shelf Life Extension; Food Waste.

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1 Introduction

In the era of globalisation, firms face highly competitive environments and technological disruption from other players, including corporate firms and start-ups in the market. This transformation is the major factor for firms to make decisions regarding their readiness to execute new plans for technology growth (Østergaard and Park, 2015). The prediction of trends and changes in technological development is a core competency needed to survive and thrive in this environment (Alzubi et al., 2019). To survive this challenge, the formulation of strategic directions for long-term growth is crucial. Technological foresight is an effective tool introduced by Cooper and Schendel (1976) to apply when firms face threats from new technologies such as disruption. This tool can help decision-makers capture important technological information and significant developments and trends (Mortara et al., 2010). Acquiring such insights as early as possible is essential to gain a competitive advantage in terms of business operations and strategic planning.

In this research, we propose strategic technology intelligence (STI) as a tool for forecasting trends and matching future societies' needs with the supply of science and technology. STI can guide research and development (R&D) and inform the timely exploitation of emerging technologies. The outcomes can promote innovative and sustainable pathways, enhancing competitiveness, driving economy, and social benefits. Accordingly, R&D becomes a core function to apply novel technologies to launch new products or services that meet customer demand.

Rothwell (1994) proposed the concept of the "networking model" as a process to foster more rapid and efficient innovation through collaborative R&D and R&D-based strategic alliances. R&D has become a core function to launch products designed using novel technologies, and a number of tools have been developed to explore insights for potential R&D collaboration and forecasting pathways of innovation. Linked to the STI tool that we introduce, most firms have selected to address technology intelligence by establishing centres of excellence close to universities, whereby industry is active in developing technology and innovation (Mortara et al., 2010). Additionally, the identification of players such as competitors, partners, and researchers can establish the unique products or services to attract the target market (Russo and Rizzi, 2014). Chandrasekaran (2005) proposed that the early emphasis on the forward-looking technologies can ensure a sustainable technological base according to market requirements.

This study utilises bibliometric analysis in the form of text mining of patents to transform raw big data into useful information. Patents databases provide data on technology, assignees, and inventors, among others, thereby enabling the measurement of the dynamic innovation environments and relationships. In addition, patents are a source of knowledge regarding the science and technology used to develop inventions. It is suggested that 80% of technical information can be found in patents that demonstrate the intensity of R&D activities (Asche, 2017).

The emerging technology of shelf life extension for agricultural food was chosen as a case study for patent analysis. Agriculture plays a critical role in the economic cycle; however, one-third of globally produced food is wasted, thereby generating greenhouse

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gases and contributing to climate change challenges (United Nations Food and Agriculture Organization, 2019). Using technology to extend shelf lives could contribute to sustainable living by reducing waste and lowering cost of living expenses. Hence, the study aims to contribute to R&D's ability to identify specific technological trends as well as present a research-mapping proposal that helps both academicians and practitioners explore professional communities and potentially form networks for future collaboration by analysing patents databases.

2 Literature review

2.1 Technology opportunity analysis

Beginning in 1990, Technology Policy and Assessment Center (TPAC) at Georgia Institute of Technology proposed a method to identify technological trends, particularly emerging technologies for strategic planning. Porter and Detampel (1995) introduced "technology opportunity analysis" (TOA) as an approach to exploit information resources such as patents and publications concerning new and emerging sciences and technologies (NEST). The approach merges bibliometric analysis with the monitoring and tracking of raw technological and socioeconomic data, which is turned into useful information by identifying key signals. Yoon et al. (2014) elaborated the usefulness of TOA for providing a core competitive advantage. Science and technology forecasting has proven to be a key business driver for corporations and has informed governments' efforts toward national policy development. Researchers have applied various methods to conduct TOA, including the identification of technological opportunities (Song et al., 2017), network collaboration (Kumari et al., 2019, Morel et al., 2009), linking technology with innovation (Nieto and Quevedo, 2005), and profiling research domains (Pei and Porter, 2011). For instance, Song et al. (2017) proposed a novel approach to discover new opportunities based on the identification of emerging or vacant technologies. Morel et al. (2009) conducted a network analysis of researchers who collaborate in strategic planning and implementation to be proactive in funding support in alignment with organisational objectives. Therefore, TOA is a useful analysis approach for both public institutions and private companies to gain insights from big data available online, particularly in scientific databases, for the purposes of planning, implementing, and execution.

2.2 Technique and tool for technology opportunity analysis

Bibliometric analysis is commonly used to obtain concise and useful information from technical or scientific databases (Kumari et al., 2019). It is a quantitative approach to analyse a wide range of indicators such as keywords, authors, and organisations and identify the relationships within or impacts to the related domains (Daim et al., 2006, Zhang et al., 2019). Methods of bibliometric analysis vary according to the issues of interest. Co-word analysis and co-occurrence analysis are mostly applied for recent research streams. Co-word analysis compiles the frequency of words or phrases in the documents and clusters them to identify evolutionary trends and relational patterns (Lee and Jeong, 2008). For example, Venugopalan and Rai (2015) analysed patent classification codes to reveal business trends in the commercialisation of inventions and related products or market sectors. Bibliometric analysis combined with text mining technique is applied to a raw big database and knowledge-based text documents to analyse trends and insights for further development and execution (Kumari et al., 2019). Text mining is a novel extraction approach that enables the identification of academic networking and the detection of research trends to understand their background and comprehend key information (Nie and Sun, 2017). This technique can serve as a tool to for policymakers, managers, and researchers.

3 Methodology

In this research, we offer strategic technology intelligence (STI) as a novel tool for technology opportunity analysis and discovery to provide useful information for better decision-making by public institutes, universities, and private companies. This study involves using bibliometric text mining to obtain insights through the analysis of raw big data from patents. The analysis is based on the process of text mining introduced by Porter and Cunningham (2005), who divided the process into nine steps leading from problem identification to utilisation. Most approaches involve only quantitative analysis; however, we combine the process with qualitative data from technological domain expert involvement in order to more efficiently interpret results and glean deeper insights. The STI approach is presented in Figure 1.

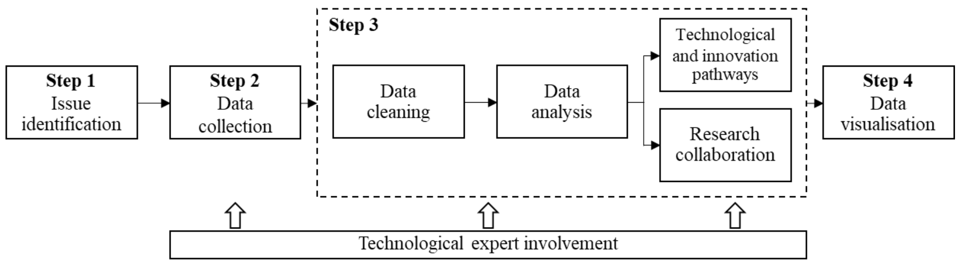

Figure 1 The Strategic Technology Intelligence framework.

First, we identified the issue that needs to be addressed. As we introduced in section 1, we chose the technology of shelf life extension of food as a case study because it is a fundamental problem for many societies. Second, we conducted an extraction of patents from the *TotalPatent One* (https://www.totalpatentone.com) database. Search strings were used based on the Boolean approach from Porter et al. (2008), and the technological expert helped to initiate relevant search terms. We identified a total of 3,740 patents from 1963 to the present. Next, the patent data were imported to the VantagePoint software version 12.0 for text mining analysis. In this case, we cleaned two main fields: applicants and inventors. The cleaning process can exclude some errors, varying names, and different (non-standard) expressions. Those unmatched data were combined to standardise the names for both fields. After that, the analysis of technological and

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innovation pathways was conducted by examining relevant trends, players, and technologies as well as identifying research collaborations performed at the individual and organisational levels. In this step, the expert assisted with interpreting the results and provided technical knowledge for further analysis. Finally, the visualisation of the results was performed. The results can be further used to present and explain trends to stakeholders such as policymakers, technology managers, and researchers.

4 Results and discussion: a case study of shelf life extension technology

The case study of shelf life extension technology in agricultural food was analysed using the strategic technology intelligence (STI) approach. In this paper, we interpreted the results in two major dimensions: 1) technological trends and predictions of pathways for further development; and 2) collaboration among researchers and organisations to speed up time and exchange ideas for R&D.

4.1 Technology and innovation pathways

4.1.1 Trend analysis

Figure 2 shows the numbers of patents (3,740 patents in total) related to shelf life extension technology from 1963 to 2019 as an exponential growth. The drop of patents in 2019 is due to incomplete data at the time of the research. However, it can be seen that patent development has intensified over time from an average of 15 patents/year from 1963 to 1999 to 164 patents/year after 2000. Only 26% of the patents have been granted whereas 74% remain in the application process. These figures indicate that this technology is of increasing interest among players and has potential for future R&D and commercialisation.

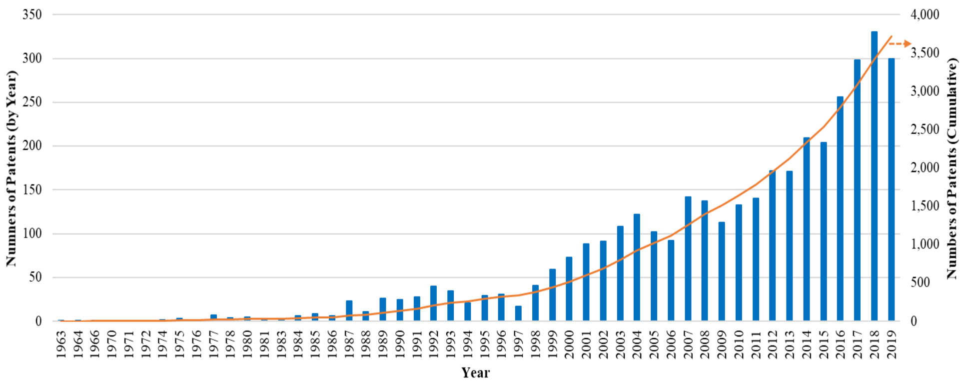

Figure 2 The development of patents over time.

4.1.2 Players

Six types of players were identified as assignees or applicants: private companies (84.7%); universities (6.7%); individual researchers (researchers' name as the applicant; 5.5%); foundations (1.4%), research and development institutes (1.4%); and state-owned organisations (e.g., departments in the government; 0.3%). The bulk of contributions come from private companies that have developed technologies to prolong shelf life of agricultural food and commercialised that unique know-how into products and services for consumers, such as a food packaging film, as well as producers, such as chemicals and food processing methods to increase food shelf life.

The trend of R&D activities for each player implies that private companies were the first movers to enter into the development of this technology (Figure 3). The priority year denotes the year in which applicants first filed a patent application for the invention; hence, Whirlpool Corporation was the first company to fill an application in 1963 (Publication no. FR1323375A; entitled "The method and apparatus for preserving food products"). Foundations supporting universities are highlighted as the second players in the patent filing. After a few years, universities have the potential to own their patent. As most foundations support universities by funding R&D activities, applicants may represent foundations that are sponsoring the research. Institutes and individual researchers are mostly among the later patent applicants. In this case, individual researchers are counted in that the first applicant name is the researcher' name, whether or not it is also accompanied by an organisation's name.

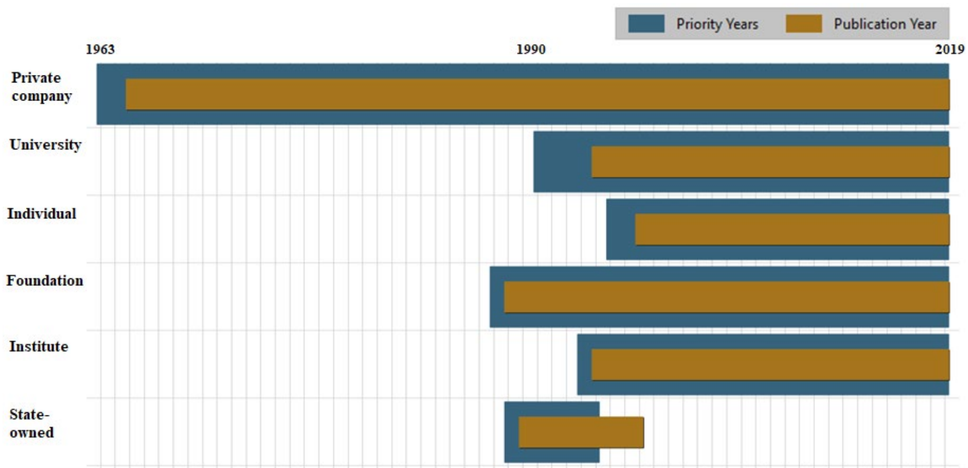

Figure 3 Gantt chart for each player with respect to priority year (blue) and publication year (brown).

Notably, there is a large gap (~27 years) between the first private company patents and those of other organization types. Specifically, there is a significant difference between the private sector and the public sector, i.e., universities. Firms need patents to protect their intellectual property (IP) and commercialise products and services with no or

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fewer competitors. In contrast, universities tended to avoid patenting costs and rather focus on researching and publishing academic papers to gain similar benefits as those gained from patenting. In 1980, the US enacted the Patent and Trademark Law Amendments Act (known as the Bayh-Dole Act) permitting the federal government, universities, and non-profit organisations to pursue ownership of inventions (Holgersson and Aaboen, 2019). As a consequence, universities established technology transfer offices (TTO) to support the commercialisation of research such as patenting, licensing, and spin-offs (Siegel et al., 2007). Thus, we can see patents from universities and others from 1980 onwards. Although universities can have ownership of patents, they need an appropriate business model or strategy to commercialise them. When universities file patents, it can be difficult to obtain a licensee because the technology may be the first breakthrough step in what can be a long development process (Hayes, 2017). It may take years before the universities realise a return on investment (ROI).

Table 1 presents the top five applicants in terms of numbers of patents and shows that the top players in this sector are private firms seeking opportunities to commercialise the technology and prevent competitors from developing completive or duplicate products or techniques. Specifically, both commercial and R&D-based firms have an interest in developing technologies to extend the shelf life of fresh and processed foods. Four of the five firms are US-based, and the fifth, DSM IP Assets B.V., is located in the Netherlands. Commercial firms such as General Mills, Inc. have researched the technology to extend foods' shelf life and applied to protect their intellectual property from competitors. In contrast, R&D-based firms have researched and acted as technology providers who offer solutions to producers, distributors, and consumers. To commercialise patents and their associated technologies, they can either license or supply chemicals as raw materials.

Table 1 Top five registered applicants for shelf life extension technology: 1963-2019

Applicant name	*Numbers of patent*	*Profile*	*Source*
Cellresin Technologies, LLC.	103	A technology company with a global patent portfolio to extend the shelf life of fruits, vegetables, and flowers.	http://cellresin.com
General Mills, Inc.	63	A dairy food company with innovations for food technology.	https://www.generalmills.com
Ecolab USA, Inc.	52	A technology company for food safety and processing solutions.	https://www.ecolab.com
DSM IP Assets B.V.	49	A science-based company active in nutrition, health, and sustainable living.	https://www.dsm.com

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Pioneer Hi-Bred International, Inc.	49	A producer of seeds for agriculture	https://www.pioneer.com

4.1.3 Technology analysis

We analysed international patent classification (IPC) codes, which provide a system for the classification of patents according to different technological areas. IPC codes are instituted by the World Intellectual Property Organisation (WIPO). This analysis enabled us to understand and foresee the technological areas of applications because one goal of the patents is to commercialise the technology in a particular field. Figure 4 demonstrates the proportions for each patent field.

Figure 4 IPC code derived from patents database.

The IPC code analysis identified four main research fields extracted from the patents, namely classification A (60%), classification C (25%), and classification B (12%), as well as others (3%). The major field is human necessities, meaning that most patents focus on consumer applications or tools to improve food shelf life rather than for purely technical purposes. Furthermore, there are sub-classifications of different patents applied in different categories. Both more and less prominent fields are of interest for R&D

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departments as they pursue innovation pathways. The most popular fields tend to indicate potential products for commercialisation, whereas less prominent areas are the whitespace for R&D to seek opportunities to initiate new technologies due to available freedom-to-operate (FTO), which facilitates the identification of opportunities for patenting or further development. Based on the experts' opinions, the technological trends and proportions of sub-IPCs are summarised in Table 2.

Table 2 Research areas based on IPC classification

IPC classification	*Proportion*	*Description*	*Interpretation of areas of interests*
A	60%	Human necessities	This group focuses on food and foodstuffs, including products (fresh food, dairy food, etc.) and processes (cooking, treatment, modification of nutritive qualities, etc.) for preservation such as disinfectants for sterilisation and to prevent the growth of organisms.
C	25%	Chemistry/ Metallurgy	This group emphasises biochemistry and organic chemistry techniques such as preserving microorganisms, mutation or genetic engineering, and enzyme-using processes to synthesise chemical compounds.
B	12%	Performing operations; Transporting	This area concentrates on systems of storing or packing materials and chemical processes, e.g., storage containers like bags, boxes, bottles, etc.
Others (e.g., G)	~3%	Physics	This area highlights measurement and testing to determine chemical or physical properties.

4.2 Research and development collaborations

4.2.1 Individual level

Figure 5 shows a cluster map of the top 10 researchers who have contributed the most patents during the study period. The linkage lines denote joint-research teams in which an inventor and co-inventor are named in the patents, and the nodes (yellow circles) indicate the number of patents for the inventor (note that values are directly indicated in cases when the numbers are too large for representation by the yellow circles). The analysis identified two main research groups. The first group accounts for 68 patents as a result of collaborations between William J. Kuduk and Willard E. Wood. Not surprisingly, they both worked at Cellresin Technologies, LLC., thereby facilitating the ability to be co-inventors. However, Willard E. Wood has also worked with other inventors, who are not shown in the figure (light green line) because they are not among the top 10 inventors. Specifically, Willard E. Wood worked with an inventor from Kimberly-Clark Worldwide, Inc. to publish a patent. There are a lot of relationships among the inventors in the second group, thus indicating some strong teams in R&D (with a maximum of eight linkages). This implies that the top inventors have worked in teams both within and outside of their firms to build collaborative R&D networks, although few collaborations between the organisations were observed. Furthermore, the analysis shows the expertise and research interests of researchers in different areas. For example, some researchers focus on developing materials to control food degradation rates, whereas others emphasise the production process to increase shelf life. If we want to search for a particular area of development, we can easily connect to those researchers.

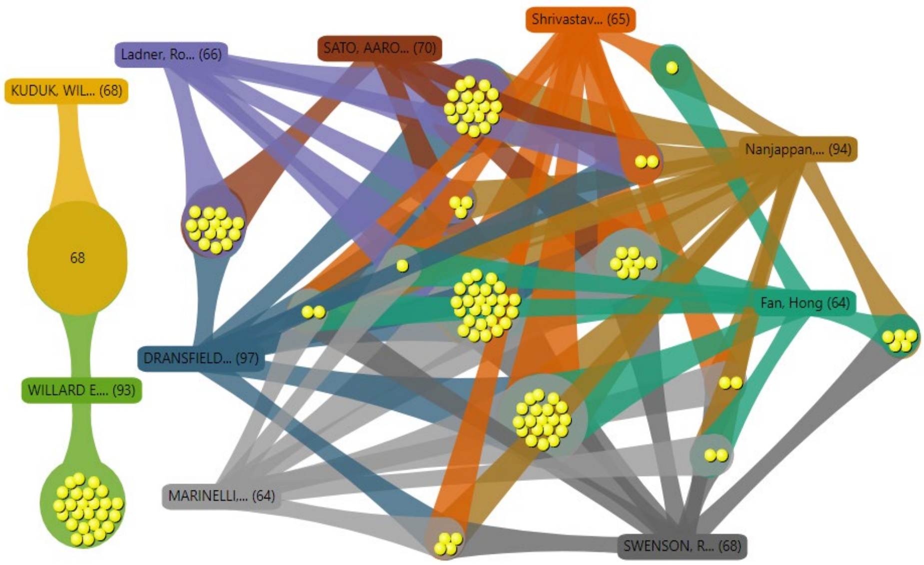

Figure 5 Cluster map of the top 10 food preservation inventors.

4.2.2 Organisational level

An analysis of the cluster map of the top 10 applicants for the shelf life extension technology revealed that none of the research collaborations among the top 10 applicants were between private companies, although there are few collaborations for other firms, as mentioned in 4.2.1. Hence, there are opportunities for top firms to explore possibilities for joint research programs to foster the speed of R&D. However, commercialisation needs present a significant difficulty limiting such collaborations and co-applicants for patents, as they can yield income from licensing. The confidentiality of intellectual

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property is another barrier to collaboration. During the R&D stage, knowledge exchange occurs between a team of researchers, which implies that one company can thereby understand the core competency of another, such as strategic R&D planning directions or scientific and technological formulations. Therefore, although collaboration at the R&D stage can enable each company to speed up and share ideas for further development, the occurrence of co-applicants among the patents will be rare.

We further analysed the relationships among players, and the result is illustrated in Figure 6. Despite the lack of relationships between private companies, several research collaborations among other players were observed. The strongest relationship is between private companies and universities. Although private companies often tend to pursue patent applications on their own, they still need to engage in collaboration with other parties due to personnel, time, and budget limitations. As informed by the experts' input, hiring or working with universities or other players can sometimes reduce cost of R&D for private companies by precluding the need for high-priced analytical instruments or equipment. The ownership (applicant name) of the patents depends on the agreement made between the parties. One possible case is that the applicant name is the player who supports the funding (e.g., private companies that fund universities' research). If the universities do not agree with this, then the collaboration may be endangered. For a win-win solution, all parties involved in the invention should be included among the patent's applicants and ownership.

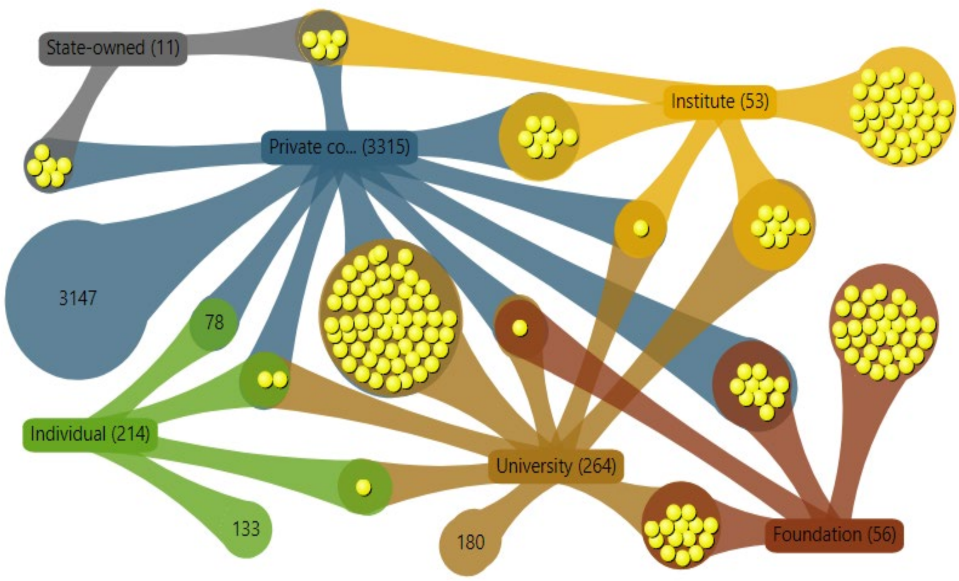

Figure 6 Cluster map among players.

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5 Implications for practice and theory

This case study of the shelf life extension technology using the STI method demonstrates the advantages of this approach to analyse raw big data to obtain useful information for further decision-making. The findings of this application of our novel forecasting approach provide several contributions to practice and theory.

5.1 Application to public and private organisations

Past technological development trends can be forecasted to evaluate whether the technology is of interest for future application to business strategy or policymaking. In addition, identifying the players who participate in technological development reveals the expansiveness of the potential market of its applications, as private companies comprise the largest proportion. Specifically, private companies were the first movers in the field of food shelf life extension and have played an essential role in its development to-date, thus indicating that food preservation technology is progressing toward improved solutions for extending food shelf life to serve consumers' needs and lifestyles. The first mover gains the most benefits from knowledge accumulation through the establishment of strong research teams. Those firms can achieve better new product development (NPD) and be technological leaders by implementing first-mover strategies and obtaining superior core competencies (Hsiao et al., 2017). From a business perspective, high R&D appropriability enables participating firms to achieve a market share advantage (Kim and Lee, 2011).

Another point relates to the speed and outcomes of R&D. Following the S-curve theory (Yang et al., 2010), once knowledge reaches a certain level, researchers can quickly research and develop technologies with a higher rate of success. Furthermore, corporate R&D can earn positive outcomes related to firm performance; hence, companies can establish R&D early to yield long-term benefits (Yang et al., 2010). On the other hand, technology transfer offices (TTO) founded by universities can provide business models to seek licensees to generate revenue to these institutions, which have the advantages of strong academic knowledge and research expertise.

An emerging technological trend is aiming to prolong the shelf life of agricultural foods through syntheses of microorganisms and enzymes using natural and safe chemical substances. A less prominent research stream is developing analytical methods for measuring chemical or physical properties to synthesise substances for prolonging shelf life. These specific technologies can be considered interesting areas, as they are emerging topics and have the potential to be commercialised in the future.

Another research stream concentrates on the research collaboration. The quadruple helix model of innovation conceptualises four major actors in innovation, namely government, industry (firms), academia, and society (Kimatu, 2016). In recent years, these actors have increasingly formed linkages for the development of socially-driven technological advancements that also profit industry and country. Policymakers can utilise the results of STI analysis to establish policies and inform sponsors of macroscopic collaborations that support national development and provide funding for less popular research areas that are nonetheless envisioned to be relevant for future

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competitiveness. R&D departments can use the method to glean global technological trends, and managers can target specific research goals that benefit company growth while also contributing to the social good. Additionally, firms can pursue collaborations with universities or research institutes for knowledge-based resources to reduce development time. Mostly, firms aim to apply technology in business, whereas academics are concerned with its underlying science and various impacts. Extending the shelf life of foods could address both concerns, and firms and universities could bridge their approaches. Two effective methods for doing so include supporting corporate funding for university research streams and participating in knowledge, idea, and scholar exchanges (Sjöö and Hellström, 2019). Finally, society can earn benefits from the implementation of advanced technologies. For example, people can consume safe foods with longer shelf lives, thereby lowering their cost of living and reducing food waste.

5.2 Academic contribution

The STI model can serve as a guideline for technology opportunity analysis and discovery by combining quantitative and qualitative approaches. This model was verified herein with a case study of shelf life extension technology; however, it could also be applied to other interesting technologies. Although researchers have proposed a number of technology forecasting models (Gerdsri et al., 2017, Song et al., 2017), we present a model that incorporates expert involvement into the important steps as a means to more precisely and efficiently search and interpret the results. Furthermore, we demonstrate the potential of the STI model for identifying both technological pathways and possibilities for collaboration among different parties. Further research can revisit the process of technology opportunity analysis to identify more effective methods and forecast pathways from different vantage points, such as the future opportunity analysis (FOA) model.

6 Conclusions

This study applied a novel approach called strategic technology intelligence (STI) to implement technology opportunity analysis and discovery by identifying innovation pathways to understand technological trends, competitors, and environments as well as exploring research collaborations and networking. The study also illustrated how to apply the text mining technique to the patents database. The research interest explored in the case study was shown to be increasing over time, meaning that advanced technology is achieving higher efficiency in increasing the shelf life of food. Private companies comprise the bulk of players in this field: both commercial firms that produce food and technology-based research firms are the core types of players in the market. Private companies were the first movers to file patents beginning in 1963, whereas other players started filing patent applications nearly 30 years afterward around 1990. The fields of food production, biochemistry, organic chemistry, storage systems, and measurement systems have dominated the recent research in shelf life extension technology. No relationship between firms for research collaboration was observed; however, a number of collaborations between players (e.g., firms, universities, and foundation) were found to

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foster R&D competency and reduce the time to market. By applying STI approach, policymakers, researchers, managers, and other stakeholders can utilise the analysed results for formulating strategies and roadmaps, forecasting future research trends, and planning policies to benefit societies by reducing the food waste problem and strengthen the organisational or national competitiveness.

7 Acknowledgements

This research was supported by the Technopreneurship and Innovation Management Program, Graduate School, Chulalongkorn University, Thailand as well as Thailand Science Research and Innovation (TSRI) through its Research and Researchers for Industries (RRI) Scholarship Program (Grant No. PhD62I0011). Furthermore, the VantagePoint (version 12.0) software from Search Technology, Inc. (www.theVantagePoint.com) is acknowledged for producing the results. Last but not least, the authors would like to thank Dr. Urarika Luesakul for fruitful help and discussions in interpreting the results obtained from the software.

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