STRATEGIC IMPLICATIONS OF TECHNOLOGY LIFE CYCLE ON TECHNOLOGY COMMERCIALIZATION

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ABSTRACT

A technology life cycle (TLC) can be a useful tool to help us to estimate the future development of a specific technology and make decisions whether to invest in it or not. However, it is not easy to understand the stage status of its TLC. One approach to analyzing TLC is to observe the patterns of patent applications or citations over time. In this paper, we build a model to calculate the TLC for a certain technology through the analysis of technology cycle time (TCT) based on backward citation of patents. The model includes the following steps: first, we focus on devising and assessing patent-based TLC indicators, then we choose some technologies with identified life cycle stages, and finally find strategic implications on firms' technology commercialization. The method used and result obtained in this study can be used in technology management practice to enable technology observers to determine the current life cycle stage of a particular technology of interest.

Key words: technology life cycle, patent citation, technology cycle time, technological innovation, technology management, technology commercialization

INTRODUCTION

The attractiveness of a technology as an investment object depends decisively on its current life cycle stage. One approach to study technology life cycles (TLC) is to observe the evaluation of patent applications or citations. This approach has some good reasons (Debackere et al., 2002). Patents inform us about the technological development itself since they contain the technological know-how, and about the commercial potential of a technology because the possibility of commercial use is one of the preconditions of patentability. Data about patent applications also inform about the TLC before life cycles of different products, which are based on the technology, can start. Furthermore, patent applications can be measured easily and objectively by using databases. Due to these advantages, it is reasonable to prefer patent application data as a basis of TLC descriptions to accumulated sales generated by products made possible by the new technology.

In particular, the TLC is closely related to the time and cost of developing the technology, the timeline of recovering cost, and modes of making the technology yield a profit.

Furthermore, most of the new technologies follow a similar technology life cycle that describes the technological maturity of a product. This is not similar to a product life cycle, but applies to an entire technology, or a generation of a technology. Technology adoption is the most common phenomenon that drives the evolution of industries along the industry life cycle.

The development of a competitive product or process can have a critical effect on the lifespan of the technology embodied, making it shorter. Likewise, the loss of IPRs due to a certain reason such as litigation also leads to reducing a technology's lifespan. Thus, it is apparent that the management of the TLC is a significant aspect of technology development, and besides, a critical consideration of the technology commercialization.

The TLC may be protected during its cycle with patents or other intellectual property (IPR) seeking to lengthen the cycle and to maximize the profit from it. The TLC can be understood in terms of the commercial gain of a product through the expense of research and development stage, and the financial return during its vital life. Some technologies have a long lifespan while others may have quite a short lifespan.

In this study, we will use patent citation data to measure TLCs of technologies showing differences particularly in their whole lifetimes and the patterns of trends in diffusion of innovations. To measure a TLC using patent citation data, we will identify technology fields based on IPC subclasses. Citation analyses mostly rely on the front page references the examiner selects in patents. These are the only types of citations that informetric analysts can access in large scale databases.

Further, we aim at presenting some strategic implications on technology management based on the analysis of TLC using patent citation data. Based on the above, we explore the relationship between the TLC and the technological improvement or the commercial use of technology in various aspects, and examine the applicability of quantitative data to finding strategic options for technology commercialization.

TECHNOLOGY S-CURVE AND TECHNOLOGY LIFE CYCLE

S-curves in Technological Improvement

Once a new technology comes into existence in the market, it shows quite a stable pattern which can be elucidated in terms of performance characteristic. The performance characteristic refers to an element of interest to a developer of a product or a user of a specific technology. The performance of a technology has a recognized pattern over time that can be used in strategic planning of technology management.

Technological innovation refers to the changes in performance characteristics of a specific technology over time. The life cycle of innovations can be described using the S-curve which maps again in a different way such as growth of revenue or productivity against time (Figure 1). In the early stage of a particular innovation, growth is slow as the new product establishes itself. At some point, customers begin to demand and the product growth increases more rapidly. New incremental innovations or changes to the product allow growth to continue. Towards the end of its life cycle, growth slows and may even begin to decline. In the later stages, new investment will not yield a normal rate of return any more.

Each technology has a number of performance characteristics of a specific technology over time. The performance characteristics show very little improvement in the early stages of the technology. This initial stage is followed by a second phase of very rapid improvement in the performance characteristic. During the third stage, the performance characteristic continues to improve, but the rate of improvement begins to decline. In the final stage, very little improvement is visible and the graph that charts the progress in the performance characteristic of a technology over time takes an S-shape (Narayanan, 2001).

In the early stage, a new technology is introduced into the market but its adoption is limited to a small group of early adopters and small niche markets. During the middle stage, a dominant design begins to emerge, winning the allegiance of the market place and also effecting standardization of everything from design to manufacturing. Then the dominant design leads to heightened competition as new entrants realize opportunities for further innovation. This is the period of rapid growth as a technology matures. In the final stage, the product reaches market saturation. The duration of each stage of the cycle varies with the product characteristics, uncontrolled market situations, the management’s support, experience in R&D and production, etc. (Kim et al, 2012).

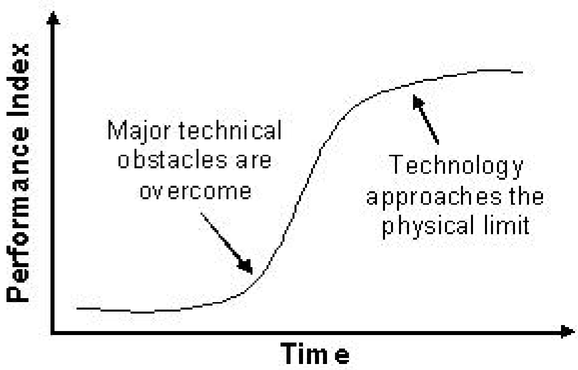

Figure 1. S-curve of Technology Performance

Technology S-curves and Discontinuous Technologies

Technologies follow S-curve from the initial introduction stage to the final maturity stage after emerging in the marketplace, but they do not always get the opportunity to reach their limits. Rather, they may be rendered obsolete by new, discontinuous technologies. A new innovation is discontinuous when it fulfils a similar market need but does so by building on an entirely new knowledge base (Anderson and Tushman, 1990; Christensen, 1999; Foster, 1986). For example, the switches from propeller-based planes to jets, from silver halide (chemical) photography to digital photography, from carbon copying to photocopying, and from vinyl recorders to compact discs were all technological discontinuities (Schilling, 2013).

At the outset, the technological discontinuity may have lower performance than the current technology and effort invested in the new technology may reap lower returns than effort invested in the existing technology (Figure 2). This causes firms to be unwilling to switch to investment in the new technology. However, if the disruptive technology has an S-shaped curve that increases to a higher performance limit, there may come a time when the returns to effort invested in the new technology (Technology B) are much higher than effort invested in the existing technology (Technology A).

New firms entering the market are likely to choose the disruptive technology while incumbent firms face the difficult choice of trying to extend the life of their current technology, or investing in switching to the new technology. If the disruptive technology has much greater performance potential for a given amount of effort, in the long run it is likely to displace the incumbent technology, but the rate at which it does so can vary significantly (Schilling and Esmundo, 2009).

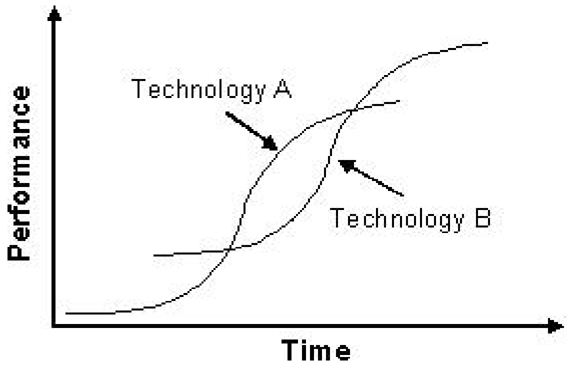

Figure 2. Technology S-curve and Inroduction of Discontinuous Technology

Technology Perception Dynamics

Most new technologies have some novelty or innovation embedded in their product. Customers will adopt an innovation earlier than others based on their perception of its advantages and its risks. The diffusion of innovations describes the process of how innovations spread through a population of potential adopters.

The diffusion of innovations forms the basis of the technology adoption life cycle. The technology adoption life cycle models the response of any given population to the offer of a discontinuous innovation, one that forces the abandonment of traditional infrastructure and systems for the promise of a set of benefits unavailable till now. It represents this response as a bell curve, separating out subgroups of population.

It is argued that people have different levels of readiness for adopting new innovations and that the characteristics of a product affect overall adoption since customers respond to new products in different ways. Rogers (2003) classified individuals into five groups: innovators, early adopters, early majority, late majority, and laggards. In terms of the S curve, innovators occupy 2.5%, early adopters 13.5%, early majority 34%, late majority 34%, and laggards 16% (Figure 3).

An innovation can be a product, a process, or an idea that is perceived as new by those who might adopt it. Innovations present the potential adopters with a new alternative for solving their problems, but they also present more uncertainty about whether that alternative is better or worse than the old way of doing things. The primary objectives of diffusion theory are to understand and predict the rate of diffusion of an innovation and the pattern of that diffusion. Innovations do not always quickly adopted (Rogers, 2003).

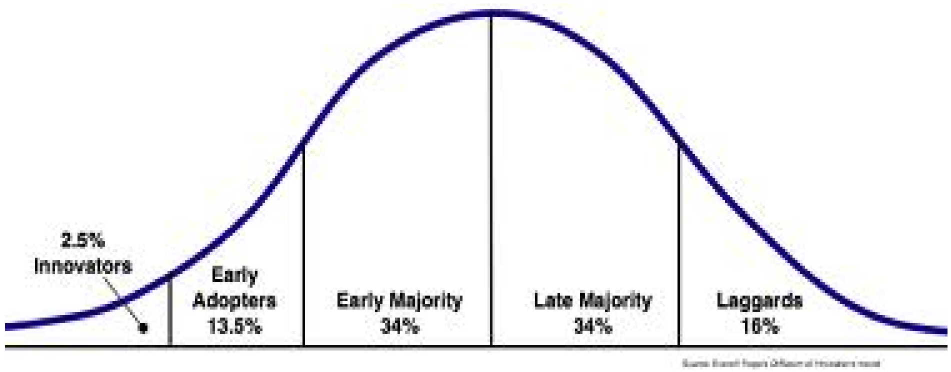

Figure 3. Technology Adoption Lifecycle

Technology Life Cycle and Business Gain

The technology life cycle (TLC) illustrates the way in which technological developments of products create commercial gain over a particular time frame. These gains are necessary to offset the research and development (R&D) costs inherent in their creation. Moreover, varying life spans make it important for businesses to understand and accurately project the returns on these investments based on their potential longevity.

Due to the rapidly increasing rates of innovation, products such as electronics and computers in particular are vulnerable to lower life cycles when benchmarks such as steel or paper are considered. Thus, the TLC is focused primarily upon the time and cost of development as it relates to the projected profits (Boundless, 2014).

The typical life cycle of a manufacturing process or production system follows the path from its initial conception to its culmination as either a technique or procedure of common practice or to its demise. The Y-axis of the diagram shows the business gain to the proprietor of the technology while the X-axis traces its lifetime (Figure 4). The TLC may be seen as composed of four stages:

a. The introduction or research and development (R&D) stage when incomes from inputs are negative and where the prospects of failure are high.

b. The growth or ascent stage when out-of-pocket costs have been recovered and the technology begins to gather strength by going beyond some Point A on the TLC.

c. The maturity stage when gain is high and stable, the region, going into saturation, marked by M.

d. The decline or decay stage, after Point D, of reducing fortunes and utility of the technology.

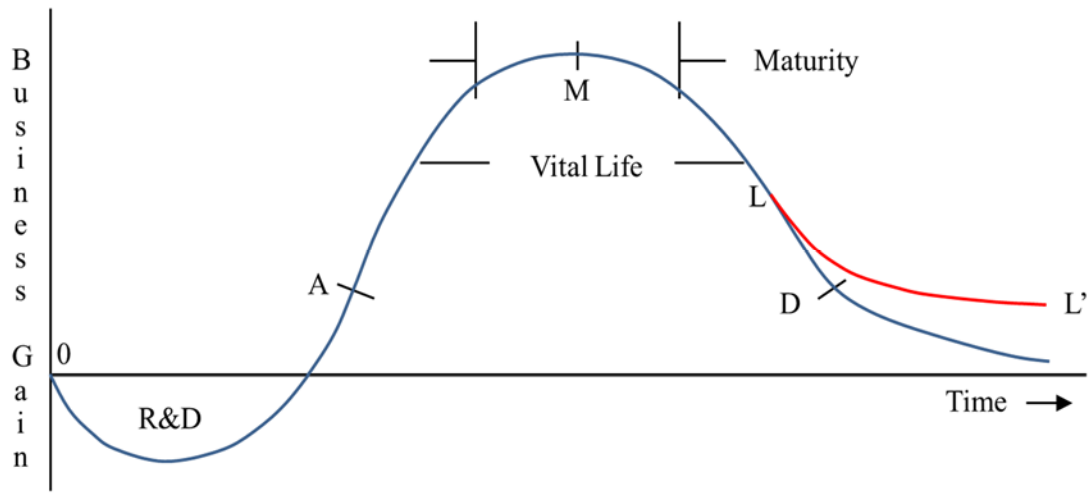

Figure 4. The Typical Technology Life Cycle Path

MEASUREMENT OF TECHNOLOGY LIFE CYCLE

Use of Patent Citations in Measuring TLC

When a technology that does not have a legal, contractual, and judicial document for its life determinant is taken into consideration for the strategic options of technology commercialization, life cycle analysis is recommended to estimate the economical useful life period for the technology. That is because the life cycle analysis incorporates qualitative considerations of future technological and market conditions with quantitative consideration of existing and historical environments. Thus, this analysis allows for changes in the future with a logically derived estimate of when these changes may occur (Reilly and Schweihs, 1998). The life cycle analysis has evolved from the theory of marketing and management.

The analysis can be dealt with in terms of technological knowledge flow that can be investigated by analyzing the patent citation data as a proxy measure of disembodied knowledge. Patent information can provide an approximate description of the innovation activity that occurs in most fields of technology in developed countries and is the only viable quantitative measurement because it is accumulated over a long period of time (Park and Suh, 2013).

Therefore, we use patent citation data to measure the technology life cycles (TLC) of some technology fields that would show differences particularly in a whole life span and the patterns of trends in diffusion of innovations. To measure the TLC using patent citation data, we identify technology fields based on IPC subclasses.

When using patent citation data, one needs to be cautious of the basic role of citations of patents. A relevant issue in patent citations is what kind of technology interaction patent citations measure. More specific questions in this context are whether patent citations can indicate the direction of knowledge transfer (Meyer, 2000).

Citation analyses mostly rely on the front page references the examiner selects in patents. These are the only types of citations that bibliometric analysts can access in large scale databases. These citations are so significant because the patent examiner uses them in establishing the patent's novelty (Narin et al., 1997). A closer look at the role of citations in patents is necessary to better understand what function these particular citations have. Patents are legal documents. Due to their specific legal functions, citations in patents are likely to be much more carefully selected.

Technology Cycle Time as a Measure of the Pace of Technological Progress

Technology Cycle Time (TCT) indicates speed of innovation. TCT measures the median age in years of the U.S. patent references cited on the front page of the company's patents.[1] Fast moving technologies such as electronics have cycle times as short as three to four years. Slow moving technologies such as ship and boat building may have technology cycle times as long as 15 years or more. Companies with shorter cycle times than their competitors in a given technology area may be advancing more quickly from prior technology to current technology (Narin, 1993).

The rationale is due to the assumption that references cited in a patent, called 'prior art', provide a unique feature, which captures linkage between an invention and the prior knowledge most closely related to it. The measure also assumes that the more recent the age of cited patents, the more quickly one generation of inventions is replacing another. Since the measure was proposed, TCT-based indicators have been used in assessing pace of progress for different technologies or different nations in the same technology (Kayal and Waters, 1999).

TCT captures some elements of the rapidity with which a company is inventing, since it measures, in essence, the time between the previous patents upon which the current patent is improving, and the current patent. It varies very substantially from one technology area to another.

TCT also varies from country-to-country. Japanese-invented U.S. patents, for example, tend to have much shorter TCT than U.S.-invented patents, which in turn tend to have shorter cycle times than European-invented patents, and this difference is particularly notable in such technologies as electronics. We interpret this as indicating that the Japanese companies are innovating very rapidly, possibly making incremental but rapid changes in their technology and products, whereas the European companies tend to be innovating at a very much slower rate, particularly in electronics, with U.S. companies somewhat in the middle (Narin et al., 1997).

Another particularly interesting aspect of TCT is that it sometimes can be used, along with the rate of increase of patents, to identify areas in which a company is intensely active, because if a company is increasing its patenting, and at the forefront of a technological area, then it will tend to have a short TCT. We sometimes find that companies which are relatively slow overall in their inventive cycles will be very fast in one area, and that is often the area in which they are known to be technology leaders.

As with many of the other indicators, the computation of TCT is not totally straightforward. For one, we use the median rather than the average age of the cited references because there are, very often, one or two old classic references used in a patent, and if we use the average, these one or two very old references would distort the data.

1) Technology Cycle Time (TCT) was proposed by CHI Research, Inc., which created a series of technology indicators based on patent citations, with support from the U.S. National Science Foundation.

Data Collection and Analysis

In this study, we chose 4 IPC subclasses including A61K, B60K, C22B, and G06F, which can be thought of as representing 4 major technology fields including health, automobile, metallurgy, and computer (or IT). The definition of the 4 IPC subclasses is as follows, respectively:

A61K - Preparation for medical, dental, or toilet purposes

B60K - Arrangement or mounting of propulsion units or of transmissions in vehicles

C22B - Production or refining of metals

G06F - Electric digital data processing

For the 4 IPC codes, or technology fields, we collected all the patents registered in the United States Patent and Trademark Office (USPTO) for 156 years from 1857 to 2012. The largest number (3,555,338) of patents was registered in the field of G06F, and the smallest number (11,320) of patents in the field of C22B in the USPTO during the period. In processing the data, we used the database (G-PASS), constructed by Korea Institute of Science and Technology Information (KISTI), which includes all of the patents registered in the USPTO.

Based on the collected US patents, we calculated the TCTs of the patents falling under each category of the codes. Using the database, we selected the patents that contain backward citation information for patents in the subject IPC codes, and calculated the TCT of patents under each IPC code for the whole period of time from 1857 to 2012. The results of analysis for TCTs of each IPC code are shown in Table 1.

According to the table, the TCT of C22B has the largest average (11.8 years) and that of G06F has the smallest average (7.3 years) while the median values of the technologies are smaller than their averages. These results are due to the fact that TCTs of the technologies are not normally distributed and skewed to the right. We can infer the skewness of the TCT distributions from the table that shows averages ranging from 7.3 to 11.8 years, and minimum values of 0 year and maximum values of longer than 50 years.

Thus, each technology has shorter median values than average values in its TCT. In fact, C22B has the largest median (9 years) while B60K and G04F have the smallest median (6 years). In the meantime, B60K has shorter Q1 (3 years), and A61K and C22B have longer Q1 (5 years). On the other hand, G06F has shorter Q3 (9 years), and C22B has very long Q3 (17 years).

Table 1. TCT and Related Statistics by Technology Field

IPC	N	Average	Variance	S.D.	Max.	Min.	Q1	Q3	Median	Mode
A61K	733,893	9.6199	46.7197	6.8352	52	0	5	13	8	6
B60K	54,862	8.4100	55.8190	7.4712	52	0	3	11	6	2
C22B	11,230	11.7933	87.2346	9.3400	50	0	5	17	9	3
G06F	3,555,338	7.3107	20.9914	4.5816	51	0	4	9	6	5

STRATEGIC IMPLICATIONS ON TECHNOLOGY COMMERCIALIZATION

Analytical Framework of Technology Commercialization

We need to formulate an analytical framework to draw strategic implications on technology transfer in a firm's technology commercialization. For the purpose, we can reasonably match, though not exactly, a technology adoption or diffusion curve of innovations based on a technology life cycle (TLC) with a technology cycle time (TCT) curve based on the pace of technology progress.

Keeping the similarity of two curves in mind, we combined technology S-curve and technology adoption life cycle. Then, we could identify the relationship between innovator groups and TCT statistics, and showed the statistics (Q1, Q2 or median, and Q3) of the distribution in Figure 5. This figure enables us to identify strategic implications on technology strategies for firms by translating it in terms of TCT.

Technology S-curve shows us stages of a TLC. As we have seen, a TLC starts with the R&D or introduction stage, progresses to the growth stage and the maturity stage, and finally winds up the cycle with the decline stage. In the figure, a technology begins to progress from the introduction stage that lasts until around Q1, and after Q1, the technology enters the growth stage that lasts until Q2. After Q2, a technology begins its maturity stage lasts until around Q3, and after Q3, it starts to decline. In view of characteristics of a TLC, Q1 can be considered as an approximate divider between the introduction stage and the growth stage, Q2 between the growth stage and the maturity stage, and Q3 between the maturity stage and the decline stage as follows:

Q1: R&D (introduction) stage – Ascent (growth) phase

Q2: Ascent (growth) stage – Maturity stage

Q3: Maturity stage – Decline (decay) stage

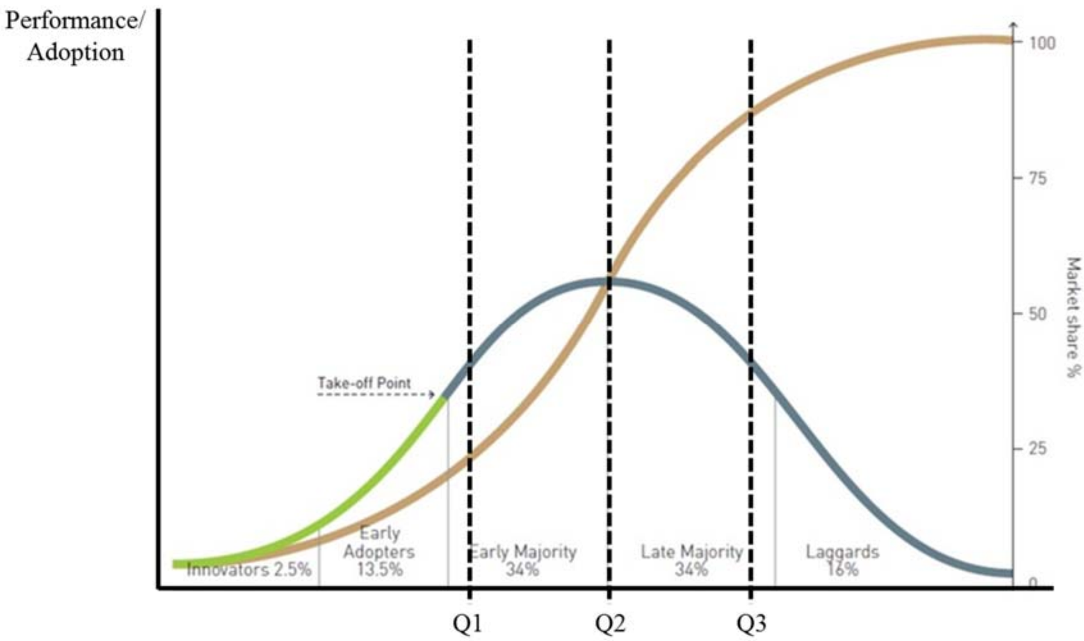

Figure 5. Analytical Framework of Technology Management

Strategic Options of Technology Commercialization

The analytical framework formulated with technology S-curve, technology diffusion curve, and TCT statistics enables us to come up with some strategic implications on technology commercialization for firms. We can use the TCTs based on the S-curve in order to design R&D and innovation strategy, and choose licensing strategy by the stages of TLC.

We can simplify and describe technology life cycles for 4 technology fields using Q1, median (Q2), and Q3 in Figure 6. These simplified distribution patterns of TLCs indicate that each technology has a different life cycle, which can be seen through median (Q2) and the IQR (Interquartile range), defined as Q3 (75% quartile) minus Q1 (25% quartile). Using the median (Q2) and IQR, we can estimate the length of a TLC for each technology.

As seen in Figure 6, G06F (electric digital data processing), a technology field representative of computer or IT technology, and B60K (arrangement or mounting of propulsion or of transmissions in vehicles), representative of automobile technology, has the relatively short median (Q2) of 6 years, which means that these two technologies have relatively short TLCs. On the contrary, C22B (production or refining metals), a technology field representative of material technology, has the longer median of 9 years, which indicates that this technology has a longer TLC. A61K (preparation for medical, dental, or toilet purposes), a typical technology of health, shows the middle level of median (8 years) or TLC.

This figure also enables us to identify the TLCs in other aspect by using the IQR. IQR, also called the midspread or middle fifty, is a measure of statistical dispersion, being equal to the difference between the upper and lower quartiles.[2] In terms of IQR, G06F has the shorter TLC or IQR of 5 years, while C22B has the longer TLC or IQR of 12 years. Other 2 technologies, including B60K and A61K are located between the previous 2 technology fields in terms of TLC.

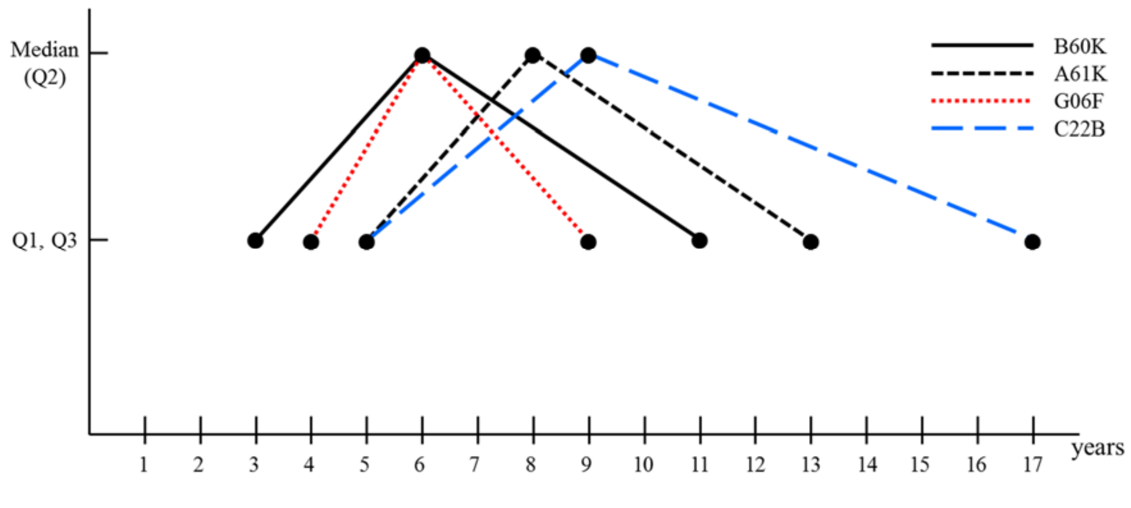

Figure 6. Simplified Distribution Patterns of TLCs of Four Technology Fields

The IQR can be differently translated from median (Q2) as an estimate of TLC. IQRs tend to be longer as medians (Q2) are longer. In particular, the IQRs enable us to identify the kurtosis, or the degree of

2) In other words, the IQR is the 1st quartile subtracted from the 3rd quartile; these quartiles can be clearly seen on a box plot on the data. It is a trimmed estimator, defined as the 25% trimmed mid-range, and is the most significant basic robust measure of scale.

concentration of distributions. Thus, in interpreting a TLC with TCT, we can say that a technology with shorter IQR has more stable and regular technology lifespan. In this sense, A61K has the more stable and regular technology lifespan than B60K although two technologies are turned out to have the same TLC of 6 years.

In relation to technology transfer, firms have traditionally had the tendency to license out their technology when the technology face a threat to the life of the TLC as it starts to decline, after Q3 in the figure. Thus, G06F would face the decline by far earlier while C22B would keep its lifespan longest until it faces the decline stage, which could mean that C22B can enjoy the longest exploitation or useful life of the technology in a firm. In other words, C22B could be used for about 12 years from 5 years (Q1) to 17 years (Q3) after starting to be able to acquiring business gain from adoption of the technology to the product.

On the other hand, G06F would make a firm consider the technology to be licensed out, from about9 years (Q3) after its TLC begins the remunerative growth stage. That is, G06F can enjoy its useful life of about 5 years from 4 years (Q1) to 9 years (Q3) after its TLC emerges.

SUMMARY AND CONCLUSION

The technology life cycle (TLC) describes the commercial gain of a product through the expense of research and development stage, and the financial return during its vital life. The TLC is concerned with the time and cost of developing the technology, the timeline of recovering cost, and modes of making the technology yield a profit. Moreover, the TLC may be protected during its cycle with intellectual properties seeking to lengthen the cycle and to maximize the profit from it.

The TLC shows us how technological developments of products create commercial gain over a particular time frame. These gains are necessary to offset the R&D costs inherent in their creation. Moreover, varying life spans make it important for businesses to understand and accurately project the returns on these investments based on their potential longevity. Due to the rapidly increasing rates of innovation, products such as electronics and computers in particular are vulnerable to lower life cycles. Thus, the TLC is focused primarily upon the time and cost of development as it relates to the projected profits.

The typical TLC follows the path from the stages of its initial conception to its culmination or to its demise. The TLC may be seen as composed of four stages: the introduction or R&D stage, the growth stage, the maturity stage, and the decline. In order to measure TLC, we used technology cycle time (TCT) that measures the median age in years of the U.S. patent references cited backward on the front page of the company’s patents. Companies with shorter cycle times than their competitors in a given technology field may be advancing more rapidly from prior technology to incumbent technology.

We formulated an analytical framework to come up with strategic implications on technology transfer in a firm’s technology management. We matched technology adoption or diffusion curve with a TCT curve, and combined technology S-curve and technology adoption life cycle considering the similarity of two curves. Then, we could identify the relationship between innovator groups and TCT statistics. Using the framework, we found strategic implications on technology strategies for firms.

We drew some strategic implications on technology management for firms based on the analytical framework formulated with technology S-curve, technology diffusion curve, and TCT statistics. We used the TCT based on the S-curve in order to design R&D and innovation strategy, and chose licensing strategy by the stages of TLC.

By combining TLC and TCT curves in the framework, we found that G06F and B60K (computer and automobile technologies) have shorter TLC than C22B (material technology), and A61K (health technology) has more stable and regular technology lifespan. We also found that G06F would face the decline much earlier than C22B. Thus, we need to consider licensing out G06F earlier than A61K or C22B. In particular, we infer that C22B could be used with acquiring commercial gain for the longest time before a firm considers licensing out the technology.

In this study, we used the framework based on technology S-curve, technology diffusion curve, and TCT statistics. Then, we can posit that distribution patterns of TCT based on backward citation information collected from the U.S. patents compared with TLCs and therefore suggest the strategic options based on the relationship between TCT statistics and TLC stages. Nevertheless, it goes without saying that the theoretical and practical relationships between TLC and TCT must be verified in broad aspects and that the relationship between TLC and PLC must be examined in more rigid sense.

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