A New Approach to Estimating Product Lifetime in Technology Valuation

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Ⅰ. Introduction

It is essential for a country or a business organization to develop or acquire new technology for economic success. In many cases, however, it is hard to make a decision whether or not it is economically feasible to invest in the development of the required technology, or it is complicated to negotiate the price of the technology between a licensee and a licensor. Although many technology valuation methods such as market approach, income approach, cost approach, and real options have been developed and established to value technologies, the income approach is the most commonly used in practice because this method gives realistic values by calculating the income-producing potential of the technology at present time. However, the valuation process is very complex even under the best of conditions because it includes three major inputs: a) the duration of the income stream (i.e., the economical lifetime), b) the amount of income to be generated and the pattern in which it will be received (i.e., the potential cash flow), and c) the risk linked with the realization of the expected income (Sampath Kumar et al., 2004). This future potential cash flow over the lifetime of the technology implies that the valuation method requires many estimates and assumptions. Therefore, it is critical to obtain realistic input with respect to technology per se, external and internal factors (Van Triest and Vis, 2006).

In this study, we focus the valuation method, specifically the duration of income stream and the pattern in which it will be received. Estimating the duration and analyzing the lifetime pattern of the product adopting the subject technology becomes fundamental in estimating the cash flows. Many studies have focused on estimating the duration of the income stream, known as the economical lifetime, through analyzing patent information. However, the output of patent-based analysis does not reflect the economical lifetime and the life cycle pattern of the subject of technology. Furthermore, there are no guidelines as to how to use other information from analyzing the technology, the market, and the firm to estimate cash flows. Thus we present an approach to estimating the economical lifetime and the pattern by providing the adjustment factors.

In Chapter 2 of this paper, we review the literature on the quantitative methods of estimating the economical useful lifetime of a technology and identify issues of the methods. Then, we suggest the product life cycle approach as a qualitative method to solve the issues. In chapter 3, we propose a framework to estimate the economical useful lifetime and develop a set of factors to be considered in each transition of a product life cycle to reflect the characteristics of the product adopting the

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technology at the valuation time. In chapter 4, the proposed method is applied to the example case to illustrate the practical use. Finally, implications of the framework for firms or valuators are discussed.

II. Approaches to Estimating Economical Life of a Technology

The income approach is considered to be suited for the valuation of intellectual property like technologies because it is based on the rationale that value is determined by income-producing capability of a subject technology (Park and Park, 2002). It determines the fair value of a specified technology by calculating the present value of the income stream over its life time (Kumar et al, 2004). Thus, estimating the economical life of a technology is the first important prerequisite step in the valuation analysis. That is, estimation of a longer economical life means a greater number of periodic economic income flows to be projected. This implies a higher value for the subject technology (intangible asset) compared to another technology (intangible asset) with a shorter economical life, all other factors remaining constant (Reilly and Schweihs, 1998).

Many empirical studies have concentrated on the patents information to estimate a length of the time period for a technology (Trajtenberg, 1990; Ernst, 1997). Hirschey and Richardson (2001) defined technology cycle time (TCT) as the median age in years of earlier U.S. patents referenced on the front page of a U.S. patent. TCT represents the amount of time that has elapsed between when a current patent and the previous generation of patents were issued. TCT is essentially a measure of cycle time between a current patent and the prior state of knowledge.

In Korea, Korea Institute of Science and Technology Information (KISTI) developed a methodology called the cited-patent life time (CLT) and then proposed the method to refer the economical life period for a technology. However, this approach to estimating technology lifetime by measuring patent activity indices raises a practical problem. This is partly due to the fact that the international system of patent classification (IPC) does not offer classes exactly corresponding to a certain, product-related technology. In addition, most technologies cannot be identified with a clearly defined set of technical search terms (Haupt et al., 2007).

When a technology that does not have a legal, contractual, and judicial document for its life determinant is valuated, life cycle analysis is recommended to estimate the economical life period for the technology. Because it 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 marketing management. A typical life cycle is described by an introduction stage, a rapidly increasing growth stage, a decreasing growth stage leading to maturity, and a decline stage when substitution occurs. Many empirical studies have focused on the factors leading to success or failure of a new product in the market (Norton and Bass, 1986; Popper and Buskirk, 1992; Mahajan and Muller, 1996; Klepper, 1996).

Although estimating the economical life of a technology is the first critical step in the whole valuation process, many studies have concentrated on quantitative analysis via the patent information. Thus, there is no approach to estimate the economical life of the technology with qualitative method such as life cycle analysis in the valuation. This study proposes a new approach that can estimate economical life of the technology by analyzing the historical lifetime of product substituted by the new technology and then by adjusting it by the important factors which are significantly influenced in the transitions during a life cycle stage. In this study, we adopt a product life cycle rather than a technology life cycle. The reason is that, in practice, monetary value for a technology is derived on the basis of the income-producing capability of a product that the subject technology is applied to.

III. Framework of New Approach to Lifetime Analysis in Valuation

3.1 New Framework to Estimate Lifetime

Current lifetime estimation analysis in the whole valuation process in Korea is fragmentary because it neither considers other important factors that influence the lifetime and nor provides explicitly the important parameters that influence the expected sales and growth rate for the period. Economical lifetime and income estimation are significantly influenced by various capacities and strategies of a firm (Griffin, 1997; Filippini et al., 2004). Therefore, this process can cause the degree of the valuation to be downgraded.

Figure 1. Current Lifetime Estimation Analysis Process

The proposed approach to lifetime analysis is designed to enhance the logic of the valuation by interconnecting with the results of analysis in diversified perspectives such as technology, market, and firm. In the new framework, the valuation progresses as follows:

First, historical life cycle analysis for the product that a new technology-adopted product will substitute is conducted. The length of each stage in the product lifetime is derived through analyzing the historical life cycle of the substituted product. Additionally, important parameters such as growth and decline rates, and maximum market size are identified.

Second, adjusting the historical life cycle of the substitute product is required to reflect the conditions that the new product faces at the time of valuing the product. That's because the product adopting the new technology faces different situation compared to that which the substituted product faced.

In this study, we propose multidimensional critical factors to consider for each transition that have been examined in the product life cycle literatures. The information for these factors can be verified by analyzing technology, market, and firm. Therefore, it can strengthen the logical structure of valuation (See figure 2).

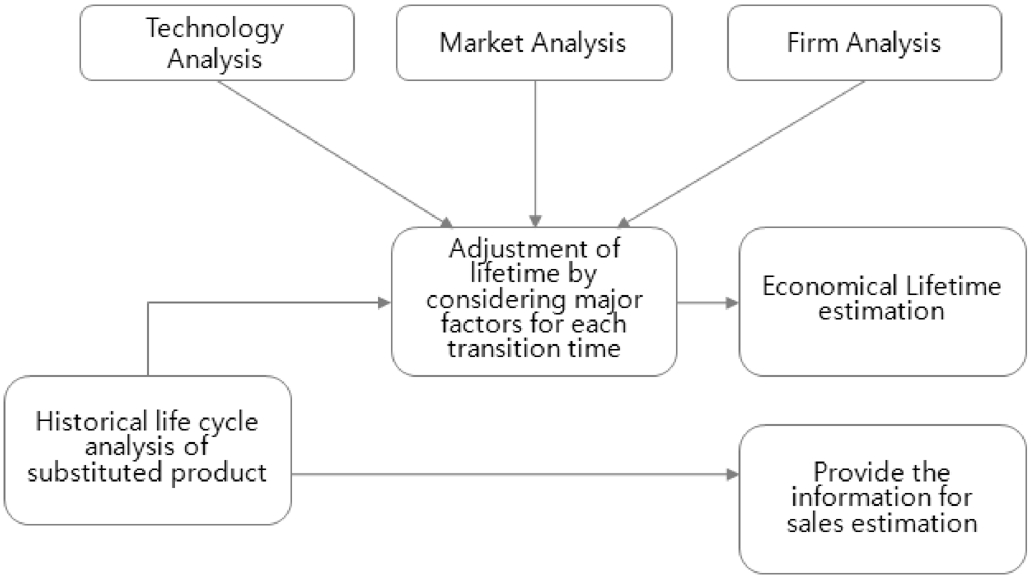

Figure 2. New Framework to Estimate Lifetime

3.2 Reconsideration of Product Life Cycle

The product life cycle (PLC) analysis provides the information for better managing the entire lifetime of a product from its conception, through design and manufacture, to service and withdraw from a market. Therefore, the understanding of a product's life cycle can help a valuator to estimate logically and rationally the economical life cycle. Generally the product life cycle is consists of four stages and each stage is defined as follows (Golder and Tellis, 2004).

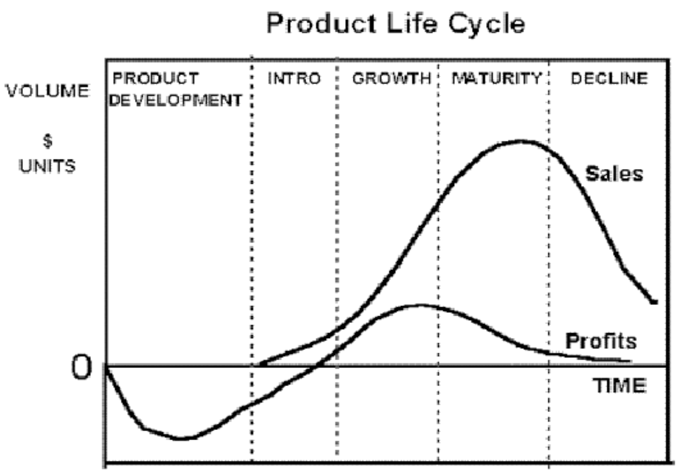

Figure 3. Product Life Cycle

1. Introduction is the period from a new product's commercialization until its takeoff.
2. Growth is the period from a new product's takeoff until its slowdown in sales.
3. Maturity is the period from a product's slowdown until sales begin a steady decline.
4. Decline is the period of steadily decreasing sales until a product's demise.

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. In order to adjust the life cycle of a new product, we use a three-dimensional approach for each distinct phase. The dimensions are a) technology, b) market, and c) firm.

3.2.1 From Introduction to Growth Stage

The degree of technological innovation may disrupt the existing economic conditions and require a change in the business context. Generally it is presented as radical or incremental innovation based on the degree of technology innovation. Radial innovations make the existing knowledge obsolete and promote an alternative user group to experiment with the new technology. Incremental innovations, on the other hand, have more to do with exploitation and competence-enhancing measures, enabling the firms to build on existing routines and skills (Elfring and Hulsink, 2003). If a new product containing radically innovational technologies is introduced, there is considerable uncertainty as to its technological performance in the market (Tatikonda and Rosenthal, 2000).

Firms tend to combine field testing and test marketing due to the initial low reliability of the new product. In order to survive during this phase, R&D is altering and improving the product's weak points. This technological evolution can lead firms to discover unknown customer benefits and applications from observing product usage (Popper and Buskirk, 1992). This implies that firms must concentrate on a market research effort more than customer support in the transition from the introduction to the growth stage. Therefore, valuators need to understand market uncertainty and technological uncertainty that could impact on the new product's life. Chen et al. (2005) suggested the conceptual construct of uncertainty in technology. Uncertainty of technology is posited in terms of novelty and turbulence.

For the organizational perspective, capacities in R&D will determine successful survival from the perspective of technology (Lilien and Yoon, 1989). In addition, these continued technological evolution activities among firms require an amount of investment in the condition that firms can not produce the same incremental profits. R&D is intrinsically characterized by high information opacity, implying more difficulties to find external financial funds constraints (Ughetto, 2008; Brighi and Torluccio, 2009). Thus, valuators should consider a firm's internal finance capabilities when in a condition of not producing enough profits.

3.2.2 From Growth to Maturity Stage

The available and advanced technological features that are embodied in the new product are explored throughout the transition from the introduction to the growth stage. As this exploration between producers and customers starts to converge on a consensus of the desired technological configuration, a dominant design emerges (Schilling, 2009). The dominant design establishes a stable architecture for the technology and enables firms to focus their efforts on process innovations that make production of the design more effective and efficient or on incremental innovations to improve components within the architecture (Schilling and Esmundo, 2009). Reducing price and increasing adoption leads to the take off of the product in the market while avoiding uncertainty. Thus, to become the dominant product design among competitors for the industry is the goal of this stage. The primary sources that shape which technology design will rise to dominance are network externalities and learning effects (Schilling, 2009).

Network externalities exist when the utility of a product to a consumer increases as more consumers adopt the new product (Rohlfs, 2001). Network externalities are considered to be direct if utility is directly affected by the number of other users of the same product, as in the case of telecommunication products and services such as faxes, phone and e-mails (installed base). Network externalities can also be indirect if the utility increases with the number of users of another complementary product (complementary goods). For the organizational perspective, as firms accumulate experience with the technology, they discover better ways to produce new technological solution that may enable to reduce input costs or waste rates. This is known as the learning effect. However, it diversely appears in every firm due to the firm’s absorptive capacity (Cohen and Levinthal, 1990).

Once the product has been proven a success, more customers become aware of it and its benefits. This increases sales and attracts numerous competitors to enter the market very quickly. Many new entrants erode market share among market leaders, triggering the start of the price war (Popper & Buskirk, 1992). However, this competition drives productivity improvements forward which induce growth in the market (Nickell, 1996; Peres et al., 2010).

3.2.3 From Maturity to Decline Stage

As the industry evolves towards the maturity and declining stage, the product design becomes more standardized and uniform, and the premium attached to technological superiority recedes (Agarwal and Audretsch, 2000). Diminishing technological differentiation in this transition leads to participating price wars and the firms which can product most effectively and efficiently rather than most sophisticatedly can be successfully maintained. Consequently, firms that are successful will be ones of that emphasize the production-oriented technology to provide low-cost and high quality output, which requires choosing a capital-intensive strategy (Popper and Buskirk, 1992).

From the aspect of market, obsolescence is a major cause which drives the transition from the maturity stage to the declining stage. If new innovative product is released in the same market, the value of a technology-related product may decline rapidly. The development of 3.5-inch diskettes and CD-ROMs, which have replaced the 5.25-inch floppy diskettes and the increasing number of compact disk (CD) musical recordings as opposed to vinyl records, are examples of retirements due to the obsolescence (Reilly and Schweihs, 1998). For a valuator, it’s mandatory to identify potential competitive products and understand the long-run trend of their development activities. The five force, the famous industry analysis framework provided by Michael E. Porter, points out the threat of substitute products or services.

Table 1. Critical Factors in the Transition Phase of Life Cycle

Stage/ Dimension	From Introduction to Growth stage	From Growth to Maturity stage	From Maturity to Decline stage	Non Managerial Controllability
Technology	* Technological Novelty/ Turbulence * Degree of Uncertainty for Technological Performance	* Network Externalities (Installed Base / Complementary Goods)		
Market		* Degree of Market Competition	* Potential Substitute Products	* Legal and Social Influence * Government Policy
Firm	* Financial Endurance * Capacities in R&D	* Absorptive Capacity	* Intensive Financing Abilities	

3.2.4 Non Managerial Controllability

For the product life, some factors are controlled within the firm, while others can be partly controlled, or are not under the control of management at all. The non managerial controllable factors including regulation, government's subsidy policy and other social influences (Lilien and Yoon, 1989) could strongly impact the new product's life cycle (Keoleian, 1993).

Restriction of Hazardous Substances Directive (RoHS) and the emission standards in the EU are good regulation examples of this. RoHS restricted the use of the six substances like lead (Pb), mercury (Hg), cadmium (Cd), hexavalent chromium (Cr^{6+}), polybrominated biphenyls (PBB), and polybrominated diphenyl ether (PBDE) due to their environmental hazards, taking effect on 1 July 2006. As a consequence, the productions of nickel-cadmium (NiCd) batteries have dramatically shrunk while the growth of lithium batteries has rapidly accelerated.

In addition, new emissions standards forced auto manufacturers to develop hybrid electric vehicles or electric vehicles, leading to the promotion of lithium batteries. These regulations not only brought the growth of lithium batteries forward, but also shortened the lifetime of NiCd batteries.

Ⅳ. Illustrative Application

In this section, we apply the proposed framework to an illustrative case to show how valuators can estimate the lifetime of a technology in consideration of the critical factors. In this example, we will value the light emitting diode (LED) backlight unit (BLU) technology for the liquid crystal display (LCD) TV which was developed by the firm that had developed and commercialized the cold cathode fluorescent lamp (CCFL) backlight. In order to value the technology, we estimate the economical lifetime of the product adopting the new technology. First, we analyze the substitute products, the LCD

TV adopting the cold cathode fluorescent lamp (CCFL) backlight unit. Second, it is required for valuators to consider the critical factors to adjust the economical lifetime of the LCD TV adopting LED BLU technology at the present time of the valuation. Finally, we obtain the important information such as growth rate and market size which may be useful to estimate the sales.

4.1 Life Cycle Analysis for the LCD TV with Conventional BLU (Substitute Product)

The pattern of global shipments of two types (Conventional BLU, mainly CCFL and LED BLU) of the LCD TV is described in Fig. 4. Shipment data were obtained from several sources, including Displayserarch, ISuppli, Digital Times, Gartner, etc. In order to investigate the product life cycle, we fitted the data to polynomial functions by using origin 7 software.

Four different stages in the life cycle of the LCD TV with conventional BLU were identified. The introduction stage covered the first 6 years (1999-2004), followed by another 3-year growth stage (2005-2007). After the growth stage, the maturity stage (2008-2010) began in the 10th year and finally it entered into the decline stage in the 12th year (2011-2012). It could be seen that the period of the decline stage is about 2 year. Consequently, we concluded that the economical lifetime of the LCD TV with conventional BLU (substitute product) was 13 years.

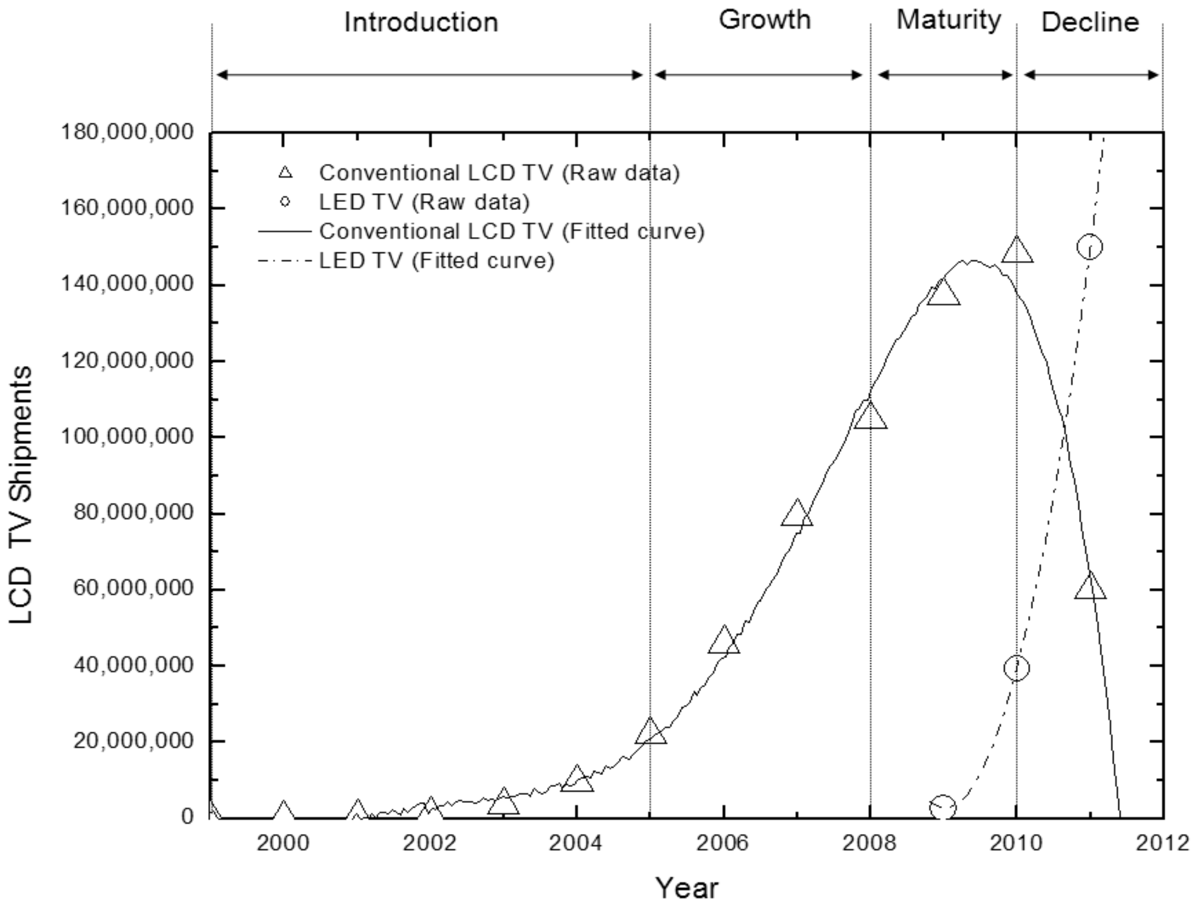

Figure 4. Global Shipments of the Conventional LCD TV and the LED TV

4.2 Life Cycle Analysis for the LCD TV with LED BLU

On the basis of the result of section 4.1, we estimated economical lifetime for LED TV. In this analysis, we selected the year of 2008 as the time period for our valuation.

4.2.1 From Introduction to Growth Stage

Except for the BLU technology, the technology of the LED TV was very similar to that of the conventional LCD TV. Hence, several technologies of conventional LCD TV could be used to develop the LED TV. The degree of uncertainty for technological performance in the LED BLU market was expected to be small since many kinds of LED products had been developed before 2008. The market uncertainty of the LED TV was estimated to be smaller than that of the conventional LCD TV since the market size of LCD TV was expected to increase during 2009 to 2015 according to the DisplaySearch. the firm developing LED BLU had sufficient R&D capacity (qualified R&D researchers) and secured funds (net profits for past 3 years). Comprehensively, we estimated the period from growth to maturity stage of the technology to be 3 year (2008-2010).

4.2.2 From Growth to Maturity Stage

There were several technological reasons for the delay in popularization of the conventional LCD TV such as the large area manufacturing technology and the digital broadcasting system. In the year of 2008, such technological difficulties were mostly solved. The degree of competition in the market of the LED TV was estimated to be similar to that of the conventional LCD TV. Firms in the LCD TV industry including the LED technology-owned company had sufficient absorptive capacity because of the similarity between the technology of the LED TV and that of the conventional LCD TV. Comprehensively, we estimated the period from growth to maturity stage of the technology to be 2 year (2011-2012).

4.2.3 From Maturity to Decline Stage

An organic light-emitting diode (OLED) display had attracted much attention because of its higher performance characteristics than those of a conventional LCD, such as an excellent image quality, its light weight and a thinner panel. OLED TV were introduced by Sony Corporation in December 2007, and became the preferred display technology among scholars and analysts. However, their production is still limited because of technological problems. If such technological problems were solved, OLED TV will become the new leader in the TV industry (Tseng et al, 2009; Hiroshige et al., 2010; Ho et al., 2011). According to DisplaySearch, the market for OLED TV will reach 2.33 million units in 2013. The company was able to raise a vast amount of capital from outsiders. It proved the company could have the financial capacity to compete with its competitors. Comprehensively, we estimated the period from maturity to decline stage of the technology to be 1 year (2013).

4.2.4 Non Managerial Controllability

The regulation of the transition to digital television has significantly influenced the sales of LCD TV. The timeline for stopping analogues services was expected by 2015 when the Geneva 2006 Agreement was set. The European Commission has designated 2012 as the year by which analogue terrestrial TV transmissions will cease in Europe. Thus, many experts predicted that the regulation would affect the LCD TV market positively. Many countries planned to complete the transition to digital service by 2012 which would extend the product lifetime of the LCD TV. Consequently, we added 1 year in the transition from maturity to decline stage.

Table 2. Lifetime of LED TV and Important Parameters

Stage			Intro.		Gro.		Mat.		Decl.	NOTE
Conventional LCD TV (CCFL BLU)			6yrs (99-04)		3yrs (05-07)		2yrs (08-09)		2yrs (10-12)	13 years (99-12)
Dim	Critical Factors									
Tech	Technological Novelty/Turbulence		-1							High similarity to conventional LCD TV
	Degree of Uncertainty for Tech. Performance		-2							Low uncertainty
	Network Externalities				-1					Digital broadcasting system available
Market	Degree of Market Competition				0					
	Potential Substitute Products						-1			OLED TV
Firm	Financial Endurance		0							Net profits for 3 yrs
	Capacities in R&D		0							Qualified R&D people
	Absorptive Capacity				0					Previous experiences in conventional LCD TV
	Intensive Financing Abilities						0			Previous financing experience
N.M.C.	Government policy						+1			Digital television transition
LED TV (LED BLU)			3yrs (08-10)		2yrs (11-12)		2yrs (13~14)		2yrs (15-16)	9 years (08-16)
RATE (%)		172.9		53.3		14.4		-59.6		
MARKET SIZE (Mil.)		9.5		79.3		137.2		148.4		

V. Conclusion

Usually, an official technology valuation is carried out based on the technology which is located after R&D stage (Park et al., 2010). Consequently, although a number of technology valuation methods are already available, the income approach is a widely accepted method used to value a technology in practice. For the income approach including discounted cash flow (DCF), estimating the lifetime of a technology is the first critical step in the whole process.

Much research on quantitative techniques has been conducted via patent information. The main reason for this may come from a longstanding misconception that the more quantitative a model, the better the valuation. For the valuator, the quantitative techniques have principally no interconnections with other important factors which should be considered. Dissel et al. (2005) emphasized on qualitative aspects of valuation and proposed that these techniques generally attempted to structure reasoning and serve as an aid to decision makers in shaping their judgement.

This study is consistent with the review of literatures. That is, qualitative techniques should be utilized to estimate lifetime of a technology. Yet, little is known about how approaches are applied. Thus, this paper aimed to establish a structural framework of estimating the lifetime of a technology by integrating the outputs of an analysis of the determinants in each transition of a product life cycle. The framework enables valuators and experts to estimate lifetime logically. Additionally, the important parameters such as growth rate and market size are provided to estimate sales. This information also enables them to assess the sales forecast.

Finally, the framework is embedded with various organizational capacities which can play a most important role in determining the lifetime. Even though the proposed framework practically contributes a practical way to estimate lifetime in technology valuation, it is an exploratory attempt and thus subject to limitations. First, adjustment factors such as intensive financing abilities may not be critical due to the outsourcing and the factors based on experts' judgements need subjective reviews. Second, further research is required to decide the length of decline stage.

References

Agarwal, R. and D. B. Audretsch (2000), "Does entry size matter?: The impact of the life cycle and technology on firm survival," *Journal of Industrial Economics*, 49, 21-43.

Brighi, P. and G. Torluccio (2010), "Traditional and R&D investments: are they really different?" In *New Issues in Financial Institutions Management*, Palgrave Macmillan

Chen, J., R. Reilly, and G. Lynn (2005), "Uncertainty: Is it a threat or opportunity for new product development teams?," *Institute for the Study for Business Markets working paper series.*

Chiu, C.-L. and K.-H. Chen (2008), "A high accuracy current-balanced control technique for LED backlight," IEEE Power Electronics Specialists Conference, 4202-4206.

Cohen, W. and D. Levintal (1990), "Absorptive capacity: a new perspective on learning and organization," *Administrative Science Quarterly*, 35, 128-152.

Dissel, M., Farrukh, C. J. P., Probert, D. R., and R. Phaal (2005), "Evaluating early stage technology valuation methods: what is available and what really matters," 2005 IEEE International Engineering Management Conference, 11-13.

Elfring, T. and W. Hulsink (2003), "Networks in entrepreneurship: The case of high-technology firms," *Small Business Economics*, 21, 409-422.

Ernst, H. (1997), "The use of patent data for technological forecasting: The diffusion of CNC-technology in the machine tool industry," *Small Business Economics*, 9(4), 361-381.

Filippini, R., L. Salmaso, and P. Tessarolo (2004), "Product development time performance: Investigating the effect of interactions between drivers," *Product Development & Management Association*, 21, 199-214.

Golder, P. N. and G. J. Tellis (2004), "Growing, growing, gone: Cascades, diffusion, and turning points in the product life cycle," *Marketing Science*, 23(2), 207-218.

Griffin, A. (1997), "Modeling and measuring product development cycle time across industries," *Journal of Engineering and Technology Management*, 14, 1-24.

Haupt, R., M. Kloyer, and M. Lange (2007), "Patent indicators for the technology life cycle development," *Research Policy*, 36, 387-398.

Hiroshige, Y., S. Higashi, K. Matsumoto, and S. Miyazaki (2010), "Formation of High-Quality SiO2 and SiO2/Si Interface by Thermal-Plasma-Jet-Induced Millisecond Annealing and Postmetallization Annealing," *Japanese Journal of Applied Physics*, 49, 08JJ01.

Hirschey, M. and V.J. Richardson (2001), "Valuation effects of patent quality: A comparison for Japanese and U.S. firms," *Pacific-Basin Finance Journal*, 9, 65-82.

Ho, M.-H., C.-Y. Wub, T.-M. Chen, C. H. Chen (2011), "Efficient and color-saturated inverted bottom-emitting organic light-emitting devices with a semi-transparent metal-assisted electron injection layer," *Journal of Luminescence* 131, 78–82.

Keoleian, Gregory A. (1993), "The application of life cycle assessment to design," *Journal of Cleaner Production*, 1(3-4), 143-149.

Klepper, S. (1996), "Entry, exit, growth, and innovation over the product life cycle," *The American Economic Review*, 86(3), 562-583.

Kumar, S. K. S., D. Myers, and D. Enke, (2004), “Valuation approaches for technology transfer: A review,” *Proceedings of the 2004 ASEM 25th National Conference,* Alexandria, Virginia, 613-620.

Lilien, G. L. and E. Yoon (1989), "Determinants of new industrial product performance: A strategic reexamination of the empirical literature," *IEEE Transactions on Engineering Management*, 36(1), 3-10.

Lilien, G. L. and E. Yoon (1990), "The timing of competitive market entry: An exploratory study of new industrial products," *Management Science*, 36(5), 568-585.

Mahajan, V. and E. Muller (1996), "Timing, diffusion, and substitution of successive generations of technological innovations: The IBM mainframe case," *Technological Forecasting and Social Changes*, 51, 109-132.

Nickell, S. (1996), "Competition and corporate performance," *Journal of Political Economy*, 104(4), 724-746.

Norton, J. A. and F. M. Bass (1987), "A diffusion theory model of adoption and substitution for successive generations of high-technology products," *Management science*, 33(9), 1069-1086.

Park, Y and G. Park (2002). “A new method for technology valuation in monetary value: Procedure and application," *Technovation*, 24, 387-394.

Park, H. W., D. B. Nah, and S. H. Yoo (2010), "The influence of technological attributes on technology valuation in Korea," Advanced Management Science (ICAMS), 2010 IEEE International Conference, 413-417.

Popper, E. T. and B. D. Buskirk (1992), "Technology life cycles in industrial markets," *Industrial Marketing Management,* 21, 23-31.

Peres, R., E. Muller, and V. Mahajan (2010), "Innovation diffusion and new product growth models: A critical review and research directions," *International Journal of Research in Marketing*, 27(2), 91-106.

Reilly, R. F. and R. P. Schweihs (1998). *Valuing intangible assets*, McGraw-Hill.

Schilling, Melissa A. and M. Esmundo (2009), "Technology S-curves in renewable energy alternatives: Analysis and implications for industry and government," *Energy Policy*, 37(5), 1767-1781.

Tatikonda, M. V. and S. R. Rosenthal (2000), "Technology novelty, project complexity, and product development project execution success: A deeper look at task uncertainty in product innovation," *IEEE Transactions on Engineering Management*, 47(1), 74-87.

Trajtenberg, M. (1990), "A penny for your quotes: Patent citations and the value of innovations," *RAND Journal of Economics*, 21(1), 172-187.

Tseng, F.-M., A.-C. Cheng, and Y.-N. Peng (2009), "Assessing market penetration combining scenario analysis, Delphi, and the technological substitution model: The case of the OLED TV market," *Technological Forecasting and Social Change*, 76, 897–909.

Ughetto, E. (2008), "Does internal finance matter for R&D? New evidence from a panel of Italian firms," *Cambridge Journal of Economics*, 32(6), 907-925.

Van Triest, S. and W. Vis (2007), "Valuing patents on cost-reducing technology: A case study," *International Journal of Production Economics,* 105(1), 282-292.