A Valuation Method for Defense Technology: Procedures, Detailed Modules and Application

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Abstract
Technology valuation is an essential element in increasing efficiency in national R&D investment in terms of invigorating technology commercialization and transfer. Even if vigorous research activities had been conducted for developing a valid method of technology valuation in each technology category to date, there have been at most rare trials to develop an appropriate valuation method for public technology possessing intrinsic public benefit. Defense technology, a representative sector of public technology, provides unique value for the public by enhancing security and defense. This public benefit is as important as its economic value when estimating total technology value. Thus, developing a new method of valuating individual defense technology is required to prevent its underestimation. The main objective of this research is to develop an overall framework and detailed procedures to valuate defense technology in monetary terms through an exemplary case. We propose a DCF based method to calculate economic value for defense technology and a cumulative weighting approach to take the public benefit of defense technology into account when determining total valuation.

Keywords: Technology Valuation, Defense Technology, Public Benefit, Technology Market, Technology Transfer

1. Introduction

Following upon the assertions by Solow (1956; 1957) that the critical success factor of American economic well-being is the advancement of technology through sufficient investment, Jamison and Jansen (2001) added the proviso that the efficiency of R&D investment is more important than absolute increases in R&D expenditure. One of the main goals of Korean national R&D policy is to maximize economic outcomes through greater effective utilization of nationally funded technology development. Technology commercialization and technology transfer are considered to be effective means to accomplish economic value creation through national R&D investment. To boost technology commercialization and transfer, developing well-organized infrastructure and policy to deal with technology trading is necessary. Technology valuation, most crucial element for evaluating technology transfer under the system developed by Barry (2000), can be generally defined as a process for estimating the monetary value of technology. Technology valuation has several useful functions in the technology market. First, the technology valuation result serves as an initial trade value of the technology in the technology market and acts as a common language to bridge the gap between technology owners and technology seekers

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for commercial application. Second, technology valuation provides policy makers with a tool to make more economically rational decisions (Ahlstrom & Garud, 1996). Third, technology valuation assists the selection of appropriate technology that has the potential to translate limited capital resources into maximum competitive advantage by increasing the efficiency of investment for technology development (Lowe et al., 2000). Farrell (1993) observed that technology valuation is a systematic process that must be consistently applied to ensure that the most optimal technologies are chosen.

In this context, Park and Park (2004) asserted that there has been growing recognition that the worth of a commercial enterprise cannot be gauged without assessing the value of technological assets. However, Park and Park (2004), following upon previous research conducted by Tipping et al. (1995), Kash (1997), Boer (1999) and Boer and Traps (1998), also pointed out that technology valuation is not a science but an art. As such, estimating the monetary value of each technology is so complex that developing a highly reasonable valuation method is essential. This, in turn, necessitates the development of the objective and rational technology valuation method for each technology category, not only to vitalize the technology market but also to effectively allocate national R&D funds to each project.

There has been meaningful research for developing an adequate method of valuation for each technology sector to apply its own characteristics in the method to date. However, even if public technology has a different value structure from commercial technology, there is insufficient effort to develop a reasonable method for valuating public technology. Public technology that is developed by governmental funding from national budgets has not only economic value but also intrinsic value for the public benefit.

Robert et al. (2007) emphasized the noble role of technology in human progress. Echeverria (2003) conducted research to classify the value subsystems of technology and claimed that the most important value in the subsystem of technology is about basic values such as life, health, survival, happiness, luck, confidence, well-being, etc. Bozeman and Sarewitz (2005) opined that science and technology hugely influence public values in ways that are independent of the marketplace. Should intrinsic social value in the technology valuation process be overlooked, the total value of public technology, which is intended to serve the public through non-economic criteria, can easily be underestimated. Defense technology, which is an exclusive domain of public technology in Korea, consumes a significant share of national R&D budgets and commercialization and technology transfers can increase their efficiency. A relevant technology valuation method, as a common language of transaction, is an essential element to pursue that goal. In this context, the main purpose of this research is to develop an overall framework and detailed procedure to valuate defense technology as a representative of public technology with monetary value. This paper will do so through the introduction of a representative case.

2. Overview of Technology Valuation

Boer (2002) asserted that the valuation process is a laborious yet critical process and Kukrus and Antonova (2005) concluded that the significance of valuation is heightened by rapid changes in knowledge based societies. Not surprisingly, the growing impact of vitalizing technology transfer and commercialization since the 1990’s has increased the attention paid to technology valuation.

Technology valuation is different from technology assessment, which estimates the strategic value of technology or enterprise as a score or index. According to the research of Smith and Parr (1994), technology valuation is a process to estimate fair market value, which is not only different from market price but also varies with the objective of valuation, i.e., analysis of technological excellence, economic potential and business opportunity.

There are basically three well known approaches for the valuation of technology: cost, market and income. Mildred (2004) analyzed advantages and disadvantages of each approach. A fourth approach, real option, has become the latest.

The cost approach is based on the fundamental economic assumption that neither buyer nor seller of an asset is willing to pay more than the cost of creating or replacing the asset. The cost approach thus typically falls into two different types, namely, reproduction cost and replacement cost, both of which take into account depreciation and obsolescence. This approach has the advantage of simplicity and ease of application. However, the cost approach, as it merely takes past investment data into account in valuation, is unable to capture future economic benefit and ignores the potential of the technology. More appropriate is the market approach, which employs case analysis of similar transactions in the market to generate technology value. Although a relatively simple and reasonable method, applying it is hard if data of similar technology-transfer transactions are not available. Another approach is the income approach, which is based on the discounted cash flow (DCF) method in which the value of technology is measured by the net present value over the lifespan of the technology. As the income approach is most commonly used incorporating measures of the real value of technologies, patents, trademarks, copyrights and other technology-related factors into the value of the technology transfer contract appears reasonable. However, doing so would increase the probability that some errors could be introduced due to its subjective estimation of major parameters. The real option approach, an extension of the income approach, is gaining growing attention these days due to its flexibility. This approach, borrowed from stock valuation, applies uncertainty to valuation with the accommodating power of decision making proposed as by Black and Scholes (1973). Recently, Jason et al. (2008) proposed the real option model of R&D valuation for the pharmaceutical industry. With respect to variability, contingency, and flexibility, the real option approach is quite useful. However, the market approach is not feasible for defense technology valuation because it is extremely difficult to gather previous defense technology valuation transaction data. Most defense technology is classified confidential or secret for national security. In terms of cost approach, the current defense technology valuation method based on cost approach faces several inter-workability issues with other sectors' technology regarding technology transfer and commercialization. In order to overcome these drawbacks, Jang et al. (2007) developed a defense technology valuation method based on the income approach. However this method is limited to defense offset technology acquisition. Jang and Lee (2010) also developed an extended model based on the income approach, this time without being restricted to the defense domain. However, these two models do not take intrinsic public value of defense technology into account. Accordingly, in this paper we propose a valuation method based on the income approach that can be generally applicable to every defense technology, takes public benefit into account to fortify the commercialization and transfer of defense technology, and interfaces with other sectors' technology.

3. Overall Framework of Valuation for Public Technology

3.1 Requirement for and Basic Concept of a Valuation Method for Public Technology

Generally, the dominant criterion in calculating technology valuation is the degree of potential economic value generated commercialization. However, public technology in the areas of defense, energy, aerospace, health and environment produces social utility in addition to economic value estimation. Public technology is intellectual property developed by national R&D funding and has its own intrinsic purpose. Unless this value of public technology is accounted for in the valuation process, the valuation result of valuation may very well be underestimated. For example, a technology that has limited promise to generate economic value in the future but is expected to contribute significantly to society will have limited value if judged by existing valuation methods. Clearly, this is suboptimal and may even defeat the very purpose of national R&D, which is the promotion of the public good. If public utility is not considered, the valuation result for public technology will not be socially acceptable. Thus, development of a new valuation method for public technology is necessary to accommodate the value of public benefit.

In this paper, we propose a valuation method for defense technology which is highly representative of public technology. Defense technology has a manifest public benefit and we designed a valuation method for defense technology in which it is possible to valuate public benefit by estimating its relative importance to the economic value calculated by income approach.

3.2 Overall Procedure of Valuation for Public Technology

The overall procedure of the valuation method for public technology consists of three basic steps as shown below Table 1. The first step is to confirm the validity of valuation prior to the commencement of full-scale of valuation. This determines whether valuation is needed in the first place. The second step estimates the value of technology in terms of both economic and public benefit. To estimate the economic value of technology, we use DCF (Discounted Cash Flow) based on the income approach. By using DCF, the economic value of public technology is calculated in monetary terms over its economic lifespan. In terms of calculating public benefit, we developed a new procedure as shown below Table 1 (third column). The first three stages in step 2 (shown in gray), ① defining the public benefit of the particular technology to be evaluated, ② developing the valuation criteria, and ③ determinate the relative weight, are preparation phases.

Once these preparatory phases are done, we can obtain the value of public benefit as a share of total value through evaluation by an expert panel. The final step is to combine economic value and public benefit. We developed the cumulative weighting method to integrate these two different elements of technology value.

3.3 Mathematical Valuation Model for Public Technology

Following the overall procedure outlined above in Table 1, valuating public technology apart from general commercial technology becomes possible. However, now the formulation of a mathematical model to conduct the practical calculation of total

Table 1 Overall procedure of valuation method for public technology

Contents	Economic value	Value of public benefit
Step 1	Analysis of the valuation adequacy (Pre-valuation)	
Step 2	Estimation of economic lifespan of technology ↓ Estimation of future cash flow ↓ Calculation of discount rate and application ↓ Calculation of technology contribution rate and application ↓ Calculation of total economic value	Definition of public benefit ↓ Development of valuation criteria of public benefit ↓ Determination of the relative weight of public benefit ↓ Decision of applicable public benefit ↓ Valuation of public benefit by expert group ↓ Calculation of multiplier of public benefit
Step 3	Calculating total value of each technology (economic value + public benefit)	

value by integrating both economic and public benefit value is required. We developed equation (1) below to estimate the total value of public technology in monetary term by combining economic value and the value of public benefit where TV is the total value, EV is economic value, and PV is value of public benefit. We can derive the total value of the public technology by integrating economic value and public benefit using the relative weight of each.

$$TV = EV \times (1 + PV) \quad (1)$$

To estimate each value, equation (1) is decomposed into two parts; EV and PV. First of all, EV is developed through equation (2), which is based on DCF with FCF (estimated future cash flows of j product at time i), N (estimation period, Economic lifespan of technology), T (number of technology products), TW (technology weight, technology contribution ratio), WACC (weighted average cost of capital, discount rate), and k (idle period of technology). We designed EV to accommodate multiple technology products and idle period before commercialization. This equation makes possible the estimation of the economic value of technology over its lifespan.

$$EV = \sum_{j=1}^{T}\sum_{i=k+1}^{N} \frac{FCF_i^j}{\left(1+WACC_i^j\right)} \times TW^j \quad (2)$$

Second, it is possible to estimate the value of the unique public benefit that the technology provides through equation (3) where PV is public benefit value, N is the number of applicable public benefits, M is the number of evaluation criteria, A* is the relative weight of public benefit i to economic value, W is the weight of the evaluation criteria i, E is the evaluation result (score) assigned by an expert group for evaluation criteria i, and P is the maximum score of evaluation criteria i.

$$PV = \sum_{j=1}^{N} A_j^* \sum_{i=1}^{M} \frac{W_i E_i}{P_{ji}} . \quad (3)$$

The above outlines the overall concept of the process to estimate the total value of a specific public technology. However, each of the elements in equation (2) and (3) requires further detailed explanation for practical calculation. To promote understanding, we present the practical valuation method for defense technology, a representative of public technology, in the following sections.

4. Detailed Valuation Method for Defense Technology

4.1 Analysis of the Valuation Adequacy (Pre-valuation)

Technology valuation is not merely a simple calculation of numbers but a harmonized balancing process between qualitative analysis and quantitative estimation. Analyzing the valuation adequacy of technology is essential before commencing the practical valuation task in detail. The analysis of the valuation adequacy as a pre-valuation step is a screening process to determine whether a detailed valuation task is needed. Critical analysis factors for the analysis of the valuation adequacy are along the lines outlined in Table 2. The analysis of the valuation adequacy covers a range from aspects from technical to security via perspectives of marketability, commercialization, defense industry and military power. According to the result of this pre-valuation, the real valuation process commences after the processes outlined in sections 4.2 and 4.3.

4.2 Economic Value Calculation for Defense Technology

Generally, economic value is the core element of commercial technology valuation in terms of technology commercialization and trade. Even in the defense sector as a public domain, economic value is the kernel of the total value of defense technology. The procedure for estimating the economic value of defense technology follows along the lines outlined in Table 3.

4.2.1 Estimation of Technology Lifespan

Estimation of technological lifespan is conducted

Table 2 Critical factors for the analysis of valuation adequacy

Factor	Content	Material
Technology	• Definition, contents and scope • Application field and organization • Similar tech. domestically & internationally • Controversy over development of technology • Uniqueness and excellence • Potential life cycle, etc.	• Report on Defense R&D plan or result • Defense Technology Roadmap (classified) • Defense R&D Planning Guidebook (classified) • Defense S&T issue paper • Jane's Paper
Marketability	• Applicable weapon systems & components • Total market size of technology • Competitive dynamics • Level of market saturation • Estimated possible revenue analysis • Cost analysis, etc.	• International reports on defense market analysis • Forecast International • Defense Core Tech. Planning Guidebook (classified) • Jane's Paper • SIPRI reports
Commercialization	• Producer R&D ability & status • Producer's financial status • Producer's managerial status	• Producer's business plan • Historical data regarding technology commercialization
Defense industry	• Analysis of localization & utilization • Analysis of defense employment change	• DAPA reports • KDIA reports, etc.
Military power	• Effect on defense capability enhancement • Satisfaction level of defense capability requirements	• JSOP / JMS (classified) • Project Analysis Reports
Security	• Impact on security improvement	• Relevant report regarding national security

Table 3 The procedure for estimating the economic value of defense technology

Step	Task	Content
Step 1	Estimation of technology lifespan	General lifespan considering specific factor
Step 2	Estimation of revenue	Annual market size × market share
Step 3	Estimation of cost structure	Development of standard income sheet
Step 4	Calculation of discount rate	WACC + MLRP[1)] + SRP[2)]
Step 5	Calculation of technology contribution rate	Tech. weight × deg. of transfer × deg. of completion
Step 6	Calculation of economic value	Net present value

over 3 steps using equation (4); ① estimation of average lifespan of the same technology group through expert survey, ② derivation of adjustment factor and idle period, and ③ final calculation of lifespan for the technology undergoing valuation where LT is the lifespan of the technology, GLT_UL is the upper value of general lifespan of the defense technology, GLT_LL is the lower value of the general lifespan of the defense technology, AF is the adjustment factor, which has a value between 0 and 1, and IP is the idle period for preparation of mass manufacturing and sales.

$$LT = [(GLT\_UL - GLT\_LL) \times AF] + GTL\_LL + IP \quad (4)$$

The general lifespan of defense technology in the same technology group is derived by a 95% confidence interval of the expert survey result. The adjustment factor is also surveyed by an expert group through a questionnaire concerning technological validity, economic performance and contribution to the defense industry, military power and security. Actually, we developed 17 questions using the Delphi method among defense experts. However, we have not included the details here because the main purpose

1) MLRP: Market Launching Risk Premium
2) SRP: Scale Risk Premium

of this paper is to propose an overall procedure and method for defense technology valuation.

4.2.2 Estimation of Revenue

Estimation of revenue is the most critical factor in the total process of technology valuation as the most fundamental data to derive economic value. Revenue can be estimated in 3 steps; ① estimation of annual market size for each technology product, ② derivation of annual market share, and ③ final calculation of annual revenue. To estimate annual market size systematically, we use a logistic model developed by Oliver (1987) and generally applicable even with small amounts of data. We use the general mathematical model of logistic function and OLS (Ordinary Least Square) method using the following equations. However, we are still open to the use of the simple CAGR[3)] method. Estimation of annual market size through the logistic model is performed by the following equations where N_t represents the cumulative purchasers at time t, n_t is the sales rate or market need in the period, M is the market potential, and a and b are factors for growth.

$$N_t = \frac{M}{1+e^{(a+at)}} \tag{5}$$

$$n_t = \frac{dN_t}{dt} = \frac{-Mbe^{(a+bt)}}{1+e^{(a+bt)^2}} \tag{6}$$

$$\ln\left[\frac{M-N_t}{N_t}\right] = a+bt+\varepsilon_t \tag{7}$$

To estimate annual market share, we assume that market share linearly increases to the maximum point during the lifespan of the technology from the initial point and decreases to the minimum point at the end of lifespan thereafter. We developed a triangular function which has minimum market share on the left and right vertices, and maximum market share lies at some point between the two ends. The graphical view of the triangular function is illustrated by Figure 1

Derivation of expected maximum and minimum market share and duration to accomplish maximum share of technology products over their lifespan to calculate annual market share is required. We are still open to using simple growth rate α and decrease rate β in cases where data is limited. To calculate annual market share in practical terms, we use equation (8) below where s_t is the market share at time t, R_m is the maximum market share, R_n is the minimum market share, t* is the duration for accomplishing maximum market share, T is the Lifespan of technology, α is the rate of increase in market share and β is the rate of decrease in market share.

$$s_t = \left\{ \begin{array}{l} \left(\frac{R_m - R_n}{t^*}\right)t + R_n, 0 \le t \le t^* \\ \left(\frac{R_n - R_m}{T - t^*}\right)\left(t - t^*\right) + R_m, t^* < t \le T \end{array} \right\}. \tag{8}$$

Finally, we calculate annual revenue for each product by multiplying total market size by share, which can be obtained through the equations above. Generally, to generate more revenue, a larger market size and share are required.

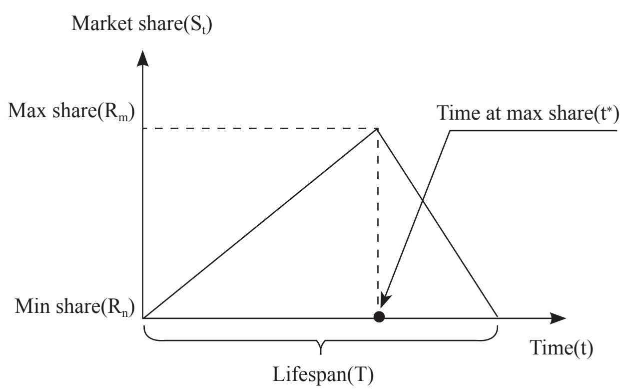

Figure 1 Graphic view of the triangular function for market share calculation

3) CAGR: Compound Annual Growth Rate

4.2.3 Estimation of Cost Structure

Estimation of the cost structure is the process used to calculate net income from estimated annual revenue. We designed the valuation method for defense technology with the standard cost structure. To obtain the standard cost structure of the defense industry in Korea, we analyzed the official financial statements of 55 representative defense companies such as income statements which are possible to obtain from the Financial Supervisory Service, the governmental organization for financial oversight. We developed the standard cost structure of the Korean defense industry based on enterprise size[4] ; ① COGS (88% of sales), SG & A (2% of sales) for companies exceeding 1,000 billion KRW in assets, ② COGS (90% of sales), SG & A (3.5% of sales) for companies in the asset range between 100 billion KRW and 1,000 billion KRW, and ③ COGS (91% of sales), SG & A (5% of sales) for companies with assets totaling less than 100 billion KRW. We use secondary comparable firms for depreciation, net working capital, and capital expenditure on a case by case basis and refrain from using standard cost structure. We can obtain FCF (Future Cash Flow) by subtracting the cost structure from estimated annual revenue through the following equation.

$$FCF = EBIT(\mathrm{R}evenue - COGS - SG\&A) \\ - Tax + Dep. - NWC - CE - Miscellaneous \tag{9}$$

4.2.4 Calculation of Discount Rate

Defense technology has more risk than commercial technology due to market limitations inherent to the defense industry, governmental regulations, political issues, etc. The discount rate for defense technology can be derived by the summation of WACC, MLRP and SRP. First, WACC is estimated by equation (10) below, which is clearly defined in the corporate finance textbook by Ross et al. (2010). WACC is Weighted Average Cost of Capital, E is the market value of equity, D is the market value of debt, V is the market value of the firm, r_e is the cost of common stock, r_d is the cost of debt, t is the firm's marginal tax rate, R_f is the risk-free rate, r_m is market-wide risk rate, rf is the firm-specific risk rate, $[E(r_m)-r_f]$ is the market-risk premium, and β is the slope coefficient in an OLS regression of stock returns on market returns. In calculating β in equation (10), we consider both equity beta and asset beta to take the leverage effect into account[5] in cases where comparable firms are used.

$$WACC = \frac{E}{V}r_e + \frac{D}{V}r_d \times (1-t)$$

$$r_e = R_f + \beta[E(r_m) - r_f] \tag{10}$$

$$\frac{E}{V} + \frac{D}{V} = 1$$

Second, we designed an expert survey to derive MLRP (Market Launching Risk Premium) with 8 questions on a 5-point Likert scale regarding market risk (5 questions), military power risk (2 questions), and security risk (1 question). According to the results of expert evaluation, MLRP is applied to the valuation process in a range from 0.5% to 10%. Third, according to the size of the firm intending to undertake technology commercializing, we apply a selective SRP (Scale Risk Premium).

4.2.5 Calculation of Technology Contribution Rate

The technology contribution rate determines the extent to which technology contributes to generating economic value through technology commercialization. Practically, one-third rule, one-fourth rule and rule of thumb are general methods to measure the contribution rate of technology over total value creation. However,

4) In terms of corporate tax, 20% for over 0.2B KRW of EBIT and otherwise 10% regardless of firm's value

5) Necessary formula : $\beta_U = \frac{\beta_L}{1+(1-t)\times\frac{D}{E}}$, where β_U : unlevered beta(asset), β_L : levered beta(equity)

we designed a more scientific method that uses the product of technology weight, degree of technology transfer, and degree of technology completion by referring to the technology factor method[6)] developed by ADL and DOW Chemical Company. Technology weight, the first element in the technology contribution rate, is the full-impact of technology on economic value creation; the other two elements consider the efficiency of influence. To increase commercialization of technology, increasing the technology transfer rate and completion is essential. This technology contribution rate is derived on the basis of expert survey with well-defined questions.

4.2.6 Calculation of Economic Value of Defense Technology

We can derive the economic value of defense technology by the product of net present value of estimated future cash flow, subtracting cost from revenue, and technology contribution rate using equation (2) above. If the technology is applicable to multiple products, we can sum the results of reiterations of steps 1 to 6 below for all products.

4.3 Public Benefit Value Calculation for Defense Technology

As already mentioned, one of the most unique characteristics of defense technology is to have a useful public benefit. In this section, we define the nature of the public benefit that defense technology provides and how the extent of that value can be measured. It is almost impossible to measure the monetary value of the public benefit directly as it is not quantitative but qualitative. Accordingly, we developed an indirect approach to measure the public benefit of defense technology, the general form of which has already been described in equation (1) and (3) above. The detailed procedure of estimating public benefit value of defense technology follows the process outlined in Table 4. To undertake the pre-preparation process for estimating the value of public benefit using steps 1 through 3, we practiced expert choice using the Delphi method and relied on 42 experts employed by DTaQ, ADD, KIDA and defense companies in Korea[7)].

4.3.1 Pre-preparation Process of Estimating Value of Public Benefit

A committee formed to develop the defense technology valuation model gathered 21 items through three public value streams of defense technology from the open question process of Delphi of which 18 items were selected for the questionnaire by the final closed question process. Details of the questionnaire with evaluation guideline are presented in Table 5. The committee also agreed on the relative weight of the

Table 4 Procedure for estimating value of public benefit of defense technology

Step	Task	Details
Step 1	Definition of public benefit	A. Value of fortifying domestic defense industry B. Value of strengthening military power C. Value of enhancing security
Step 2	Development of valuation criteria of public benefit	Questionnaire with 18 items: value A (4), value B (7), value C (7)
Step 3	Determination of relative weight of public benefit	A*, relative weight of public benefit to economic value is 1
Step 4	Determination of applicable public benefit	Decision of valuation committee
Step 5	Evaluation of public benefit by expert group	Conducting survey with AHP[8)] method according to decision at step 4 and using the questionnaire at step 2
Step 6	Calculation of multiplier of public benefit	Calculating result of survey at step 5

6) Technology factor method was developed by ADL consulting group and is currently used by the Dow Chemical Company.
7) DTaQ: Defense Agency for Technology and Quality, ADD: Agency for Defense Development, KIDA: Korea Institute for Defense Analyses
8) AHP: Analytic Hierarchy Process

Table 5 Questionnaire to measure public benefit of defense technology

		Very low	Low	Mid.	High	Very high
Q1. Value for fortifying the domestic defense industry						
Q1-1	Localization of weapons & components	5%↓	~10%	~15%	~20%	20%↑
Q1-2	Utilization of domestic defense industry	5%↓	~10%	~15%	~20%	20%↑
Q1-3	Employment in defense industry	10M↓	~20M	~30M	~40M	40M↑
Q1-4	Defense R&D and operational ability	Qualitative evaluation				
Q2. Value for strengthening military power						
Q2-1	Enhancement of firepower	Ref.> Spray penetration, accuracy rate, etc.				
Q2-2	Enhancement of performance	Ref.> Engine output, range, max. speed, etc.				
Q2-3	Enhancement of viability	Ref.> Protective armor, active defense, etc.				
Q2-4	Enhancement of command & control systems	Ref.> Identification of friend or foe, C4ISR, etc.				
Q2-5	Enhancement of reliability	Ref.> MTBF, failure rate, etc.				
Q2-6	Enhancement of maintainability	Ref.> Compatibility, ease of attach & detach, etc.				
Q2-7	Contribution to future military needs	Ref.> NCW, unmanned weapons, low carbon, etc.				
Q3. Value for enhancing security						
Q3-1	Contribution to self-defense	Qualitative evaluation through 5-point Likert scale				
Q3-2	Sea power & control of the air					
Q3-3	Military potential & war potential					
Q3-4	Risk management					
Q3-5	Balance of power					
Q3-6	Power projection					
Q3-7	Deterrent power & retaliation power					

value of public benefit to economic benefit as being 1 (A*) in the survey result.

As we can see from the questionnaire below, the values of fortifying the domestic defense industry, strengthening military power and enhancing security were ultimately selected as the public benefit that defense technology provides to the public. The value for fortifying the domestic defense industry is assessed by using the guidelines with the improvement ratio of each element. The value of strengthening military power is assessed with reference of practically comparable index. The value of enhancing security is assessed through the qualitative evaluation of experts who comprised the valuation committee. Every question in the questionnaire uses the 5-point Likert scale.

4.3.2 Evaluation of Public Benefit for a Specific Defense Technology

We designed the practical evaluation procedure of public benefit for a specific defense technology through three steps; ① determining applicable public benefit, ② conducting expert survey using the AHP method through the developed questionnaire, and ③ calculating multiplier using the results of expert survey. First, the decision-making process from the valuation committee confirms the elements of public benefit. Second, conducting a survey with the developed questionnaire evaluates the value of public benefit derived from defense technology. At this stage, including at least 25 experts for the expert survey is essential to ensure credibility. We use the AHP method to prioritize the elements of public benefit and derive their relative weights. Maintaining a certain level of consistency in the pair-wise comparison in AHP is also important. Accordingly, we prudently developed the questionnaire and conducted the expert survey. Third, we calculated the multiplier for the value of public benefit through equation (3) above. The multiplier is a number between 1 and 0. If the specific technology is given a higher evaluation result in the expert survey, it will be assigned a multiplier closer to 1. The monetary value of the public benefit of defense technology is calculated by the product of multiplier and economic value which has been previously computed.

4.3.3 Calculation of Relative Weight of Each Evaluation Element

The relative weight of the evaluation elements of public benefit will vary not only with each project but also with prevailing national defense policy. Accordingly, we developed a mixed model in computing the final weight of each element of public benefit in order to accommodate these different needs on two levels; general policy level and specific project level.

$$FW_i = \alpha IW_i + \beta PW_i \quad \text{where, } \alpha + \beta = 1 \tag{11}$$

The final weight *(FW)* of the evaluation element *'i'* can be derived from the integrated computation of the initial weight *(IW)* with contribution rate *'α'* to the final weight and project-specific-weight named *'PW'* with contribution rate *'β'*. At this point, the matter now becomes determining the value of α and β. We developed a relevant computation mechanism using the relative importance approach while considering the amount of budget allocation of projects because we thought the greater budget the projects has, the greater possibility of unique needs they are likely to have.

$$\hat{\beta} = \frac{nP_{i \in S}(m)}{S(m)} \tag{12}$$

$$\beta = \begin{cases} 1, & \hat{\beta} \geq 2 \\ \dfrac{\hat{\beta}}{2}, & 0 \leq \hat{\beta} < 2 \end{cases} \tag{13}$$

$$\alpha = 1 - \beta$$

$\hat{\beta}$ is the multiple of the average budget level of total '*n*' projects where *S(m)* is the total sum of the annual project budgets and $P_i(m)$ is the allocated budget of project *'i'*. We can easily obtain *α* after finding *β* value using equation (13).

4.4 Calculating Total Value of Defense Technology

The total value of defense technology is derived by the cumulative weighting method with two value elements, economic outcome and public benefit, through equation (1) above. The estimation procedure of economic value, the left side of step 2 in Table 1 above, is a quantitative calculation method with mathematical tools but the evaluation procedure of public benefit, the right side of equation (1), is a qualitative process for deriving the relative weight of public benefit of defense technology.

5. Exemplar Application

In this section, we introduce one application of defense technology valuation result briefly to demonstrate the procedural effectiveness and practical applicability of the proposed valuation model. The selected defense technology A[9] is owned by one of the major corporations in the Korean defense sector.

5.1 Estimation of Economic Value of Technology A

After confirmation and agreement about the need for a detailed valuation within the valuation committee, the estimation of economic value of technology A was conducted. First, the lifespan of technology A was derived as 17 years through equation (4). We surveyed 25 experts in the defense area and determined the critical factors for estimating the lifespan of technology A; GTL_UL(18.67), GTL_LL(14.21), and the adjustment factor (0.7462). Second, to estimate revenue, we defined two products that have the potential to generate sales through technology commercialization. The estimation of

9) Due to the security reason, we present technology name anonymously

revenue of these two product was conducted through equations (5) ~ (9) with consideration of technology lifespan and standard cost structure. The discount rate was 16.33% based on the calculation factors: WACC (10.33%), MLRP (6%), and SRP (0%). In this case, there was no need to consider β transformation with comparable firms because the eligible firm has its own β. The technology contribution rate was 26.98% with component factor's rates: technology weight (48.40%), technology transfer rate (74.80%), and technology completion rate (74.51%). The final estimation result of the economic value of defense technology A is 4.73 billion KRW. We display the detailed data of calculation result in Table 6 below.

5.2 Public Benefit Value of Technology A

The multiplier of public benefit value was 0.70. We employed expert survey with full questionnaire having 18 questions. We considered not only the weight of each individual question but also the weight of 3 sections. The result is shown in Table 7.

5.3 Total Value of Defense Technology A

We can calculate the total value of defense technology A using equation (1). Finally, 8.04 billion KRW is the calculated total value of defense technology A.

Table 6 Economic value of defense technology A

(Unit; 0.1B KRW)

Year	1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year	9th year	10th year	11th year	12th year	13th year	14th year	15th year	16th year	17th year
Sales	52.42	83.31	148.49	223.45	329.49	473.56	650.12	886.57	1070.58	916.06	566.71	306.22	160.72	84.81	45.47	24.87	13.90
COGS (88%)	46.13	73.32	130.67	196.64	289.95	416.74	572.10	780.18	942.11	806.13	498.71	269.47	141.43	74.63	40.02	21.89	12.23
SG&A (2%)	1.05	1.67	2.97	4.47	6.59	9.47	13.00	17.73	21.41	18.32	11.33	6.12	3.21	1.70	0.91	0.50	0.28
EBIT	5.24	8.33	14.85	22.35	32.95	47.36	65.01	88.66	107.06	91.61	56.67	30.62	16.07	8.48	4.55	2.49	1.39
EBIT* (1-t)	4.19	6.67	11.88	17.88	26.36	37.89	52.01	70.93	85.65	73.28	45.34	24.50	12.86	6.78	3.64	1.99	1.25
Add Dep.	2.82	4.48	7.99	12.02	17.73	25.48	34.98	47.70	57.60	49.28	30.49	16.47	8.65	4.56	2.45	1.34	0.75
Less Cap. Exp	71[10]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Less Inc. NWC	16.48	6.24	21.44	4.32	1.76	5.28	10.4	10.56	-4.96	-17.6	-15.68	-9.44	-5.28	-2.72	-1.44	-0.64	-0.64
Free Cass Flow	-80.47	4.91	-1.57	25.58	42.33	58.08	76.59	108.06	148.20	140.17	91.51	50.41	26.78	14.07	7.52	3.97	2.64
Total Cash Flow	-80.47	4.91	-1.57	25.58	42.33	58.08	76.59	108.06	148.20	140.17	91.51	50.41	26.78	14.07	7.52	3.97	2.64
Discounted Cash Flow	-80.47	4.22	-1.16	16.25	23.11	27.26	30.90	37.48	44.19	35.93	20.16	9.55	4.36	1.97	0.91	0.41	0.23
Total NPV	**175.31**																
Technology weight	**48.40%**																
Technology transfer rate	**74.80%**																
Technology completion rate	**74.51%**																
Technology Contribution Rate	**26.98%**																
Economic Value	**47.29**																

10) We take previous investment (as high as 7.1B KRW) into account

Table 7 Result of expert survey for public benefit value of defense technology A

Question	Weight	Score	Question	Weight	Score	Question	Weight	Score
Q1-1	0.31	4.2	Q2-1	0.21	3.9	Q3-1	0.18	2.1
Q1-2	0.38	4.1	Q2-2	0.18	3.1	Q3-2	0.09	1.9
Q1-3	0.12	3.4	Q2-3	0.17	3.3	Q3-3	0.19	2.8
Q1-4	0.19	3.9	Q2-4	0.19	4.1	Q3-4	0.08	3.3
-	-	-	Q2-5	0.11	4.8	Q3-5	0.21	3.7
-	-	-	Q2-6	0.09	3.8	Q3-6	0.18	2.2
-	-	-	Q2-7	0.05	4.4	Q3-7	0.07	2.4
Q1	0.24	4.009	Q2	0.44	3.807	Q3	0.32	2.686
Score	3.50							
A*	1							
Multiplier	0.70							

6. Application of the Valuation Model

We can categorize the usage type of valuation result depicted in Figure 2 based on the fact that the main purpose of the valuation is technology transfer and commercialization. There are 4 types of applications of the valuation result for public technology. Type A is domestic technology transfer only within public sectors. Type B is domestic technology transfer between the public sector and the private sector. Type C is international technology transfer only within the public sphere. Type D is international technology transfer between the public sector and private sector. As far as the value of public benefit is concerned, the valuation result needs to be applied adaptively according to the type of technology transfer.

In type A transactions, it is necessary to take into account both economic value and the value of public benefit when public technology is to be transferred to other domestic public technology fields. However, redefining the nature of value of public technology is a prerequisite process as the recipient’s public purpose of the technology that is to be transferred is likely to be different from that of the developer’s. For example, when space technology is applied to defense technology, it is natural that the nature of public benefit will likely differ depending on the perspectives and needs of each side and thus a redefinition of the new benefit that is expected to be generated by the technology acquirer is required.

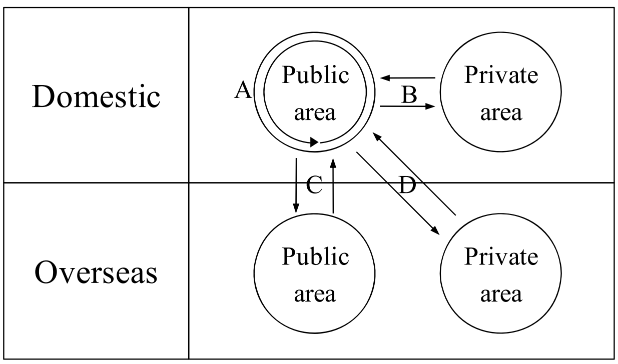

Figure 2 Technology transfer types of public technology

Type C transactions are quite similar to type A as they both need to take into account both economic value and the value of public benefit; however, the nationality of each party of technology transfer is different. Thus, redefinition of the contents of public benefit is required because the potential public benefit generated could differ according to the situation of each nation even though the technology under consideration is the same.

If technology is intended to be transferred from the public sector to the private sector, as is the case of both type B and D transactions, it is desirable to consider only economic value as the negotiation value of technology transfer because even if technology is developed for the purpose of public benefit, the main objective of technology transfer is not new creation of another public benefit but rather commercial gain. However, in reverse transactions from private to public in types B and D, both the value of economic and public benefit should be considered in the valuation because the purpose of technology transfer is strongly related to public benefit.

In sum, the value of public benefit needs to be adaptively applied to the negotiation value of technology transfer of public technology according to nationality and purpose.

7. Conclusion

Even if there had been vigorous research activities for developing a valid valuation method in each technology category, it remains true that there has been insufficient effort to develop a valuation method for public technology that has intrinsic value for the public and funded by national budget. As one representative of public technology, defense technology has intrinsic value for the public through its unique roles of fortifying the domestic defense industry, strengthening military power, and enhancing security. In this paper, we proposed a fundamental valuation framework for public technology. Also, we proposed a practical valuation method for defense technology and presented a representative application to show its effectiveness. The proposed valuation method has the following features: (1) scientific sales estimation method through application of the logistic model for forecasting market size and the triangular function for deriving market share, (2) potential to take the public benefit provided by the technology into account during valuation and thus prevent underestimation of public technology value, and (3) maintenance of balance between qualitative and quantitative valuation of technology in the valuation process. Through this valuation method, valuators can estimate the economic value of public technology more systematically. Furthermore, it is also possible to define the nature and degree of benefit to the public that nationally-funded technology provides. This enlargement of the valuation scope will increase the flexibility and power of decision-making in governmental R&D field.

However, the valuation result concerning the value of public benefit is not always applicable for technology transfer and trade in the real technology market because public benefit is not physically formed. Accordingly, we categorized the transaction types of technology transfer and trading. According to the type of transaction, the public benefit of nationally funded technology can be selectively applied to the total valuation result.

Defense R&D activity is conducted under the noble mission of both increasing defense technological capability to ensure self-defense of the nation and strengthening the defense industry to contribute to national economic well-being. However, defense R&D investment is also popularly acclaimed to be efficient. To make defense R&D cost effective, fortifying technology transfer and commercialization under the concept of open innovation as promoted by Henry Chesbrough (2003) is necessary. In this context, we strongly believe that a new valuation method for defense technology, which is presented in this paper, will significantly contribute to the enhancement of defense R&D efficiency.

For future studies, developing more standardized elements on estimating future cash flow for increasing credibility of the valuation result is recommended. Even if we assumed that the growth function of market share, which has same value at entry and exit, is linear for simplification, considering non-linear functions with different values at entry and exit would probably be more reflective of reality. More fundamentally, if there is no consensus on converting public benefit into economic terms, deriving one single value of public technology will not be particularly helpful. However, the valuation results provided by this model are still useful as it also permits the calculation of both economic and public utility valuation separately.

To support the decision making process of governmental R&D investment, developing a well-shaped and balanced method to evaluate each technology is necessary. However, if public benefit, which is the *raison d'etre* of public technology development projects, is not adequately considered, its value will be underestimated. As the first step to increase the rationality of the valuation process of public technology, this research result will at a minimum stimulate controversial debate and discussions on developing more advanced valuation methods.

References

Ahlstrom, D., & Garud, R. (1996). Fordoottend paths in medicine: The case of the low protein diet in chronic renal failure. In Geneisler, E., & Heller, O. (Eds), Managing technology in healthcare (pp. 154-187). Boston: Kluner Academic Publishers.

Bozeman, B. (2000). Technology transfer and public policy: Areview of research and theory. Research Plicy, 29, 627-655.

Bozeman, B., & Sarewitz, D. (2005). Public values and public failure in US science policy. Science and Public Policy, 32(2), 119-136.

Black, F. and Scholes, M. S. (1973). The pricing of options and corporate liabilities. Journal of Political Economy, 83, 637-659.

Boer, F. P., & Traps, A. (1998). Pitfalls and snares in the valuation of technology. Research Technology Management, 41(5), 45–54.

Boer, F. P. (1999). The valuation of technology. New York: Wiley

Boer, F. P. (2002). The real options solution: Finding total value in a high risk world. New York: John Wiley & Sons Inc.

Chesbrough, H. (2003). Open Innovation: The new imperative for creating and profiting from technology. Boston, Massachusetts: Harvard Business School Press.

Echeverria, J. (2003). Science, technology, and values: Towards an axiological analysis of techno-scientific activity. Technology in Society, 25, 205-215.

Farrell, C. (1993). A theory of technical progress. Technology Forecast and Social Change, 44, 161-178.

Frodeman, R., Klein, J. T., Mitcham, C., & Tuana, N. (2007). Interdisciplinary studies in sciency, technology, and society: "New Directions: Science, Humanities and Policy". Technology in Society, 29, 145-152.

Hastbacka, M. A. (2004). Technology valuation: The "Market Comparables" method. Technology Management Journal, June. 1-4

Hsu, J. C., & Schwartz, E. S. (2008). A model of R&D valuation and the design of research incentives. Insurance: Mathematics and Economics, 43, 350-367.

Jamison, D. W., & Jansen, C. (2001). Technology transfer and economic growth. Industry and Higher Education, 15(3), 189-196.

Jang, W. J., Kim, C. W., Kim, T. Y. & Joung, T. Y. (2007). The defense offset valuation model. DISAM Journal of International Security Assistance Management, 29(4), 91-101.

Jang, W. J., & Lee, C. J. (2010). Defense R&D technology valuation model with income approach. 2010 Proceedings of PICMET '10, 1-11.

Kash, D. (1997). Taking the measure of basic research. Chemical and Engineering News, 20, 30–33.

Kukrus, A., & Antonova, V. (2005). Valuation of intellectual property as pledge object: Theoretical aspects. 13th Scientific Conference on Economic Policy: Berlin-Tallinn, 248-256.

Lowe A., Ridgway K., & Atkinson H. (2000). QFD in new production technology evaluation. International Journal of Production Economics, 67(2), 103-112.

Mard, M. (2000a). Financial factors: Cost approach to valuing intellectual property. Licensing Journal, August, 27-28.

Mard, M. (2000b). Financial factors: Income approach to valuing intellectual property. Licensing Journal, September, 27-30.

Oliver, R. M. (1987). A bayesian model to predict saturation & logistic growth. Journal of the Operational Research Society, 38(1), 49-56.

Park, Y. T., & Park, G. M. (2004). A new method for technology valuation in monetary value: Procedure and application. Technovation, 24, 387-394.

Pavri, Z. (1999). Valuation of intellectual property assets: The foundation for risk management and financing. Proceedings of INSIGHT Conference: Toronto.

Ross, S. A., Westerfield, R. W., & Jaffe, F. (2010). Corporate Finance (9th eds.). New York: McGraw- Hill.

Smith, G. V., & Parr, R. L. (1994). Valuation of intellectual property and intangible assets (2nd ed.). New York: John Wiley & Son.

Solow, R. M. (1956). A Contribution to the theory of economic growth. Quarterly Journal of Economics, 70(1). 65-94.

Solow, R. M. (1957). Technical change and the aggregate production function. Review of Economics and Statistics, 39, 312-320.

Tipping, J., Zeffren, E., & Fusfeld, A. (1995). Assessing the value of your technology. Research Technology Management, 38(5), 22–39.