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# A New Framework Integrating Environmental Effects into Technology Evaluation

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ABSTRACT. This study aims to propose a framework considering both economic issues and environmental effects in technology evaluation in order to provide firms' decision makers a useful reference in adopting technologies that will enable them to fulfill corporate social responsibilities and get competitive advantages at the same time. Recently, the demands for technology evaluation have increased with the flourishing development of technology licensing, technology transaction or joint venture on the one hand and with the pressing needs of environmental protection for human beings' sustainable development on the other hand. Under such conditions, it thus goes without saying that firms' decision makers are propelled to take into account both economic benefits and environmental effects in evaluating technologies by choosing low or nonpolluting technologies for manufacturing products. Although technology evaluation is not a new and emerging subject currently besetting scholars in the field of management, previous research on this topic has unwittingly left behind the pressing issue of environmental effects. Based on this observation, this study purports to develop a new framework for technology evaluation by taking both economic benefits and environmental perspectives into consideration. In it, we seek to demonstrate that our proposed framework will not only be a workable model but also can serve as a useful point of reference for technology appraisers and firms' decision makers.

KEY WORDS: corporate social responsibility, environmental effects, environmental wastes emissions, sustainable development, technology evaluation

## Introduction

With the increasing awareness of environmental hazard and the urgent need for environmental protection, the effective control of environmental pollutions has been prioritized by global societies and firms. Such protective environmental agreements, protocols or regulations as the Kyoto Protocol, the PFCs (PerFluoroCarbons) Reduction Agreement in WSC (World Semiconductor Council), the $CO_2$ Reduction Agreement between the ACEA (European Automobile manufactures' Association), RoHS directive and WEEE directive by EU (European Union), have been signed or launched for the purpose of reducing environmental pollutions. WBCSD (The World Business Council for Sustainable Development), a CEO-led global association of companies dealing with business and sustainable development, introduced the concept of eco-efficiency in 1992. The eco-efficiency is a management concept aiming for manufacturing more products while using fewer resources and generating less wastes and pollutions. Eco-efficiency can support sustainable decision making not only within the company but also industry-wide and beyond (Cha et al., 2008).

Moreover, an increasing number of consumers are inclined to purchase environmentally friendly products driven by environmental concerns and even willingly pay comparatively higher prices for these green products (Cambra-Fierro et al., 2008; Chen, 2008; Zhou and Schoenung, 2007). In response to the trends of international severe environmental regulations and consumers' awareness, firms are also urged to take their corporate social responsibilities seriously by considering environmental effects in technology evaluation and adopting green technologies for producing green products (Fairchild, 2008; Fukukawa and Teramoto, 2009). Apart from the utilization of eco-efficiency, a firm's performance can also be judged by its friendliness to the environment; namely, by its emissions of greenhouse gases and wastes. The amount of greenhouse gases and wastes released by a firm depends heavily on which technology it uses. As a result, considering environmental effects in technology evaluation and choosing low or non-polluting technologies to manufacture products for the purpose of reducing environmental pollutions and protecting environment has never been more urgent than before.

Technology evaluation is a complex business process of evaluating technology (Goldscheider, 2002). Many firms have to adopt new technologies for getting competitive advantages or surviving in the marketplace by resorting to technology licensing, technology transaction or joint venture for the sake of saving the costs and reducing the risks of developing new technologies (Chatterji, 1996; Vanhaverbeke et al., 2002). Yet, before adopting or using technologies, these firms need to evaluate them first which increases the great demands for technology evaluation. Previous literature on technology evaluation has discussed many approaches and factors. Cost approach, market approach and income approach are the three basic approaches under discussion. The cost approach evaluates the value of a technology according to the cost expended to develop it. The market approach assesses a technology based on the value of an equivalent technology in the marketplace. The income approach evaluates the value of a technology depending on the economic benefits derived from using the technology (Hastbacka, 2004). The factors that have been observed for the use of technology valuation include the strength of legal protection (Granstrand, 1999; Udell and Potter, 1989), cost dimension, technology market and product market (Bidault, 1989; Chiu and Chen, 2007; Park and Park, 2004; Udell and Potter, 1989). All factors used for technology evaluation in the previous literature have only been considered from the monetary perspective.

This article attempts to redress this lack of concern by elaborating a framework that integrates environmental factor into technology evaluation. The remainder of this article will be organized as follows: section ‘‘Literature review’’ offers a literature review; section ‘‘Evaluation framework and process’’ introduces the framework of integrating environmental factor into technology valuation; section ‘‘Application’’ demonstrates its application followed up with a conclusion in section ‘‘Conclusion.’’

## Literature review

Past literature on technology evaluation has unintentionally ignored the devastating effects of environmental pollutions. Therefore in what follows, we will not only provide a concise overview of past research on the topic but will also bring up the urgent issue of environmental effects. Our aim is to demonstrate the significance of incorporating the environmental factor into technology evaluation.

### *Approaches and factors of technology evaluation*

Many approaches and factors have been observed for the use of technology evaluation in previous literature (Bidault, 1989; Boer, 1999; Chiesa and Gilardoni, 2005; Chiesa et al., 2007; Hastbacka, 2004; Mard, 2000a, b, c; Park and Park, 2004; Razgaitis, 2003; Smith and Parr, 2000; Udell and Potter, 1989). In evaluating a technology's monetary value, three basic approaches – cost approach, market approach, and income approach – have been adopted (Hastbacka, 2004; Mard, 2000a, b, c; Smith and Parr, 2000).

The cost approach is used for evaluating a technology based on the economic principle of substitution. Under the principle of substitution, an inclined technology demander would pay no more than the cost to develop a technology of equal usability and a willing technology supplier could not demand more for a technology than the cost to develop a technology of equal usability (Mard, 2000a). That is, the cost approach is used to evaluate the monetary value of a technology based only on the cost spent to develop it. This approach ignores the potential income of the technology and is hard to evaluate its fair value. The market approach is used for evaluating the monetary value of a technology based on the value of an equivalent technology in the marketplace (Mard, 2000c; Smith and Parr, 2000). The advantage offered by this approach is that it is simple and based on actual transaction data, but it is hard to find an equivalent technology's transaction data in the market. The income approach evaluates a technology based on the future economic benefits over the life of the subject technology, discounted to a present value (Boer, 1999; Mard, 2000b; Razgaitis, 2003; Smith and Parr, 2000). The income approach has been subdivided into various branches for the sake of different aspects. Among these approaches, the discounted cash flow (DCF) approach is the most widely used one in technology evaluation (Baek et al., 2007).

In addition to approaches consideration, other scholars have also examined the uses of factors in technology evaluation. For instance, Bidault (1989) considers three major factors including legal protection, cost dimension, and product market, which can be further itemized as patent, R&D costs (research and development costs), transfer costs, total manufacturing costs, market size, and the market shares when pricing a technology. Udell and Potter (1989), on the other hand, have provided nine factors for pricing a technology, including the importance of the technology, commercial level, scope of application, competitive structure of the technology market, strength of the patent or trade secret, the profit margin available from the product, competitive advantage, commercialization cost, and other terms. The importance of the technology, commercial level, scope of application, and competitive structure of the technology market are used for evaluating the potential value embedded in the subject technology. Strength of the patent or trade secret is used for measuring the strength of legal protection to a technology. The stronger the legal protection is, the more valuable the subject technology becomes. The profit margin available from the product and competitive advantage are used for estimating the market size and potential market share of the subject technology manufacturing products. Commercialization cost is used for estimating the amount needed to spend in order to successfully commercialize the subject technology. Although Udell and Potter (1989) have considered almost every factor that may influence the value of a technology, they do not indicate the process of estimating the monetary value of the subject technology.

Classifying the factors provided by prior research into two main categories, Park and Park (2004) point out the value of technology and the value of market. The value of technology factors are used for evaluating the potential value that is embedded in the subject technology itself. The value of market factors are used for evaluating the practical value of the subject technology that is materialized in product markets. The greatest contribution Park and Park made to the extant studies is designing a flowchart as a reference point for estimating the monetary value of a technology.

Drawing from the aforementioned research, we classified the factors provided by the previous research into four main factors, including technology market factor, legal protection factor, product market factor, and cost dimension factor. Technology market factor includes number of supplier, number of demander, life of technology, commercial level, scope of application, and contribution ratio. Legal protection factor contains patent and trade secret. Product market factor includes market size, potential market share, and competitive advantage. Cost dimension factor contains costs of R&D, transfer, and commercialization.

### *Effects of environmental wastes emissions*

The releases of environmental wastes from firms during the manufacturing processes have caused plenty of environmental problems and led to many destructive effects. For instance, greenhouse gases (GHGs) warm the surface and the atmosphere with significant implications for rainfall, retreat of glaciers and sea level (Ramanathan and Feng, 2009). Acidification emissions are causing damages to human health, freshwater systems, and natural ecosystems worldwide (Bini and Bresolin, 1998; Renshaw et al., 1997). Ozone depleting substances (ODS) significantly deplete the ozone layer in a manner that is likely to result in unfavorable effects on human health and the environment (Orellana, 2002; Slaper et al., 1998; Winter-Sorkina, 2001). Heavy metals emissions, such as lead, cadmium, can directly influence human behaviors by impairing mental and neurological functions, influencing neurotransmitter production and utilization, and altering numerous metabolic body processes. Breathing heavy metal particles, even at levels well below those considered nontoxic, can have serious health effects (Herman et al., 2009; Järup, 2003; Mishra, 2009). Volatile organic compounds (VOCs) have been found to be a major contributing factor to ozone, a common air pollutant which has been proven to be a public health hazard (Boeglin et al., 2006; Park and Jo, 2004; Phillips et al., 1999). Industrial organic pollutants have been manufactured and released in very large amount for a long time and pose threats to the environment and human health all over the globe (Goudie, 2000). As the main source of pollution for rivers, lakes, and oceans, the release of wastewater can cause potential hazards to human health and ecosystem (Khan et al., 2008).

Indeed, all the above-mentioned environmental wastes emissions released by a firm depend heavily on which technology it uses. As a consequence, considering environmental effects in technology evaluation and selecting greener technologies for manufacturing is an efficient way to reduce the environmental wastes emissions. But as we can see clearly from the above discussion, all of the approaches and factors that previous literatures afforded for technology evaluation only think about monetary issues. None of them has, in effect, taken environmental effects into consideration in technology evaluation.

## Evaluation framework and process

Following the latest trend in environmental protection, it is now firmly believed that societies and consumers will pay more attention to it and governments will launch more severe environmental regulations to limit the emissions of environmental wastes for controlling environmental problems in the future. Therefore, adopting a framework that can take account of environment factor in technology evaluation has been invaluable in the light of its usage as a point of reference for firms' decision makers and technology appraisers to evaluate technologies.

In this research, we adopt DCF approach, consider all factors that prior research offered and add environmental effects into current studies in order to come out with a new framework in technology evaluation. This framework is used for evaluating economic values and environmental wastes emissions brought by using a technology. In it, we adopt the technology market factor, legal protection factor, product market factor, cost dimension factor as drawn from the prior research to evaluate the net monetary value of a technology and use environmental factor to estimate the amount of environmental wastes emissions resulting from using the subject technology. These factors are linked either in parallel or in sequence.

Significantly, this proposed framework will enable the technology appraisers and firms' decision makers to realize not only how much a technology values but also how many environmental wastes emissions will be released. The framework, each main factor, indicator or measured unit and evaluation process for technology evaluation will be shown in detail as follows.

### *Evaluation framework*

The overall framework of integrating environmental effects into technology evaluation is depicted in Figure 1. There are five factors in the framework, including technology market, legal protection, product market, cost dimension, and environment. As will be elucidated in the following paragraphs, each factor includes several indicators.

Technology market factor consists of six indicators, which are number of supplier, number of demander, life of technology, commercial level, scope of application, and contribution ratio. Technology market is a market for the licensing or transaction of technologies (Glynn and Randall, 2004). If there are more technology suppliers than demanders, the demanders will have more choices to choose the suppliers in the market, resulting in lowering the value of this subject technology. Conversely, if there are more technology demanders than suppliers, the demanders will have limited choices to choose the suppliers in the market, leading to the increase of the value of technology. With regard to the life of technology, it is referred to as the income-generating period of the subject technology (Park and Park, 2004). The longer the life of a technology has, the longer time it is likely to generate its income. As for the commercial level, it is a critical indicator of the subject technology (Chiu and Chen, 2007). A technology moves through several stages of the development process. With the accomplishment of each task, the uncertainty associated with the task is reduced (Udell and Potter, 1989). That is, the more commercialized a technology becomes, the lower risk there is for the use of the subject technology.

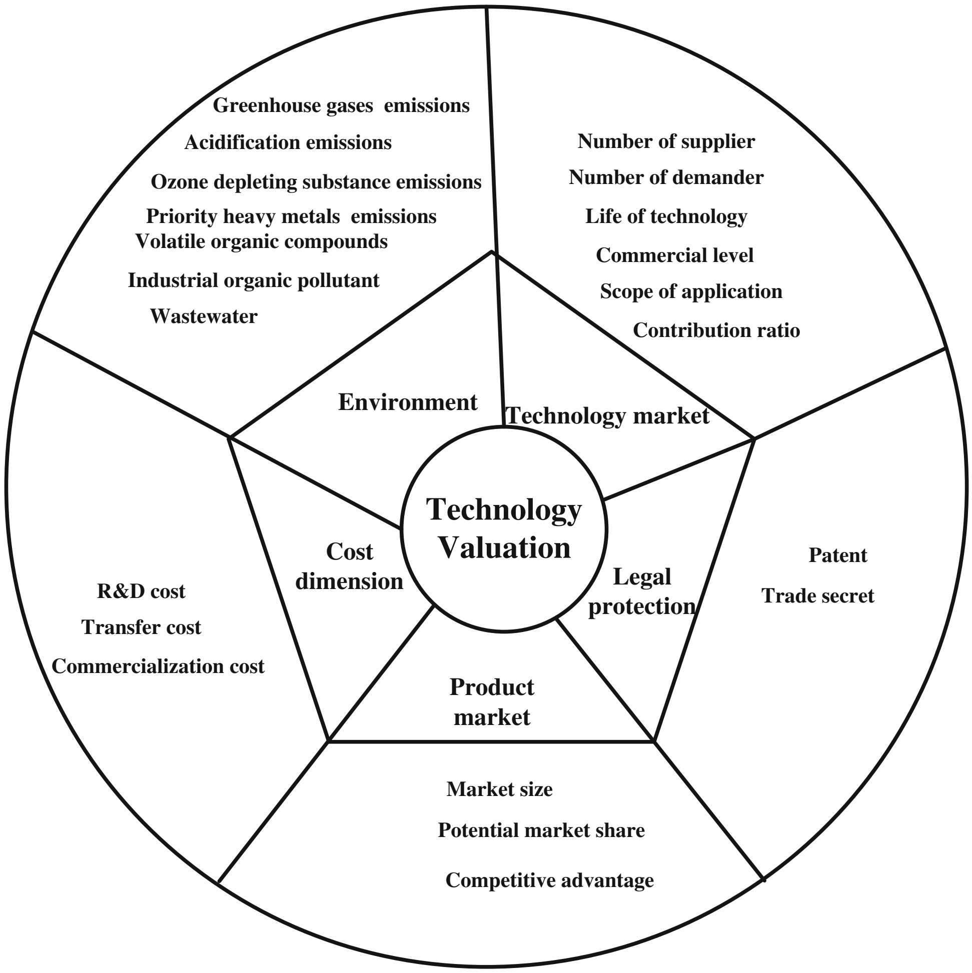


Figure 1. The framework of technology evaluation.

And the scope of application is referred to the kinds of products that can be applied to the subject technology (Park and Park, 2004). If the subject technology is applied to more than one kind of products, the value of every related indicator has to be evaluated separately. Contribution ratio is the contribution percentage of the subject technology to total expected income (Park and Park, 2004). The higher the contribution ratio becomes, the superior the subject technology is.

Legal protection factor includes two indicators, which are patent and trade secrets. Patenting is the most commonly used legal way a firm uses for protecting their technological assets against imitation. The strength of legal protection to a technology asset depends on the patenting strategy of a firm (Granstrand, 1999). Protecting a technology with essential patents is the most powerful type of patent protection. An essential patent is one whose infringement is unavoidable in a compliant implementation of a standard technology. This means that developing a workable standard technology requires obtaining the essential patents as a bundle (Aggarwal and Walden, 2005). In addition, multiple patents protecting a technology provide a stronger patent protection than a single one. The number of countries to which the patent protection has been extended also influences the strength of a technology's patent protection. As a firm protects a technology with patents, it may expand the market shares of its patented products by enforcing its patent rights to exclude the competitors from using the subject technology to manufacture products. With regard to trade secrets, any confidential business information which provides a firm a competitive edge may be considered a trade secret (Granstrand, 1999). Contrary to patents, trade secrets are protected without registration and can be protected for an unlimited period of time.

Product market factor consists of three indicators, which are market size, potential market share, and competitive advantage, which are used for estimating the total amount of income generated by the subject technology. Market size is measured by the total value of all sales in the marketplace. Estimating market size is an essential step to calculate the market share of a business as well as its competitors. This is especially important for a firm intent to launch a new product. Small markets attract fewer competitors and allow early entrants to shape the market to fit their own distinctive competencies. Large markets are likely to be able to support a high volume of goods and could bring in more competition (Czepiel, 1992). Competitive advantage is determined by the price, the appearance, and other attributes of the product. Products that offer distinct advantages in one or more of these dimensions will get higher market shares (Udell and Potter, 1989). The potential market share is determined by the scope of application, the strength of legal protection, and competitive advantage.

Cost dimension factor includes three indicators, which are costs of R&D, transfer, and commercialization. The R&D costs indicate the amount of money spent on research and development to develop a new technology (Bidault, 1989). They include costs of materials, equipments, and facilities that have no alternative future uses, salaries, wages, and other related costs of personnel engaged in R&D activities, purchased intangibles that have no alternative future uses, and a reasonable allocation of indirect costs but exclude general and administrative costs (Gornik-Tomaszewski and Millan, 2005). The transfer costs are the costs of transmitting and absorbing the relevant knowledge required for the effective transfer of the technology without considering the cost of the technology itself. The transfer costs encompass the costs of pre-engineering technological exchanges, engineering costs related to the transfer of the process or product design, researching and development costs arising from adaptation or modification of the technology, training costs prior to the start of manufacturing, and the operating losses during the launch period (Teece, 1977). The commercialization cost is referred to the spending of financial resources before a technology becomes commercialized.

There are many kinds of environmental wastes emissions released from firms during the manufacturing process. We selected seven kinds of environmental wastes emissions that have caused serious environmental problems as the indicators of environmental factors. They are greenhouse gases emissions, acidification emissions, ODS emissions, priority heavy metals emissions, VOCs, industrial organic pollutant, and wastewater. The indicators of environmental factors are flexible and could be added by technology appraisers. Among the indicators of environmental factor, greenhouse gases emissions that bring about global warming are the main cause of climate changes. Climate changes are the greatest environmental, social, and economic threats we face nowadays. The direct effects of climate changes include changes in temperature, precipitation, soil moisture, and sea level. Such changes exert extremely harmful effects on ecological systems, human health, and national economies around the globe (Ramanathan and Feng, 2009). Acidification emissions are causing damages to human health, plant growth, freshwater systems, and natural ecosystems worldwide (Bini and Bresolin, 1998; Renshaw et al., 1997). Ozone depleting substances are those substances depleting the ozone layer and widely used in air-conditioners, fire extinguishers, and electronic devices. The depletion of ozone layer is likely to result in unfavorable effects on human health and the environment (Orellana, 2002; Slaper et al., 1998; Winter-Sorkina, 2001). Priority heavy metals emissions can have a direct impact on human behaviors by impairing mental and neurological functions, influencing neurotransmitter production and utilization, and altering numerous metabolic body processes (Herman et al., 2009; Järup, 2003; Mishra, 2009). VOCs have been found to be a major contributing factor to ozone, a common air pollutant which has been proven to be a public health hazard (Boeglin et al., 2006; Park and Jo, 2004; Phillips et al., 1999). Industrial organic pollutants pose threats to the environment and human health all over the world (Goudie, 2000). As the main source of pollution for rivers, lakes, and oceans, the release of wastewater can cause potential hazards to human health and ecosystem (Khan et al., 2008).

*Evaluation process*

The evaluation process is indicated in Figure 2. The indicators of all factors and their related measured units are illustrated in Table I. The details of evaluation process are described as follows:

*Step 1: Assessing the value of technology market*
At the first stage, the value of technology market factor is assessed. Among the indicators of technology market factor, life of technology is the income-generating period of the subject technology. Scope of application is used for determining how many types of products that can be applied to the subject technology. These two indicators are used as a reference to estimate the income flow of product as manufactured by the subject technology. They are determined by consulting the R&D director's opinion of the subject technology. Contribution ratio is used for evaluating the income flow brought about from the subject technology and is determined by consulting the R&D director's opinion. The number of supplier, the number of demander and commercial level are used as a reference to estimate the risk-adjusted hurdle rate and are determined by consulting the R&D director and experts' opinions.

*Step 2: Evaluating the strength of legal protection*
At the second stage, the strength of legal protection to the subject technology is estimated. Among the indicators of legal protection, both patents and trade secrets are used as references for estimating potential market share. The strength of patent protection is determined by consulting the R&D director's opinion and inspecting the patent type and patent family that protect the subject technology. The strength of trade secrets protection is determined by consulting the R&D director's opinion, which depends on the level of economic advantage the subject technology provides.

*Step 3: Assessing the value of product market and determining risk-adjusted hurdle rate*
At the third stage, the value of product market factor and risk-adjusted hurdle rate are assessed. Among the

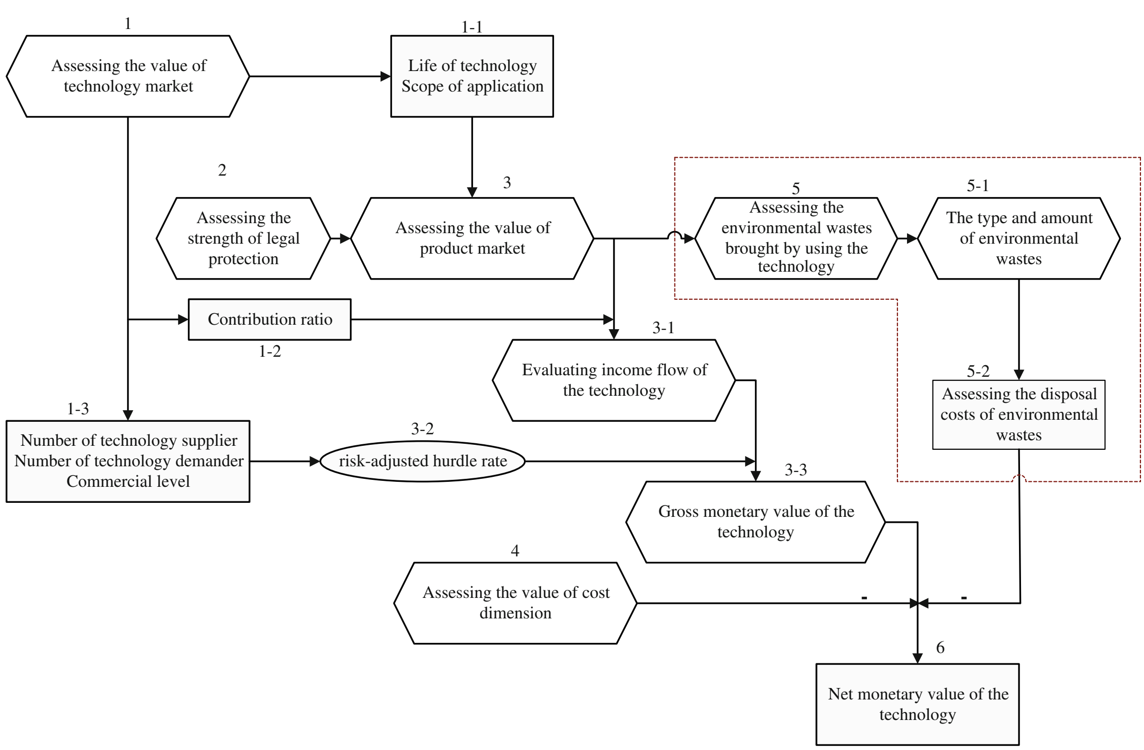


Figure 2. Overall flowchart of evaluation process.

TABLE I

Factors, indicators, and measured units of technology evaluation

| Factor | Indicator | Measured unit |
|---|---|---|
| Technology market | Number of supplier | Number |
| | Number of demander | Number |
| | Life of technology | Year |
| | Commercial level | Score (0–10) |
| | Scope of application | Number |
| | Contribution ratio | Percent |
| Legal protection | Patent | Score (0–10) |
| | Trade secret | Score (0–10) |
| Product market | Market size | Dollars |
| | Potential market share | Percent |
| | Competitive advantage | Score (0–10) |
| Cost dimension | R&D cost | Dollars |
| | Transfer cost | Dollars |
| | Commercialization cost | Dollars |
| Environment | Greenhouse gases emissions | Tons of $CO_2$ equivalents |
| | $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$ | |
| | Acidification emissions | Tons of $SO_2$ equivalents |
| | $NH_3$, HCl, HF, $NO_2$, $SO_2$ | |
| | ODS emissions | Tons of $SO_2$ equivalents |
| | Priority heavy metals emissions | Tons of Cu equivalents |
| | As, Cd, Cr, Cu, Pb, Hg, Ni, Zn | |
| | Volatile organic compounds | Tons |
| | Industrial organic pollutant | Tons |
| | Wastewater | Tons |

*Note*: The indicators of environment are adapted from measuring eco-efficiency: a guide to reporting company performance (WBCSD, 2000).

indicators of product market factor, the market size is estimated by consulting the experts' opinions and depending on related market reports. Potential market share is estimated by consulting the experts' opinions and judged by the scope of application, the strength of legal protection and competitive advantage of the subject technology. After getting the results of market size and potential market share, we can be more aware of the amount of sales and profits. The income of the subject technology can thus be acquired from contribution ratio and the gross monetary value of the technology can be gleaned from the risk-adjusted hurdle rate. The risk-adjusted hurdle rate under illustration here is linked with inflation, alternative available rates of return, and risk of return, where risk of return is determined by commercial level, number of technology supplier, and number of technology demander. The approximate values of risk-adjusted hurdle rate of different characterization are shown in Table II.

*Step 4: Estimating the value of cost dimension*

At the fourth stage, the value of cost dimension factor is measured. Among the indicators of cost dimension factor, the information of R&D costs is provided by the financial section. The transfer costs and commercialization costs are determined by consulting the experts' opinions.

*Step 5: Assessing the amount and the disposal costs of environmental waste emissions*

At the fifth stage, the amount of environmental waste emissions gleaned from the use of subject technology and the disposal costs are assessed. The

TABLE II

The approximate values of risk-adjusted hurdle rate

| Characterization of risk | Approximate risk-adjusted hurdle rate |
|---|---|
| 1. Risk-free, such as building a duplicate plant to make more of a currently made and sold product | 10–18% |
| 2. Very low risk, such as incremental improvements with a well-understood technology making a product presently made | 15–20% |
| 3. Low risk, such as making a product with new features using well-understood technology | 20–30% |
| 4. Moderate risk, such as making a new product using well-understood technology | 25–35% |
| 5. High risk, such as making new product using a not well-understood technology | 30–40% |
| 6. Very high risk, such as making a new product with new technology | 35–45% |
| 7. Extremely high risk, such as making a product not presently sold using unproven technology | 50–70% or even higher |

Adapted from approximate values of risk-adjusted hurdle rate used in license negotiations (Razgaitis, 2003).

information of environmental waste emissions is gathered from the environmental management section of the firm. The total disposal costs are assessed according to the types of environmental waste emissions and the disposal cost of every unit of environmental waste emission. The disposal cost of every unit of environmental waste emissions is determined by consulting the experts' opinions and the literature related to the treatments of environmental wastes.

*Step 6: Estimating the net monetary value of the technology*
At the sixth stage, the net monetary value of the subject technology is estimated. The net present value of the subject technology is estimated based on the DCF approach considering the risk of future payments and the costs of developing the subject technology (Boer, 1999; Razgaitis, 2003), the disposal costs of the environmental wastes brought by using the subject technology. The net present value of the subject technology is estimated as follows:

$$\mathrm{NPV} = + \sum_{n=1}^{m} \frac{P_n}{(1+k)^n} - I_0 - C_t$$

where $m$ is the life of technology, $P_n$ is the future cash flow in year $n$, $k$ is the risk-adjusted hurdle rate; "$k$" is considered from inflation, alternative available rates of return, and risk of return; $I_0$ is the initial investment, $C_t$ and is the total disposal costs of environmental wastes emissions.

## Application

In this section, we will put our proposed framework into application to demonstrate how it works. We select an LED (Light Emitting Diode) packing technology that has been used for LED manufacture for our study here. LEDs provide many advantages over traditional light sources including lower energy consumption, longer lifetime, smaller size and faster switching. They are used as low energy indicators and as replacements for traditional light sources in general lighting and automotive lighting. The manufacturing process of LED includes wafer fabrication, wafer probe, packing, and testing. The process of LED packing will generate carbon dioxide emissions, heavy metal emissions, VOCs, industrial organic water pollutant, and wastewaters. The subject technology under evaluation here is owned by a Taiwan's LED packing company. It enables manufactured chips to be lighter and smaller. The LED packed by the subject technology has better optical performance, electrical performance, higher yield rate, and longer product life cycle. The firm also protects it with multiple patents and trade secrets.

The value of every indicator is estimated based on R&D director, experts' opinions, market report, information provided from environmental management section and gleaned from financial statements and is illustrated in Tables III. The evaluation process and its results are described as follows.

The subject technology was commercialized in 2002 and used for packing LED with a lifespan of 6 years (2003–2008) and a 20% contribution ratio. It is protected by multiple patents and the firm also owns some trade secrets in the LED packing process. The strength of legal protection of the subject technology is, therefore, stronger than that of its competitors in Taiwan. The global market size is estimated about US $5.5 billion in 2003 and US $7 billion in 2008 (Department of Investment Service, Ministry of Economic Affairs, Taiwan, 2008) whereas the market share is estimated about 2.8% in 2003 and 5% in 2008. The amount of sales, profits, and incomes gained from the technology between 2003 and 2008 are indicated in Table IV (Taiwan Stock Exchange, 2009). The value of risk-adjusted hurdle rate is determined by considering inflation, alternative available rates of return, risk of return, and consulting experts' opinions. The characterization of risk of the subjected LED packing technology is moderate and the risk-adjusted hurdle rate is assumed as 30% (Razgaitis, 2003).

The R&D cost is estimated as US $9.5 million. The subject technology has been commercialized and used by the firm itself without any estimation of commercialization costs and transfer costs. The environmental waste emissions brought from using the LED packing technology are also illustrated in

TABLE III

Evaluation of the "LED packing" technology

| Factor | Indicator | Value | Note |
|---|---|---|---|
| Technology market | Number of supplier | 4 | a |
| | Number of demander | 5 | a |
| | Life of technology | 6 years | b |
| | Commercial level | 10 | a |
| | Scope of application | 1 | b |
| | Contribution ratio | 20% | b |
| Legal protection | Patent | 4 | c |
| | Trade secret | 3 | b |
| Product market | Market size | US $5.5 billion (2003) to US $7 billion (2008) | d |
| | Market share | 2.8% (2003) to 5% (2008) | a |
| | Competitive advantage | 7 | a |
| Cost dimension | R&D cost | US $9.5 million | e |
| | Transfer cost | 0 | |
| | Commercialization cost | 0 | |
| Environment | Greenhouse gases emissions $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$ | 30,840 tons | f |
| | Priority heavy metals emissions As, Cd, Cr, Cu, Pb, Hg, Ni, Zn | 270 tons | |
| | Volatile organic compounds | 16.5 tons | |
| | Industrial organic pollutant | 2684.43 tons | |
| | Wastewater | 559,250 tons | |

a: R&D director and experts' opinions.
b: R&D director's opinion.
c: R&D director's opinion and inspecting the patent type and patent family that protect the subject technology.
d: Market report.
e: Provided by the financial section.
f: Provided by the environmental management section.

TABLE IV

Estimating income flow of the "LED packing" technology

| Year | Sales | Profit | Income flow of the technology |
|---|---|---|---|
| 2003 | 153.3 | 29 | 5.8 |
| 2004 | 180.5 | 34.8 | 6.96 |
| 2005 | 204.1 | 44.6 | 8.92 |
| 2006 | 240.9 | 57.3 | 11.46 |
| 2007 | 298.6 | 67 | 13.4 |
| 2008 | 334.2 | 41.1 | 8.22 |

*Note*: Unit is million U.S. dollar (Sales and Profits are estimated from financial statements).

Table III. For instance, the use of the subject technology has released 30,840 tons of greenhouse gases, 270 tons of industrial organic pollutant, and 559,250 tons of wastewater. The disposal cost of every unit of environmental waste emissions and the total disposal costs are illustrated in Table V. The disposal cost of greenhouse gases emissions is assumed as US $50/ton (Klemeš et al., 2007; Rao and Rubin, 2002); the disposal cost of priority heavy metals emission is assumed as US $2000/ton (Bhattacharyya et al., 1999);the disposal cost of VOCs is assumed as US $750/ton (Petrides et al., 1995, 1998); the disposal cost of industrial organic pollutant is assumed as US $700/ton (Petrides et al., 1995); and the disposal cost of wastewater is assumed as US $3.3/ton (Al-Redhwan et al., 2005; Üstün et al., 2007). Hence, the total disposal costs brought by using the subject "LED packing" technology are estimated as US $5.818 million.

The net monetary value of the LED packing technology is estimated from the following equation:

$$
\begin{aligned}
\mathrm{NPV} &= \sum_{n=1}^{6} \frac{P_n}{(1+0.3)^n} - I_0 - C_t \\
&= \left(\frac{5.8}{1.3} + \frac{6.96}{1.3^2} + \frac{8.92}{1.3^3} + \frac{11.46}{1.3^4} + \frac{13.4}{1.3^5} + \frac{8.22}{1.3^6}\right) \\
&\quad - 9.5 - 5.818 = 6.646
\end{aligned}
$$

Therefore, the net monetary value of the subject LED packing technology in 2002 is estimated as US $6.646 million. After getting the results of total sales, profits, and environmental waste emissions, we can also estimate the amount of environmental wastes emissions per unit sale or profit brought from using the subject technology. Table VI illustrates the environmental wastes emissions per million US dollars sale and profit of the estimated technology present in this article.

Judging from the above discussion, previous studies only focus on estimating the monetary value of a technology for technology licensing, technology transaction, or joint venture (Baek et al., 2007; Bidault, 1989; Boer, 1999; Chiesa and Gilardoni, 2005; Chiesa et al., 2007; Hastbacka, 2004; Mard, 2000a, b, c; Park and Park, 2004; Razgaitis, 2003; Smith and Parr, 2000; Udell and Potter, 1989). They unintentionally ignore to consider the adversely effects brought by using the technology. Significantly, our framework evaluates the monetary value of a technology, the kinds and the amount of environmental wastes emissions brought by using the technology, and the disposal costs of treating these environmental wastes emissions. Furthermore,

TABLE V

Estimating the disposal costs of environmental wastes emissions

| Waste type | Amount (tons) | Disposal cost US$/ton | Disposal costs (million US$) |
|---|---|---|---|
| Greenhouse gases emissions $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$ | 30,840 | 50 | 1.542 |
| Priority heavy metals emissions As, Cd, Cr, Cu, Pb, Hg, Ni, Zn | 270 | 2000 | 0.54 |
| Volatile organic compounds | 16.5 | 750 | 0.012 |
| Industrial organic pollutant | 2684.43 | 700 | 1.879 |
| Wastewater | 559,250 | 3.3 | 1.845 |
| Total disposal costs | | | 5.818 |

TABLE VI

Estimating the environmental wastes emissions of per million US dollars sales/profits brought from the "LED packing" technology

| Type of environmental emission | Amount of environmental wastes emissions | |
|---|---|---|
| | Per million US dollars sales (tons) | Per million US dollars profits (tons) |
| Greenhouse gases emissions | 21.857 | 112.967 |
| Priority heavy metals emissions | 0.191 | 0.989 |
| Volatile organic compounds | 0.0117 | 0.0604 |
| Industrial organic pollutant | 1.903 | 9.833 |
| Wastewater | 369.35 | 2048.53 |

this framework enables the technology appraisers and decision makers to calculate the amount of environmental wastes emissions every unit sale or profit brought by using a technology. By means of this framework, the decision makers can indeed select a low-polluting technology with high economic values. In other words, this model offers a win–win solution where potential technology adopters can gain economic benefits while also fulfill their corporate social responsibilities by reducing environmental effects. In the long run, this framework will make a significant contribution to the society's sustainable development.

## Conclusion

Since environmental hazards have been one of the gravest challenges confronting us today, protecting the environment has been a communal endeavor around the globe. Bearing this in mind, this article has highlighted the significance of incorporating environmental factors into technology evaluation and has also proposed a feasible way by setting up a new framework based on this observation. By so doing, this article has filled the gap in existing literature on technology evaluation by providing a more evolving approach catering to the current needs of global civil society. Taking both economic and environmental factors into account in technology evaluation, we drew from the existing monetary paradigm to form a new structure. Our finding gained from applications affirms that technologies not only generate economic profits but also produce plenty of environmental wastes. With an aim to look after both sides, this new framework thus serves as a useful point of reference for both firms' decision makers and technology appraisers where they can adopt a lower polluting technology without sacrificing the needs for economic profits. Besides, an added contribution to our proposal of the new framework is that we materialize it by affording the possibility for a working estimation of environmental wastes emissions released from the use of technology and the disposal costs of treating these environmental wastes.

Although the proposed framework made a noteworthy contribution to current studies on technology evaluation, it also has its own limitations. First and foremost, part of the estimation that we did regarding calculating the amount of corporate release of environmental wastes can only be seen as tentative at this preliminary stage. Aiming for accuracy could, therefore, be the goal for future study. Second, as illustrated in our estimation where we took the cases of environmental wastes emissions and disposal costs as examples, further studies could still experiment with other possibilities such as calculating the potential environmental costs by consulting our framework. Last but not least, although there are varied research approaches to studies of technology evaluation and factor consideration is only one of them, our study does firmly prove that we do not pay lip service to the study concerned but practice what we preach. In a word, adding environmental factors in technology evaluation is indeed a sound consideration, one that is not only attainable but also beneficial to all living beings.

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