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Low-risk opportunity recognition from mature technologies for SMEs

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ABSTRACT

It is common that SMEs recognize low-risk technological arbitrage opportunities in mature technologies, enter the global market, and occupy significant market shares. This opportunity is characterized by imitable technology complexity, market insignificance for oligopoly companies, and technology maturity. We propose a new and systematic method to recognize the most appropriate low-risk technological arbitrage opportunities for SMEs. The four-phase opportunity recognition procedure consists of technology complexity analysis, market appropriateness analysis, technology maturity analysis, and organizational fit analysis using empirical measures and analytic tools. An illustrative example of a company searching for technological arbitrage opportunities in semiconductor equipment is provided.

Introduction

Globalization and technological change have brought new opportunities for small and medium enterprises (SMEs), but they have also created risks. Thus, SMEs have made efforts to seize opportunities under accelerating competition. However, compared to large firms, SMEs have disadvantages, including weaker R&D capability and fewer resources. Nevertheless, some SMEs can combine the advantages of their small scale and great adaptability with the economies of scale and

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scope provided by networks of SMEs (Davidsson et al., 2010; Jennings and Beaver, 1997; Thorgren et al., 2012). Some SMEs also collaborate with multinational giants and enjoy the benefits of joining their global networks (Sawers et al., 2008). SMEs have developed several ways to survive today's hypercompetition.

For this purpose, one of the most important initiatives for SMEs is to recognize the most appropriate business opportunities for them. Once an inappropriate business opportunity is regarded as being appropriate due to bounded rationality and thus is chosen, it is difficult to make profits, even if SMEs put forth a strong effort. Also, SMEs are less able to recognize opportunities on a global scale due to their limited access to global information and knowledge. Thus, opportunity recognition has been regarded as the central function not only of international entrepreneurship, but of international business development (Eckhardt and Shane, 2003; Mainella et al., 2013). We argue that an effective opportunity recognition method should be addressed and further developed for SMEs.

According to the current literature, opportunities can be divided into innovative and arbitrage opportunities. Whereas innovative opportunities are created by the introduction of new means, ends, or means-ends relationships, arbitrage opportunities are opened by market inefficiencies (Eckhardt and Shane, 2003; Kirzner, 1997; Schumpeter, 1934). Arbitrage opportunities can be classified as either market or technological.

If a market-altering change causes a particular resource to be heterogeneously priced in several markets, some alert entrepreneurs may quickly recognize this phenomenon and profit by buying low and selling high (Kirzner, 1973). This situation is a typical market arbitrage opportunity. Somewhat differently, technological arbitrage opportunities are directly linked to innovation. Often, new innovation enables innovators to make a higher profit (Anokhin et al., 2011). It also creates technological arbitrage opportunities for alert entrepreneurs to benefit from imitating the advanced technologies in pursuit of temporary cost advantages.

Overall, previous studies have been lopsided, focusing on innovative opportunities. Entrepreneurial strategies have been characterized by either early recognition or creation of innovative opportunities (Marcati et al., 2008; Morone, 1993). The adoption of emerging technologies has been a primary focus of attention (Newbert et al., 2006). Many scholars have investigated innovative opportunities in emerging technologies, emphasizing the role of entrepreneurs to identify them and use them effectively (Baron and Ensley, 2006; Gruber et al., 2008).

In contrast, research practice has ignored arbitrage opportunities. Since Kirzner (1973) suggested the entrepreneurial process of discovering de facto arbitrage opportunities, there have been few attempts to deepen our understanding of market arbitrage opportunities, except for the following works: Eckhardt and Shane (2003), Kirzner (1997), and Kirzner (2009). Not so differently, although Aldrich (1999) and Ghemawat (2003) suggested that a significant number of new firms have been started not by innovators, but by imitators using technological arbitrage opportunities, researchers have made little effort to offer an acceptable operationalization.

Recently, Anokhin et al. (2010) tackled this issue and suggested a way of identifying and measuring technological arbitrage opportunities by employing the minimum performance inefficiency. A company can identify the presence of arbitrage opportunities through the comparison of its own inefficiency score with the scores of other companies. Using data envelopment analysis (DEA) and Malmquist productivity index, they attempted to quantify the amount of both innovative and technological arbitrage opportunities in national economies (Anokhin et al., 2011). However, although technological arbitrage opportunities can be identified, some companies cannot capitalize on these opportunities because of various reasons, including weak R&D capability and strong competitors (Su et al., 2013; Teece, 1986, 2006). Even worse, there is no established way to identify appropriate technological arbitrage opportunities for a specific company.

Some recent cases and reports have suggested that the globally successful SMEs recognize and utilize a specific technological arbitrage opportunity (Lee et al., 2012; STEPI, 2009). These SMEs enter a global market characterized by oligopoly and mature technology, develop the same or slightly better products at lower price, encroach upon the market share gradually, and become global dominant players (STEPI, 2009). This is regarded as a new type of international arbitrage opportunities in global markets. Thus, it holds some common characteristics with previous international opportunity studies, including opportunity recognition as a stimulus for internationalization and markets favorable to opportunity development (Crick and Jones, 2000; Oviatt and McDougall, 2005).

Through interviews with CEOs of these SMEs, STEPI (2009) suggested that the SMEs recognize and choose these opportunities because the overall risk is smaller than that of innovative opportunities, as the technologies are already developed and products are commercialized and being sold in the market. Successful ways of marketing, distribution, and service are also established. Above all, these SMEs have enough organizational capabilities to catch up to the market leaders. This is a low-risk technological arbitrage opportunity characterized by a modest technology barrier, relatively unimportant market for oligopoly companies, and mature technology in global markets.

Although some cases have been reported, there is no research about how SMEs can recognize low-risk technological arbitrage opportunities. Tackling this issue, we suggest a way of recognizing such opportunities based on the real activities of SMEs. In Section 'Methodology', we review the previous studies on innovative and arbitrage opportunities and define technological arbitrage opportunities to distinguish those from general arbitrage opportunities. We define our low-risk technological arbitrage opportunity by its distinctive characteristics in Section 'Empirical analysis'. Then, the overall process of opportunity recognition is described using analytic tools and measures. Key conceptual constructs are linked to those empirical measures. Subsequently, an illustrative empirical analysis of a company engaged in recognizing new opportunities in front-end semiconductor equipment is provided. Finally, we conclude with some discussions and conclusions.

Theoretical overview of opportunity research

Over the recent decades, opportunity research has been obsessed with innovative opportunities (Anokhin et al., 2011). Innovative opportunities are defined as situations in which new goods, services, raw materials, markets, and organizing methods can be introduced through the formation of new means, ends, or means-ends relationships (Eckhardt and Shane, 2003). Entrepreneurs have been charged with creating these opportunities by combining resources in novel ways (Schumpeter, 1934). If their new combinations are better than existing uses of resources, this new efficiency is then converted into economic benefits that entrepreneurs appropriate as entrepreneurial rents (Alvarez and Barney, 2004).

Some researchers have investigated the unique way that entrepreneurs recognize innovative opportunities (Hills and Shrader, 1998; Shaver and Scott, 1991). They argue that entrepreneurs have superior cognitive and thinking processes that enable them to recognize the future potential of innovative opportunities better than others when presented with the same information. Notably, there have been many success stories of entrepreneurs who recognized innovative opportunities from emerging technologies and successfully exploited them (Morone, 1993; Newbert et al., 2006). Some researchers have focused on such innovative opportunities, emphasizing entrepreneurs' abilities to anticipate future technological changes and recognize innovative opportunities (Savioz and Blum, 2002).

Taking this idea a step further, Porter and Detampel (1995) presented an innovative opportunity recognition method called the Technology Opportunities Analysis (TOA), which combines technology monitoring with bibliometric analysis. Combined with other methods, TOA has been developed and applied to various sectors (Huang et al., 2011; Preez and Pistorius, 1999,2002).

However, innovation is not the only way for entrepreneurial rents to exist. When certain market-altering changes occur, some resource owners with bounded rationality can fail to recognize that the existing resource pricing becomes ineffective (Kirzner, 1973). As a result, a particular resource is priced differently in different markets. This is an arbitrage opportunity. Alert and creative entrepreneurs will notice this opportunity and exploit it (Kirzner, 2009).

There are two major types of arbitrage opportunities. Market arbitrage opportunities are situations in which the pricing mechanism becomes ineffective due to shifts in the balance between supply and demand. Entrepreneurs can make profits by buying low and selling high so long as spatial price differentials persist. Differently, technological arbitrage opportunities are situations in which alert imitators can emulate newly introduced technological innovation practices in the pursuit of temporary cost advantages (Eckhardt and Shane, 2003; Lane et al., 2002).

Technological arbitrage opportunities have been driving entrepreneurial behavior for centuries, creating huge economic value (Ghemawat, 2003). Yet, there have been few efforts to identify and assess these opportunities. The first approach to identify and measure technological arbitrage opportunities was suggested by Anokhin et al. (2010). They presented a technique called the minimum performance inefficiency to estimate arbitrage opportunities and validated this technique at the industry level. Taking a step further, they suggested a way of measuring the amount of innovative and arbitrage opportunities at the national level (Anokhin et al., 2011). These methods are useful to identify the presence of technological arbitrage opportunities, but not enough to find the most appropriate opportunity for a given company.

Globalization has made the scope of arbitrage opportunity recognition broader, calling for international opportunity recognition across national borders (Oviatt and McDougall, 2005; Zahra et al., 2005). Previous studies on international entrepreneurship have identified several ways of international opportunity recognition including networks, entrepreneurial orientation, participation in international fairs and exhibitions, and new formal partners (Blomqvist et al., 2008; Dimitratos et al., 2012; Ellis, 2010; Kontinen and Ojala, 2011). Although these studies identified key determinants and effects of international opportunities, those opportunities have not been deeply studied.

A number of previous studies have been conducted to investigate the entrepreneurial process of recognizing, creating, and utilizing innovative opportunities. Also, several innovative opportunity recognition methods have been suggested, focusing on emerging technologies. However, arbitrage opportunity literature has not been the focus of researchers. Specifically, despite the economic value of international technological arbitrage opportunities, no method has been developed to identify the most appropriate technological arbitrage opportunities at the firm level.

Low-risk technological arbitrage opportunity recognition for SMEs

Recently, it has been observed that some SMEs have made global successes by using specific technological arbitrage opportunities. EO Technics in Korea is a typical example (STEPI, 2009). Founded in 1989, it started with four employees, but now occupies almost 50% market share in global laser marking instruments. In the 1990s, the laser marking instrument market was a duopoly where USA's GSI and Germany's Rofin split the market share. The size of the global market was consistently about 100 million dollars. This number is adequate for SMEs, but small for large companies. Laser marking is a mature technology that has shown incremental improvement over the last decade. The technological complexity is not so high that a small company cannot develop technologies and a product. Put another way, it is a small oligopoly market with mature technologies.

Over time, a business model and product platform were established with specification of the commercialization pathway in the laser marking instrument market. A company entering this market does not have to create all of these things from scratch, but can just duplicate those of existing players. A variety of the risks associated with identifying and building such capabilities became very low. Yet, GSI and Rofin did not exploit opportunities from low cost production because most products were made in USA and Germany. This is a typical technological arbitrage opportunity. A company can emulate technological advances of existing players, improve production efficiency, and thus has a potential opportunity to develop a low cost advantage. EO Technics recognized this opportunity and decided to enter the market. The company concentrated on reducing the line width and improving the marking speed, and it developed laser marking equipment slightly better than its competitors. Also, it reduced production cost by more than 20% when compared with existing players. With a lower price and slightly better performance, its products have gradually increased in global market share. EO Technics became an oligopoly player when GSI made a decision to withdraw from the market due to falling profits.

It has been observed that some SMEs recognized similar technological arbitrage opportunities to EO Technics. Some researchers have argued that there are diverse growth paths for technology-based small firms, implying technological arbitrage opportunities from mature technologies (Hicks and Hedge, 2005; Tether, 1997). Some recent reports describe how SMEs recognize and grasp such opportunities over several countries, including Korea, Japan, and China (Economist Intelligence Unit, 2010; STEPI, 2009; Zheng et al., 2010). We collect 32 reports, 11 magazine articles and 19 interviews

Table 1
Characteristics of low-risk technological arbitrage opportunities for SMEs.

Category	Sub-category	Number of SMEs	Characteristics
Technology	Complexity	41	Not easy but possible for SMEs
	Lifecycle	39	Maturity
Market	Structure	35	Oligopoly
	Size	41	Big for SMEs but small for large companies
Competency	Performance	24	Slightly better performance at same price
	Price	17	Same performance at lower price

through Google, Scopus and other databases by using queries of arbitrage opportunity and others. Reviewing those, we find 41 cases of SMEs exploiting technological arbitrage opportunities in eight countries. Then, arbitrage opportunity characteristics including technology, market and competency are identified per case, and then are narrowed down to common characteristics, summarized in Table 1.

Note that there are two types of competencies. Some SMEs, such as EO Technics, choose the competitive strategy to have solid performance advantages in some of their key functions. They focus on R&D, develop products with better performance, and challenge large companies. Technological improvement is not disruptive and instead is incremental. SMEs using this competitive strategy become oligopolistic players more quickly than others, in four years on average. CEOs argue that the performance advantage should facilitate the switching of customers. Other SMEs enter markets only with a low cost advantage. These SMEs usually spend more than six years becoming oligopolistic players because the switching of customers is relatively slow due to the advantages of existing players, such as brand. We calculate the time for a SME to become an oligopoly player since market entry by using the Herfindahl-Hirschman Index (HHI) based on the market share data, and get the average time per competency category in Table 1.

Note that some typical characteristics of technological arbitrage opportunities for SMEs can be found. SMEs can imitate mature technologies of leading players, improving production efficiency. Also, markets are distinctively oligopolistic, but relatively unimportant in terms of sales volume and R&D activities for existing oligopoly companies. In summary, these low-risk technological arbitrage opportunities are characterized by modest technology barriers, an relatively unimportant market for oligopoly companies, and mature technology.

However, methods and processes of opportunity recognition vary among companies. Some SMEs depend on the insights of their CEOs. Some recognize opportunities through a variety of interactions with other companies, such as product exhibition and R&D consortium. Others come up with ideas while reading patents or annual reports of other companies. Managers in SMEs have difficulty recognizing these opportunities without any established method. The approach by Anokhin et al. (2010) is useful in identifying general technological arbitrage opportunities, but not useful enough to recognize a specific opportunity, as previously noted. Considering this finding, we suggest a new method of recognizing low-risk technological arbitrage opportunities, complementing the general approach by Anokhin et al. (2010).

Methodology

Overall framework

Fig. 1 shows the four-phase procedure. Given the new business strategy, the purpose of Phase I is to eliminate complex technologies beyond SMS' R&D capability after all relevant technologies are listed. As a result of our literature review, we define technology complexity as difficulty of imitating leading technologies by SMEs. It is measured by time for imitation by SMEs. For empirical measurement, we define a key technology performance indicator, build its growth curves both of SMEs and leading companies, forecast future values, and calculate time for imitation.

Phase II ascertains market appropriateness of opportunities. Above all, market share data and HHI index are used to identify oligopoly markets. As previously noted, the oligopoly market is hard to

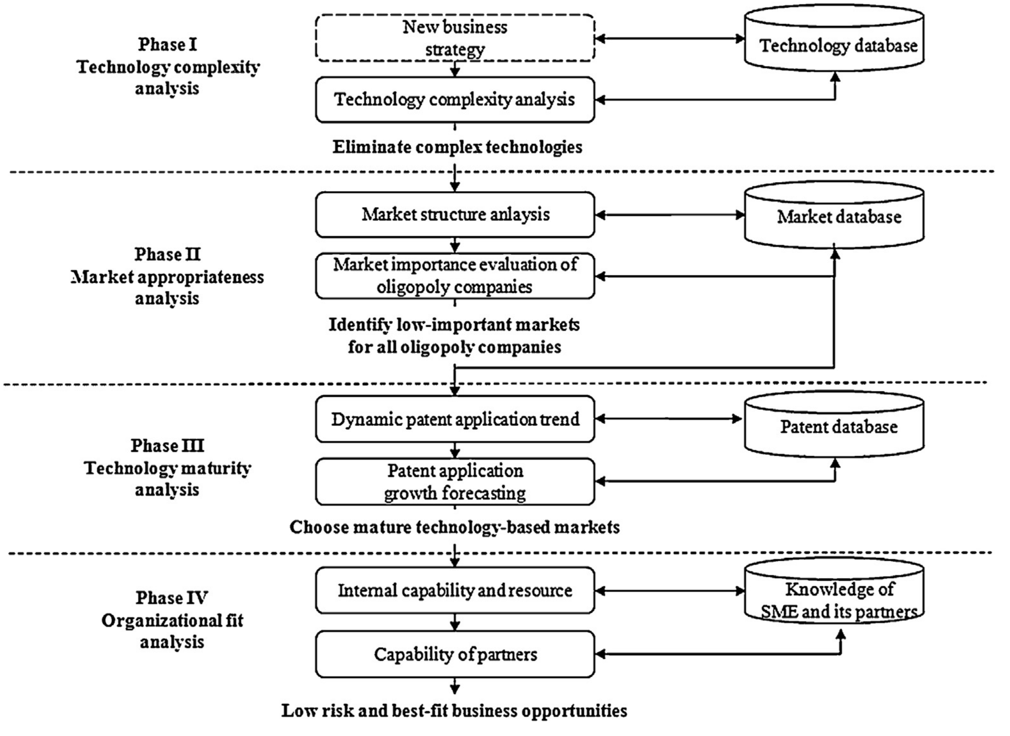

Fig. 1. Four-phase low-risk technological arbitrage opportunity recognition.

enter, but it is easy for SMEs to become major players because the competitive advantage is not so diverse. We define appropriate markets as relatively unimportant product markets in terms of sales proportion of oligopoly companies. By analyzing the sales proportion of key product markets for each oligopoly company, we find some markets that are regarded as unimportant by all oligopoly companies. SMEs can enter such market easily because its internal importance is low for all oligopoly companies.

However, in some markets, technologies can be emerging or growing. Although the revenue proportion is small, these are important markets for future growth. Oligopoly companies usually boost their R&D, increasing their patent applications. Thus, to filter out these markets, we introduce technology maturity, which is defined as a slowing down period of technological advances. Using the number of patent applications as proxy measures of technology maturity, we collect patent data, plot the number of patent applications over time, forecast their growth, and determine the maturity of technologies for oligopoly companies. Markets with mature and soon-to-be mature technologies survive Phase III. In other words, we choose markets where the R&D activities of oligopoly companies are decreasing or will decrease in the future.

Through the previous three phases, we can recognize low-risk technological arbitrage opportunities characterized by modest technology complexity, relative unimportance for oligopoly companies, and slowing R&D activities. Key external risks of opportunities are reduced, but internal risks remain. Thus, Phase IV evaluates the organizational fit of these opportunities and eliminates high-risk opportunities due to a company's weak capabilities and resource constraints. The organizational fit is defined as having capabilities and resources enough to utilize opportunities. Consequently, we can identify the low-risk and best-fit business opportunities. Table 2 summarizes concepts, definitions, measures, and processes.

Table 2
Concepts, measures and processes.

Concept	Definition	Measures	Processes
Technology complexity	Difficulty of imitating leading technologies	Time for imitation	Define key performance Collect time-series data Build growth curves Forecast future key performance Calculate time for imitation
Market appropriateness	Oligopoly structure Insignificance of markets for oligopoly companies	Herfindahl Index Market importance index	Collect market share data Calculate Herfindahl Index Collect sales proportion data of oligopoly companies Calculate the market importance of each oligopoly company
Technology maturity	Slowing down of technological advances	Number of patent applications	Collect patents Calculate the number of annual patent applications by oligopoly companies Forecast the future growth Identify the peak
Organizational fit	Having capabilities and resources enough to utilize opportunities	Experts judgments	Select internal experts Select external experts Make presentation and have discussion on capabilities and resources Evaluate the fit of opportunities

Technology complexity analysis

Technology complexity is defined and measured in engineering design (Suh, 2005) and product innovation (Chapman and Hyland, 2004; Novak and Eppinger, 2001). Product innovation can be divided into product development and manufacturing processes. Note that R&D processes are overlapped with product development process more than engineering design. Thus, focusing on the R&D of SMEs, we adopt the measure of technology complexity in product innovation.

The most recurrent measures of technology complexity in R&D are the number of sub-technologies and the maturity of technology (Tani and Cimati, 2008; Zhang and Luo, 2007). These are absolute measures with the assumption of sufficient R&D resources. However, most SMEs are operating with severe resource constraints (Burg et al., 2012). This idea implies that absolute measures for moderately complex technologies could be too complex to develop for SMEs. Considering this idea, we suggest a simple but appropriate measure of technology complexity as follows.

$$TC_{ij} = t_j - t_i > TT_i$$

TC_{ij} denotes time needed for a company i to catch up to a company j for a certain technology. TT_i is the tolerable R&D time for a company i under its resource constraints. Reviewing the interviews with CEOs of Korean SMEs, we find that they usually reject R&D projects that take more than five years (STEPI, 2009). Thus, it is reasonable to measure technology complexity by the time for imitation between a SME and a leading company and also to set the tolerable time as five years. In other words, for technological arbitrage opportunities, if the time taken for R&D is more than five years, the opportunities are filtered out. However, it should be noted that TT_i could vary among countries and industries.

$$TL_i(t) = \frac{ULT}{(1 + e^{-a(t-t_0)})}$$

To calculate TC_{ij}, we develop a technological growth curve showing the performance increase of a certain technology over time. The above formula shows a typical growth curve, which is a logistic curve. $TL_i(t)$ denotes the performance of a technology for a company i. ULT is the upper limit of a certain technology's performance. The absolute gap of technology performance between company i and company j is denoted as $TL_j(t_j) - TL_i(t_i)$. Using $TL_j(t_j)$ and the above formula, we can measure the time for technological catch-up as $t_j - t_i$.

Market appropriateness analysis

As previously noted, the oligopoly markets are chosen using HHI shown below. MS_i is the market share of company i in the market, and n is the number of firms. There are also other indexes, including the comprehensive concentration index (Horvath, 1970) and the Hannah–Kay index (Hannah and Kay, 1977). Since the formulas of those indices are similar, we choose HHI because it is widely used. Usually, a HHI between 0.15 and 0.25 indicates moderate concentration, and a HHI above 0.25 indicates high concentration (Kwoka, 1985). Considering this, we set the threshold value as 0.15.

$$HHI = \sum_{i=1}^{n} MS_i^2 > 0.15$$

Besides the market structure, there are several criteria to judge market appropriateness for SMEs, including size, competition, and regulation. Country-specific factors, such as regulation, should be examined when a company selects target countries. Among the general factors for SMEs, the most important factor to minimize market risk is the competitive pressure from industry leaders (STEPI, 2009). Industry leaders react aggressively to new entry when the revenue proportion of that market is significant. Therefore, we modify HHI and suggest a measure of market importance for a company, as shown below.

$$MI = \frac{\sum_{j=1}^{n} r_j^2}{\sum_{i=1}^{n} r_i^2}$$

where the denominator is the sum of n markets from the smallest market, and the numerator is the sum of n markets from the biggest market. Note that each is an HHI measure. An HHI below 0.01 indicates a fragmented market where each firm occupies a small market share. Thus, when the denominator is below 0.01 and the numerator is above 0.15, an MI larger than 15 means that the revenue proportion of markets included in the denominator is insignificant and that the same in the numerator is significant. Using this, we can identify some small and insignificant markets for oligopoly companies.

Technology maturity analysis

Technology maturity is usually evaluated qualitatively by experts. However, doubts have been cast on the reliability of expert judgments due to subjective errors and information asymmetry (Van Wyk, 2010; Woudenberg, 1991). As an alternative, patents have been highlighted because they provide global-scale and objective data (Haupt et al., 2007). Among patent indicators, the patent application has the advantage of the shortest time lag between R&D and patent record and thus is appropriate to measure R&D activity. However, patent counts have several weaknesses including data availability, inevitable time-lag, little technological quality consideration and others, and thus should be used with due consideration to those problems (Hall et al., 2001; Khan and Dernis, 2006).

Previous studies have shown that a given technology heads into the maturity stage when it reaches a peak of total revenue and technology performance (Klepper, 1996; Mahajan et al., 1990). Thus, it can be assumed that a technology should become mature when it reaches the peak of its patent applications. Considering the time for R&D, we formulate two conditions of technology maturity of oligopoly companies as follows.

$t > t_j(PT)$ or $t < t + t_i(RDT)$ where $t_j(PT)$ denotes the peak when the number of patent applications of the company j is highest. The first condition is that a company j reaches the peak before a SME's opportunity recognition at time t. For the second condition, the patent application of a company j is growing at time t, but will reach the peak before the completion of imitative R&D denoted by $t + t_i(RDT)$. If either of the two conditions is met, the technology of the oligopoly players has already entered or will enter the maturity stage, implying a reduction in R&D activities.

Table 3
Organizational fit criteria.

Category	Criteria	Strong/favorable	Acceptable	Weak/unfavorable
R&D	Internal capability			
	Partners' capability			
Manufacturing	Internal capability			
	Partners' capability			
Commercialization	Internal capability			
	Partners' capability			
	Entry barriers			
Resource constraints	Financial constraint			
	Labor constraint			
	Knowledge constraint			
	Time constraint			

Organizational fit analysis

To evaluate business opportunities that fit a specific company, previous studies have suggested various criteria including R&D capability, manufacturing capability, and financing capability (Linton and Walsh, 2008; Marino, 1996; Walsh and Linton, 2011). We select common criteria for SMEs from the findings of these studies. Above all, we put constraints on evaluating opportunities because most SMEs are operating under severe resource constraints (Burg et al., 2012). Also, SMEs have become increasingly specialized in a specific capability, and thus need not only internal capabilities, but capabilities of their partners and networks (Mesquita and Lazzarini, 2008). Last but not least, SMEs can enjoy some advantages in R&D or manufacturing, but rarely have advantages in commercialization including marketing, distribution and regulation. Thus, successful commercialization depends on entry barriers by competitors, governments, and others. Considering these facts, we fix four categories and key criteria in Table 3.

If all criteria are beyond acceptable, the opportunity makes an acceptable fit with that company. However, if some criterion is below the acceptable level, the opportunity has some risks due to weak capabilities, insufficient resources, and unfavorable conditions. Note that these are basic criteria. To customize criteria to a particular company, we can add and exclude criterion.

Empirical analysis

Background

In the late 1990s, several Korean SMEs jumped into the semiconductor equipment markets. Among those, some companies, such as EO Technics, became major players. Driven by these successes, many Korean SMEs explored and assessed semiconductor equipment business opportunities in the mid 2000s.

For example, a small Korean company was going to enter the front-end semiconductor equipment market in 2008. Founded in 2002, it had been a provider of some semiconductor equipment to Hynix Semiconductor since 2004. Between 2004 and 2008, the compounded annual growth rate of sales was 13.4% with sales of 60 million dollars in 2007. Despite the high growth rate, the company needed new growth engines as the sales growth rate of main products began to decrease.

Like other SMEs, the company had limited capabilities due to its resource constraints. Employees came to a consensus that innovative opportunities from emerging technologies should not be a viable option because they could not take high risks. Also, they were in pursuit of low cost advantages because they had confidence in production efficiency. Moreover, most front-end semiconductor equipment markets had been dominated by oligopoly companies, and some markets became less attractive to those companies because of limits to growth and technology maturation. This example illustrates the typical situation of recognizing low-risk technological arbitrage opportunities in mature technologies. Thus, the company is appropriate to demonstrate our method in terms of both internal capabilities and characteristics of target markets. The application process will be described in the following sections.

Technology complexity analysis

The manufacturing of a semiconductor is divided into a front-end process and a back-end process. The front-end process creates circuits on silicon wafers and consists of nine processes. Each process has a core function and matches with a technology shown in Table 4. The Korean Ministry of Education, Science and Technology (MEST) collected technology performance data for Korea, the USA, and Japan and then developed growth curves for several semiconductor equipment in 2008 (MEST, 2009). We basically use these data and collect complementary data from the Korean Semiconductor Industry Association (KSIA). With these data, we develop growth curves and calculate the technology performances of Korea and leading countries for nine front-end semiconductor technologies in 2008.

As shown in Table 4, the technology gaps measured by the years for imitation are more than five years for four technologies, including of lithography, ion implant, PVD, and metrology & inspection. Therefore, these four technologies have a high technology complexity. High technology complexity makes it difficult for SMEs to imitate leading technologies. Thus, the risk of pursuing technological arbitrage opportunities based on these technologies is higher than other technologies. Also, the companies want to avoid R&D of more than five years due to resource constraints. Therefore, we eliminate the opportunities based on these technologies. Although we can select technologies with the smallest technology gaps at this stage, an early application of very strict criteria should be avoided because we do not consider the R&D capability of the companies and thus could eliminate some good opportunities.

Market appropriateness analysis

Using the market share data of front-end semiconductor equipment by Gartner and KSIA, we identify the main semiconductor equipment in each of the technology and oligopoly companies and calculate the HHI of each equipment market (Gartner, 2008). As shown in Table 5, the values of HHI are above 0.15 in all equipment markets, meaning that those are oligopoly markets. Notably, there are two Korean SMEs composed of PSK in the Asher market and Jusung Engineering in the ALD market. The success of those companies stimulated other Korean SMEs to explore opportunities in these markets.

To judge the importance of equipment markets for oligopoly companies, we collect the sales data of eight oligopoly companies in Table 4. PSK and Jusung Engineering are not included because these SMEs have limited capability of imposing competitive pressure on a new entry. For instance, the sales data of Applied Materials in 2007 are as shown in Table 6. Although it is easy to recognize the relative importance of markets, the boundary between markets of high and low importance is not obvious.

Thus, changing the number of types of equipment in both the numerator and denominator of the market importance measure, we explore the smallest value of that measure above 15. As shown in Table 7, we can find the value of 15.8 when the top five markets are put in the numerator and the bottom five markets in the denominator. This means that the bottom five, composed of ALD, RTP, CMP, ion implant, and wet cleaning, are not likely to be core markets for Applied Materials. Applied Materials will react to a new entry in these markets less aggressively than in the top five markets. The ion implant market is eliminated due to technology complexity at the previous stage, and thus should

Table 4
Technology performance and gap.

Technology	Technology performance (Korea, %)	Technology performance (leading country, %)	Technology gap (years)
Lithography	59.0	80.3	5.4
Etching	66.3	79.2	3.4
Diffusion	67.3	82.7	2.1
Ion implant	51.3	83.5	6.5
CVD	64.0	80.5	1.2
PVD	49.3	81.3	5.3
CMP	67.2	80.5	3.5
Wet etch & cleaning	66.3	78.0	3.7
Metrology & inspection	56.9	86.3	6.4

Note: CVD (chemical vapor deposition), PVD (physical vapor deposition) and CMP (chemical mechanical planarization).

Table 5
Market share and HHI.

Technology	Equipment	HHI	Oligopoly companies (market share, %)
Etching			
	Dry etcher	0.30	LAM (41.1%) TEL (27.8%)\ Applied Materials (16.8%)
	Asher	0.17	PSK (24%) Novellus (23%) Mattson (18%) Axcellis (12%)
Diffusion			
	RTP	0.52	Applied Materials (68.2%) Mattson (22.4%)
CVD			
	Tube CVD	0.57	TEL (72.4%) Hitachi Kokusai (18.9%)
	Vertical/barrel CVD	0.36	Applied Materials (52.4%) Novellus (22.4%) TEL (10.7%)
	ALD	0.26	Hitachi Kokusai (38.0%) Jusung Engineering (25.8%) ASM (17.7%)
CMP			
	CMP	0.53	Applied Materials (69.3%)
Wet etch and cleaning			
	Wet station	0.41	Dainippon Screen (57.4%)
	Spin-spray	0.42	Dainippon Screen (60.3%)

Note: RTP (rapid thermal processing) and ALD (atomic layer deposition).

Table 6
Sales data of Applied Materials in 2007.

Equipment	Sales (dollars in millions)	Sales proportion (%)
Lithography	847.6	26.9%
Dry etcher	587.9	18.6%
PECVD	473.7	15.0%
Wafer inspection	421.5	13.4%
Sputter	265.9	8.4%
Wet cleaning	214.6	6.8%
Ion implant	133.7	4.2%
CMP	123.0	3.9%
RTP	60.0	1.9%
ALD	26.9	0.9%

Source: Annual Report FORM 10-K (Applied Materials, 2009).

be filtered out. Also, it should be noted that this is the maximum number of low-importance markets. To reduce the risk of the aggressive competitive pressure from Applied Materials, we can choose the smaller number of markets.

For eight oligopoly companies identified in Table 5, using the market importance measure, we select relatively unimportant semiconductor equipments for each company and identify three commonly unimportant markets of Asher, RTP and ALD for all companies.

Technology maturity analysis

To collect patents, several patent databases are available, but the U.S. Patent and Trademark Office (USPTO) database, characterized by applications on a global scale in semiconductor equipment, is one

Table 7
Market importance evaluation of Applied Materials.

Equipment in numerator	Equipment in denominator	Market importance
Lithography	ALD	893.3
Lithography, dry etcher	ALD, RTP	242.0
Lithography, dry etcher, PECVD	ALD, RTP, CMP	65.9
Lithography, dry etcher, PECVD, wafer inspection	ALD, RTP, CMP, ion implant	39.6
Lithography, dry etcher, PECVD, wafer inspection, sputter	ALD, RTP, CMP, ion implant, wet cleaning	18.5
Lithography, dry etcher, PECVD, wafer inspection, sputter, wet cleaning	ALD, RTP, CMP, ion implant	42.7
Lithography, dry etcher, PECVD, wafer inspection	ALD, RTP, CMP, ion implant, wet cleaning, sputter	9.6

of the most appropriate databases to avoid local biases and thus is the one we use. Using keywords extracted from technical reports and patents, we collect patents of Asher, RTP, and ALD between 2000 and 2007. Then, available information is used to assign patents to oligopoly companies in each equipment market. With these data, time series graphs of the number of patent applications by oligopoly companies are constructed to understand dynamic trends.

We find that three companies in the Asher market had already gone over the peak, meaning that the Asher technology had been in the midst of the maturity stage. R&D activities of Axcellis and Mattson had weakened far before 2007, and Novellus showed a sharp fall in 2007 (see Fig. A.1). All oligopoly companies reached their peaks before the opportunity recognition of this company in 2008, satisfying the first condition of technology maturity, as previously noted.

The trends of patent applications for RTP were very different between the two oligopoly companies. The number of patent applications by Mattson reached the peak in 2001 and could not get back on a steadily growing path afterwards. Contrastingly, the number of patent applications by Applied Materials grew between 2003 and 2007. As for ALD, Hitachi Kokusai and ASM had increased the number of patent applications showing ups and downs by 2007.

Obviously, the first condition is not met for patent applications of Applied Materials in RTP and two ALD companies. Thus, we forecast the future number of patent citations using the curve fitting technique. This technique is proven to be appropriate for technology growth processes (Daim et al., 2006). Cumulatively, three time series graphs have the best fit to a logistic curve with the coefficients of determination more than 0.93 and statistical significance less than 0.01.

We expect that the number of patent applications by Applied Materials will reduce sharply after 2007, meaning that its peak will be reached in 2007 (see Fig. B.1). Similarly, we anticipated that ASM will show a sharp decline in the number of patent applications after 2007. The only exception is Hitachi Kokusai. We expect that the company will increase its patent applications by 2008 and will maintain this level of applications until 2009. However, our forecast tells us that the company will head into a declining period in 2010 (Table 8).

Overall, the first condition is met in Asher and RTP. However, as shown in Table 4, it will take slightly more than one year for the technological catch-up of ALD. The second condition is not satisfied in ALD, let alone the first, implying that the new entrant in the ALD market will be exposed to strong competitive pressure. Put another way, if the company decided to enter the ALD market and could release its ALD product in 2008, it would be in fierce competition with Hitachi Kokusai because Hitachi Kokusai would still be increasing R&D. However, Hitachi Kokusai is expected to reduce its ALD R&D after 2008 (see Fig. B.2). Thus, it is recommended that companies enter the ALD market at least after 2008. ALD is one of the next-generation CVD technologies. Old CVD and several new technologies including ALD have been competing in the same market. Thus, if some technologies become dominant due to performance increases, the ALD market could evaporate. Considering these risks, we eliminate the ALD business opportunity.

Organizational fit analysis

Given the two remaining business opportunities of Asher and RTP, we evaluate the fit of each opportunity with an example company. This company runs a strategy committee including a CEO, four

Table 8
Peaks of patent applications of three types of equipment and technology maturity.

Equipment	Companies	Peak of patent applications (year)	Technology maturity
Asher	Novellus	2006	Matured
	Mattson	2007	Matured
	Axcellis	2003	Matured
RTP	Applied Materials	2007 (forecasted)	Matured
	Mattson	2001	Matured
ALD	Hitachi Kokusai	2009 (forecasted)	Will head into maturity in 2010 (after two years)
	ASM	2007 (forecasted)	Matured

CEOs of partners, and four managers of global semiconductor companies. The committee holds the meeting for evaluation. At first, the CEO of this company explains the results of previous analyses, the pros and cons of survived opportunities, and its own capabilities and resources. CEOs of partner companies make brief reports on their capabilities and resources. Finally, four managers provide others with some information, including the required quality and price of two types of equipment. Then, committee members individually evaluate the fit of two opportunities. Collecting and sharing the evaluation results, they make some discussions on the problems for which opinions are split or various and fix the evaluation, as shown in Tables 9 and 10.

Obviously, the organizational fit of RTP is better than that of ALD. As for RTP, this company has strong R&D capability and could use partners with strong manufacturing capability. Resource constraints and entry barriers are above an acceptable level. The main weakness comes from weak commercialization capabilities. This weakness suggests that the company should find a capable commercialization partner with which to enter the RTP market.

Table 9
Organizational fit evaluation of RTP.

Category	Criteria	Strong/favorable	Acceptable	Weak/unfavorable
R&D	Internal capability	S		
	Partners' capability		A	
Manufacturing	Internal capability		A	
	Partners' capability	S		
Commercialization	Internal capability			W
	Partners' capability			W
	Entry barriers		A	
Resource constraints	Financial constraint	S		
	Labor constraint		A	
	Knowledge constraint		A	
	Time constraint		A	

Table 10
Organizational fit evaluation of ALD.

Category	Criteria	Strong/favorable	Acceptable	Weak/unfavorable
R&D	Internal capability			W
	Partners' capability		A	
Manufacturing	Internal capability		A	
	Partners' capability		A	
Commercialization	Internal capability			W
	Partners' capability			W
	Entry barriers	S		
Resource constraints	Financial constraint		A	
	Labor constraint			W
	Knowledge constraint			W
	Time constraint		A	

Contrastingly, to seize the ALD business opportunity, this company and its partners do not have any strong capability. Under severe labor and knowledge constraints, they have little R&D and commercialization capabilities. To enter the ALD market, this company should either collaborate with others to compensate for its weaknesses or improve its own capabilities.

Discussion and conclusion

This paper suggests a new method for recognizing low-risk technological arbitrage opportunities in mature technologies for SMEs. Above all, this is a first attempt to define a specific type of technological arbitrage opportunity, distinguishing it from general technological arbitrage opportunities. Reviewing cases and reports of some globally successful SMEs, we identify low-risk technological arbitrage opportunities with distinctive characteristics comprising imitable technology complexity, insignificant market for oligopoly companies, and mature technologies. These opportunities might be particularly useful for SMEs, implying other useful types of technological arbitrage opportunities. In this regard, our study opens a door for the study of various technological arbitrage opportunities.

Our method goes beyond simple opportunity recognition. Anokhin et al. (2010) presented a technique to measure and identify technological arbitrage opportunities, but did not suggest a way of assessing the appropriateness of opportunities for a specific company. As they pointed out, if the production functions of firms are different, their opportunity estimates could be wrong, and thus become inappropriate for some companies. Important characteristics of technological arbitrage opportunities including technology barriers and competitors are not considered enough.

In our method, three key characteristics, including technology complexity, market importance for oligopoly companies, and technology maturity, are identified and used as criteria to minimize the risks of technological arbitrage opportunities. Note that core risks of opportunities are evaluated and then unperceived risks are converted into perceived risks. We also provide basic criteria to evaluate the organizational fit of opportunities. Using these criteria, we suggest a systematic method to filter out high-risk opportunities and identify low-risk technological arbitrage opportunities for a specific SME. Our approach complements previous works by Anokhin et al. (2010), providing specific evaluation criteria and analytic tools to recognize low-risk and best-fit technological arbitrage opportunities for a specific SME.

Practically, our approach can help SMEs recognize appropriate low-risk technological arbitrage opportunities from mature technologies and thus identify a new path of market entry and business growth in global markets. Although SMEs can recognize some technological arbitrage opportunities using existing methods, they have difficulty in filtering out inappropriate opportunities among those. Large companies can use the qualitative judgments of several internal experts. However, under severe expert and knowledge constraints, SMEs cannot use experts' judgments and thus cannot recognize appropriate opportunities. Using our method with empirical evaluation criteria and analytic tools, they can assess the appropriateness of opportunities and recognize the best-fit opportunities. Also, with mostly publicly available data and easy-to-analyze tools, our method has advantages over sophisticated methods such as TOA, which uses a huge amount of data and complex analytic tools.

Governments are probing for a way to boost the growth of SMEs. Various policies have been set and implemented. One of those policies is to invest in high-technology start-ups with government R&D funding. However, only over one third of government-funded SMEs reported an increase in sales (OECD, 2010). Put another way, the efficiency of these policies is not high in some countries. Through effective technological arbitrage opportunity recognition, our approach can help policymakers perceive low-risk and appropriate opportunities for SMEs and thus increase the efficiency of government policies for SMEs.

Despite the value of our findings, our study has several limitations. Above all, it is notable that some successful SMEs with low-risk technological arbitrage opportunity recognition depend on internal entrepreneurs. Reviewing cases of SMEs, we find that some entrepreneurs involved in the opportunity recognition process made important contributions. Thus, the role of entrepreneurs should be investigated. Although basic criteria are available, the organizational fit criteria need to be extended because there are company-unique but important capabilities, resources, and other criteria.

These limitations demonstrate the need for future studies. Above all, there are alternative empirical data, measures, and analytic tools available that are not provided here. For instance, technology maturity can be analyzed using technology adoption data and diffusion models. Such alternatives can enhance the applicability of our methods and thus should be explored in future studies. Also, some approaches for very small companies need to be developed. From a broader perspective, we expect that our research will stimulate specific approaches to find and utilize technological arbitrage opportunities. Last but not least, it should be noted that good opportunity recognition is not a guarantee of business success. Some SMEs can experience success by exploiting innovative opportunities. Similarly, some can fail to make profits from low-risk technological arbitrage opportunities. We make further efforts to identify the key factors of such phenomena and integrate those into the opportunity recognition framework.

It is confirmed that this item has not previously been published and has not being submitted for publication elsewhere

Appendix A

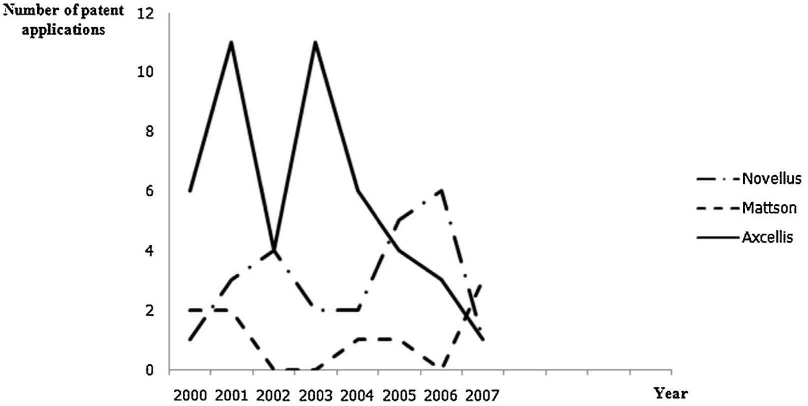

Fig. A.1. Patent applications of Asher by Novellus, Mattson and Axcellis.

Appendix B

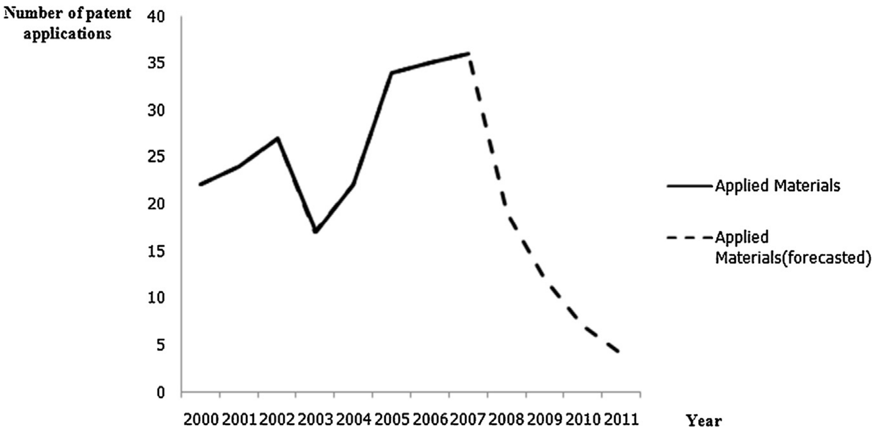

Fig. B.1. Forecasted patent applications of RTP patents by Applied Materials.

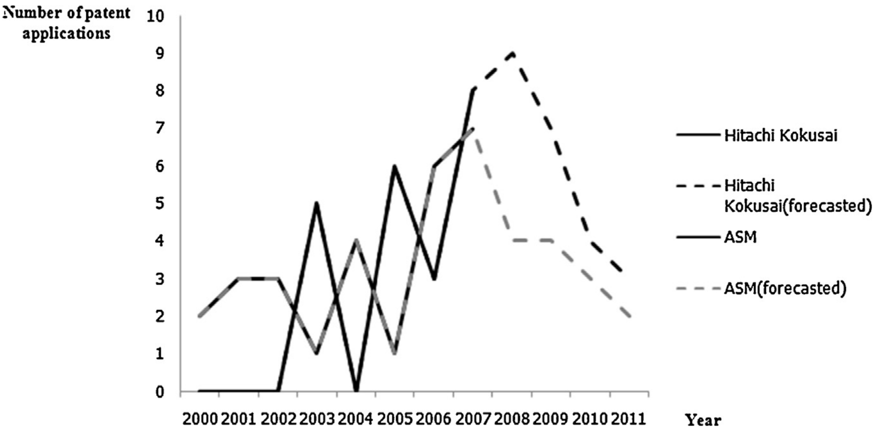

Fig. B.2. Forecasted patent applications of ALD patents by Hitachi Kokusai and ASM.

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