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What Causes Technology Commercialization to Succeed or Fail after Transfer from Public Research Organizations

Yong-Jeong Kim*, Seowon Joseph Shin**

Abstract This study explores how the technology commercialization process leads to either success or failure after transfer from PROs to SMEs by conducting a binomial logistic regression analysis. We found that the more additional development a firm implements on the transferred technology, the more likely the commercialization is to fail. The higher number of alternative technology and bigger market risk are associated with a greater likelihood of failure. On the other hand, the existence of complementary technology, the degree of cooperation with the technology provider, the size of the target market, the willingness of the CEO, and the funding availability are known to have positive effects on the success of technology commercialization. In addition, the case studies we conducted from the sample companies demonstrated that "market uncertainty," "technological issues depending on the technology-specific characteristics," and "a lack of funding capability" are some of the causes for failure of technology commercialization.

Keywords Technology commercialization, success factors of commercialization, barriers to commercialization, public research organizations

I. Introduction

In the field of technology commercialization, the importance of innovation has been highlighted because technology development is understood as an important driver of firm performance (Eisenhardt and Martin, 2000; Nerkar and Shane, 2007; Zahra and Nielsen, 2002). To have technology sourced and successfully commercialized, firms search for proper modes of technology transfer. This search ranges from traditional 'make, buy, or ally' decisions to narrower decisions such as licensing patented technologies, transfer of technology ownership, joint venture or a mix of those (Arora and Fosfuri, 2003; Lungeanu, Stern and Zajac, 2015; Somaya, Kim and Vonortas, 2011;

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* Corresponding, Korea Institute of Science and Technology, Evaluation and Planning, 68 Mabang-gil, Seocho-gu, Seoul, 06775, Korea; yongjkim@kistep.re.kr
** Foster School of Business, University of Washington, Seattle WA98195, U.S.A.; seowon@uw.edu

Van de Vrande, 2013). For example, according to Somaya and his colleagues (2011), contractual licensing, especially exclusive licensing followed by patent scope restriction, offers a way to harness valuable technologies from other firms. Obtaining exclusive rights limits opportunistic behaviors and other appropriable hazards and effectively increases the chances of successful commercialization of the technology.

Although these studies advanced our understanding of technology commercialization, we argue that the success of technology commercialization depends more on the source of the technology, particularly from a public sector perspective, rather than the mode of technology transfer. In the past, many studies have attributed the success of technology to universities as a major source of patented technology (Link, Siegel and Bozeman, 2007; Rothaermel and Thursby, 2005; Thursby and Kemp, 2002). The representative study by Thursby and Thursby (2002) examined the role of university technology transfer, particularly with respect to the source of the commercial outputs. By dividing the university technology transfer process into a multistage procedure, including three levels of disclosure, patent evaluation, and license agreements, the authors sought to understand the reasons behind the growth in university licensing. Each stage is analyzed by using total factor productivity and survey findings, resulting in identifying two reasons for the growth in university licensing. The first reason is that university faculty and staff members are more likely to seek business partnerships to commercialize their research findings. The second reason is that more firms are relying on external R&D. The changes in faculty's focal subject and in demand for university technologies from private firms have caused universities to become a popular source of technology for commercialization. Given this, the technological source of commercialization is an important topic to consider (Thursby and Thursby, 2002).

Previous research has limited the sources of technology for commercialization to the private sector and neglected the role of the public sector. In particular, network approaches in the private sector have dominated the literature. For example, scholars have largely concentrated on inter-firm R&D partnerships with firms in the same industry, suppliers, or buyers (Hagedoorn, 2002; Hoang and Rothaermel, 2005; Li, Eden, Hitt and Ireland, 2008) to understand the sources of commercialization success. Meanwhile, a limited number of studies have focused on public research organizations (PROs) - universities and government research institutes - as a source of technological invention (Cohen, Nelson and Walsh, 2002; Park, Ryu and Gibson, 2010).

In this paper, we investigate the technological effect of PROs and its impact on the success of commercialization. We distributed a questionnaire to technology-intensive firms that had relevant technologies transferred from PROs and had proceeded to commercialize them. The data from the survey include questions related to the commercialization processes, technology-specific characteristics, institutional contexts, market conditions, CEO and firm-specific characteristics. We subjected the data to a logistic regression analysis and derived factors that influence the commercialization procedures. For the validity of the study, we added a qualitative perspective by including case studies of firms we had sampled from the population. We expect our empirical findings will help firms and policy makers to take decisions that contribute to ensuring that firms avoid failures.

The purpose of this study is, then, to understand the commercialization process after technology has been transferred from PROs to private firms, particularly small and medium-sized enterprises. We investigate what causes the commercialization of technology originated from PROs to succeed or fail. The research questions we want to answer are:

- How do firms that acquired patented technology from PROs successfully commercialize that technology?
- What are the factors of success of commercialization after the technology transfer from PROs?
- What are the barriers to commercialization after the technology transfer from PROs?

The paper is organized as follows. The following section provides a theoretical background of studies related to technology transfer and commercialization. Section 3 introduces the data and methodology; we give an overview of the data collection process and research model. To understand the commercialization process in a qualitative aspect and to ensure the validity of the empirical model, Section 4 provides details of the case of four firms from different industries. The firms are selected from those that have introduced public patents, have attempted to commercialize and have responded to our survey. Section 5 concludes by presenting implications of the study and policy recommendations.

II. Theoretical Backgrounds

The commercialization of technology to industry by universities has a long history, and research topics related to it has dominated the commercialization literature[1]. The number of cases of knowledge transfer from universities to private firms through licensing and patenting and the number of contracts have dramatically increased, particularly in the 1980s and 90s, since the Bay-Dole Act in the United States (Mowery, Sampat and Ziedonis, 2002; Mowery and Ziedonis, 2002; Shane, 2004).

The individual and team characteristics of academic faculty or firm members, the organizational characteristics of universities or firms, and the means of knowledge transfer (i.e. technology itself) are three major topics that previous research has highlighted to explain university commercialism (Kim and Shin, 2016).

Some scholars emphasize attributes of individual or group-level researcher(s) to understand what causes commercialization in universities. Owen-Smith and Powell (2001) suggested faculty perceptions of the benefits of patent protection as an important factor to consider. Measuring the institutional success of patenting as a performance of commercialization, the authors interviewed 68 faculty and licensing professionals. The authors concluded that although benefits from patenting vary according to the research area, the perception of personal and professional benefits and the appreciation of time and resource costs are positively related to the disclosure of their intellectual property for commercialization. Similarly, Haeussler and Colyvas (2011) found that the scientific productivity of researchers has a positive relationship with commercialization. In their study, the authors showed that higher publication productivity is related to more patenting and licensing results by analyzing a survey-based dataset of 2,294 German and UK life scientists. Such demographic characteristics as age and gender are also shown to have an impact on commercial activities. Older tenured faculty members are more likely to succeed in commercialization than younger researchers. Males are likely to have better results from commercialization than females, a result consistent with other studies (Colyvas, Snellman, Bercovitz and Feldman, 2012; Murray and Graham, 2007). Also, the degree of team heterogeneity is salient to the relationship with commercialization. Bercovitz and Feldman (2011) found that creative team members with higher heterogeneity in experience level and knowledge novelty are more likely to succeed in the commercialization process. Researchers of 1,425 invention disclosures from well-known medical schools were selected as a sample of the study with probit analysis. The study shows that not only the individuals, but also the composition of the research team itself determine whether the research will provide more marketable ideas.

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[1] For detailed review, refer to Bozeman, Fay and Slade (2013); Rothaermel, Agung and Jiang (2007)

While some scholars have previously focused on the individual and team characteristics of the researchers, others have suggested that the individuals or teams in the technology-recipient firms are more important. The majority of these studies focus on managers, top management team members, and founding members or CEOs who make the significant decisions within a firm. According to Knockaert and her colleagues (2011), tacit knowledge is more likely to be transferred to firms when more researchers join the top management team. That is, the proportion of researchers among the founding members and composition of their knowledge are expected to be positively associated with commercialization. Although the study is an inductive case study and needs empirical support to prove the theory, it is nevertheless a representative study of how entrepreneurs' knowledge can influence the success of a firm in commercialization (Knockaert, Ucbasaran, Wright and Clarysse, 2011). On the team level of the firms, the heterogeneity of entrepreneurial teams is also associated with commercialization successes. A study by Vanaelst and her colleagues (2006) found that in the spin-off venture dynamics, the founding team members of a startup are likely to experience personnel changes within the team. The change can be experiential, entrepreneurial, or cognitive and it also evolves through the different stages of the firm's development. As new members join the founding team and it becomes larger, the heterogeneity of the entire firm increases, and the likelihood of a venture to commercialize its innovation also increases. Thus, the evolution of heterogeneity is a necessary condition for commercializing research ideas.

There also are studies that attribute certain characteristics of universities as organizations to describe commercialism. For example, more R&D expenditure (Coupe, 2003), rewards and incentives system of university, proximity to the firms' location (Friedman and Silberman, 2003), the institutional setting or initiatives of universities (Bercovitz and Feldman, 2008; Goldfarb and Henrekson, 2003), past institutional experience (Mowery et al., 2002), and the commercial-orientation culture of a university (Di Gregorio and Shane, 2003) are some of the factors that influence commercialism. The more R&D expenditure the university commits, the more incentives are given to faculty members, and the closer the university is to an associated firm, the more likely a firm will succeed in commercializing its product or service.

Meanwhile, other scholars argue that a consideration on the attributes of the technologies themselves is conducive to understanding inventions originating from universities and their commercialization. According to Nerkar and Shane (2007), the scope of a patented technology and the degree of an invention's innovativeness are useful to know because a technology with a broader scope provides a wider range of alternative technologies, thereby reducing the risks related to commercialization and, eventually, securing Schumpeterian rents.

The analysis was based on data from the technology licensing office of the Massachusetts Institute of Technology and a dataset containing 966 technology transfer events between 1980 and 1996.

The results of the studies mentioned suggest that commercialization of innovation from universities is a complex mix of factors including the characteristics of the individuals and teams in both the universities and firms, and also the characteristics of the technology itself.

While commercialization of technologies originating from universities has been widely studied, the commercialism from government-subsidized research institutes (GRIs) has been relatively neglected in the specialist literature. One reason for this state of affairs is that, among the commercialization cases from PROs, the number of cases from universities outnumbers that of GRIs'. That is, firms approach universities more often than GRIs to search for sources of knowledge. The phenomenon is based on the market change from "opportunity push" to "demand pull" (Cohen et al., 2002). Another reason is that the roles of state and government institutions have also changed. In the past, GRIs played a coordinating role in helping the government as a "market-constructing state". Currently, the governmental role has shifted toward "market-facilitator state", thereby decreasing the role of GRIs in terms of scientific commercialization (Mok, 2005). This shift in governmental role is put forward similarly by Link and Link (2009). In their study, the authors define the government "in a Schumpeterian manner as entrepreneur" that "leverages the ability of firms and other actors in a national innovation system to participate efficiently in the innovation process and thereby to contribute to technology-based economic growth."

However, the role of public-sector research institutions is still vital to understanding the commercialization process for several reasons. First, the technology commercialization activities originating from PROs differ from inter-firm licensing transactions (Jeong and Lee, 2015; Park et al., 2010). According to a study by Cohen and his colleagues (2002), firms are more likely to select PROs as a knowledge source for commercialization completion. Particularly in the petroleum, steel, machine tool, semiconductor and aerospace industries, public research provides the means to achieve the final goals of commercializing projects. Second, contribution to technology commercialization from the public sector can reach the largest macroeconomic level, including quality-job creation and improved national competence (Bozeman, 2000; Roessner, Bond, Okubo and Planting, 2013). To estimate the contribution of public licensing to the national U.S. economy, Roessner and his colleagues (2013) used input-output (I-O) model coefficients of the licensing of intellectual property data from US universities between 1996 and 2010. The total contribution of licensing to the national GDP of the US was at least $162.1 billion, given a 2% royalty assumption, and at most

$686.9 billion, given a 10% royalty assumption (2005 USD). Also, during the fifteen years, the number of additional jobs created from the licensing and commercialization totaled an estimated 277,000 person-year of employment. Third, the commercialization process from public organizations to private firms is a canonical example of the interdependence of public and private interests (Aldridge and Audretsch, 2010; Mahoney, McGahan and Pitelis, 2009). The entire commercialization process starting at public institutions and developed at private firms shows how public and private interests are aligned. This is because, on the one hand, GRIs fulfill their goals of fostering fundamental discoveries and research strategies, which can benefit the general public by successfully providing necessary technologies to private firms. On the other hand, the firms achieve their goals of sustaining their organization by providing values to customers through products and services derived from the commercialized technologies. Therefore, commercialization from public R&D to private firms demonstrates the interdependence of the public and private sectors in that the private interest is defined in reference to the public one through GRIs.

III. Methodology

1. Research Setting

Some cases of successes or failures of commercialization previously examined focused on the initial sales of products or services embedded in the transferred technology (Mitchell and Singh, 1996; Nerkar and Shane, 2007), while others considered success as the achievement of specific milestones, such as when new employees are hired or when licensing agreements are consummated (Siegel and Wessner, 2012). In this study, we concentrate on whether the firm had launched its product or service into the market. We opted to examine the issue from a more market-oriented perspective than the market-share perspective of the past because the market for technology is known to be imperfect (Thursby and Kemp, 2002; Jeong and Lee, 2015). In other words, if the firm launched its product or service through the implementation of the transferred technology, we considered that to be a successful commercialization. Although this measure does not necessarily indicate a complete ‘successful commercialization,’ the launch of product or service in the market is a necessary condition for commercialization.

In this paper, we track the patents initially registered by such PROs as universities and government research institutes (GRIs) and then transferred to small and medium-sized enterprises (SMEs). Despite the various types of technology transfer without patenting technology, we focus on the patented technologies transferred from GRIs to SMEs because of the ease of tracking them. Through the examination of the patented technologies, we seek to understand the factors contributing to the success of the technology commercialization process by using the logistic regression model.

2. Model and Estimation

The logistic regression model assumes the relationship between dependent variables and independent variables as nonlinear. The non-linearity assumption is fundamental to estimate the probability of an event to occur. That is, it is not binomially approaching whether the event will occur or not, but rather we estimate the probability of its occurrence. The model, therefore, includes a dependent variable in the form of binary numbers, 0 or 1. If the result of the dependent variable is greater than 0.5, we expect that the event will occur, but if it is less than 0.5, we consider the result as non-significant and expect that the event will not occur. Because the value of the dependent variable is always between 0 and 1, we adopt the following estimation equation for the logistic function.

$$\mathrm{E}(\mathrm{Y}|x) = \frac{\exp(\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_k x_k)}{1+\exp(\beta_0+\beta_1 x_1+\beta_2 x_2+\cdots+\beta_k x_k)} \quad \text{(Equation 1)}$$

Generally, while the relationship between the probability of occurrence and the independent variables is an S curve, if the probability is transformed into logit, the upper and lower limits of probability disappear. The relationship then becomes linear and it is possible to express it as a linear function.

The expected value of (Equation 1) is E(Y|x) and this indicates probability. We were able to set E(Y|x) as p and transform into logit form by the following process.

$$\mathrm{p} = \ln\left(\frac{p}{1-p}\right) \quad \text{(Equation 2)} \qquad \mathrm{p} = \ln\left(\frac{E(Y|x)}{1-E(Y|x)}\right) \quad \text{(Equation 3)}$$

We selected the maximum likelihood for the estimation of the logistic coefficient to explicate relationships between the dependent variable and the independent variables, rather than ordinary least squares from the linear regression model. In order to test the coefficients, we decided to execute a likelihood value test. To understand the significance of the coefficient, the Wald value was derived from the square of the coefficient divided by the standard error. Also, rather than using the coefficient of determination R^2 to understand the goodness of fit of the model, this logistic regression model uses the correct classification rate. The correct classification rate is obtained by comparing the actual value and expected values of the dependent variables. In particular, for the goodness of fit in this model, we apply the Hosmer-Lemeshow test that assesses whether the rates of the observed event match the expected event rates. In other words, the Hosmer-Lemeshow method tests the null hypothesis that there is no difference between observed and expected values. When the null hypothesis is rejected, it is assumed that the model has an appropriate goodness of fit.

3. Data and Variables

Data for the logistic regression model is sourced from the survey questionnaire that the governmental research administrative institution [2] distributed to technology-intensive firms in South Korea. We omitted the firms that have not initiated commercialization or that have commercialization in progress. The final dataset includes 80 successful commercialization cases that had launched products in the market, and 35 failed commercialization cases, making a total of 115 firms with analyzable feedback.

The firms in the survey supplied with patented technology from PROs include 55 universities and 21 GRIs between 1999 and 2013. The transfer data was sourced from the National Science and Technology Information Service (NTIS), a database constructed by the South Korean government to provide information on government-subsidized R&D programs for administrative purposes. The questionnaires were sent to the managers or top management team members who were in charge of the commercialization projects.

The variables for the logistic regression model are shown in Table 1. The dependent variable (COMM) is a dichotomous success or failure variable. The following independent variables fall into six categories: the technology-specificity, the commercialization project-specificity, the target market, the institutional context (rules/regulations), the CEO-specificity and the firm-specificity.

[2] Korea Institute of Science and Technology Evaluation and Planning (www.kistep.re.kr)

Table 1 Definitions and description of variables

Variable	Definition	Description	Mean	Std. Dev
COMM	Success / Failure	Binomial		
ADDTECH	additional technology development	Binomial		
COMPTECH	complementary technology	Binomial		
ALTTECH	alternative technology	Binomial		
RELTECH	relevance to conventional technology	5 Likert Scale		
DURATION	Duration of commercialization project	Number of project months	2.365	1.071
RDINPUT	R&D Input	Number of R&D related employees	4.861	2.905
MNGINPUT	Management Input	Number of administrative managers	2.183	1.814
FUNDING	Funding amount of commercialization project	Units in 100K USD	3.631	5.236
SOURCECOOP	Cooperation with Technology Provider	5 Likert Scale		
GOVSUPPORT	Government Support	Binomial		
MKTSIZE	Market Size	5 Likert Scale		
MKTUNC	Uncertainty in the Market	5 Likert Scale		
COMPINT	Competition Intensity of the Market	5 Likert Scale		
ENTREGINT	Entry Regulation Intensity	5 Likert Scale		
MKTPROINT	Local Market Protection Intensity	5 Likert Scale		
ENVREGINT	Environmental Regulation Intensity	5 Likert Scale		
IPPROINT	Intellectual Property Protection Intensity	5 Likert Scale		
CEOAGE	CEO Age	5 Categories (under 30, 30~39, 40~49, 50~59, over 60)		
CEODEG	Final Degree	3 Categories (BA or less, MS or equivalent, PhD or more)		
CEOREL	Career Relevance	5 Likert Scale		
CEOEXCOMM	Past Experience of Commercialization	Binomial		
CEOWILL	CEO's Willingness to Commercialize	5 Likert Scale		
FIRMAGE	Firm Age	Number of years since firm establishment	18.748	8.781
FIRMSIZE	Number of Employees	4 Categories (under 10, 10~49, 50~299, over 300)		
FIRMEXCOMM	Past Experience of Commercialization	Binomial		
CORETECHCAP	Core Technology Development Capability	5 Likert Scale		
FUNDINGCAP	Funding Capability	5 Likert Scale		
HUMCAP	Human Capital Development Capability	5 Likert Scale		
MKTINFOCAP	Market Information Capability	5 Likert Scale		

Technology-specific characteristics consist of four variables: additional technology development (ADDTECH) that indicates whether the firm conducts further development in order to enhance the completeness of the transferred technology; complementary technology (COMPTECH) represents whether the firm has different kinds of technologies that can enhance the value of the transferred technology when combined with conventional technology; alternative technology (ALTTECH); and relevance to conventional technology (RELTECH).

Project-specific characteristics are measured by six variables: duration of the commercialization project (DURATION), the number of employees focusing on the R&D itself (RDINPUT), the number of employees focusing on management, specifically marketing (MNGINPUT) funding (FUNDING), cooperation with technology providers (SOURCECOOP), and government support (GOVSUPPORT).

The variables related to the target market are market size (MKTSIZE), the uncertainty in the market (MKTUNC), and the level of competition intensity of the market (COMPINT).

The institutional context and environment were measured by entry regulation intensity (ENTREGINT), local market protection intensity (MKTPROINT), environmental regulation intensity (ENVREGINT), and intellectual property protection intensity (IPPROINT).

Furthermore, we considered variables related to CEO characteristics (Rothaermel & Deeds, 2006; Yli-Renko, Autio, & Sapienza, 2001) such as CEO's age (CEOAGE), degree (CEODEG), career relevance (CEOREL), past experience of commercialization (CEOEXCOMM), and willingness to commercialize (CEOWILL).

Lastly, we also included firm-specific control variables such as firm age (FIRMAGE), number of employees (FIRMSIZE), past experience of commercialization (FIRMEXCOMM), core technology development capability (CORETECHCAP), funding capability (FUNDINGCAP), human capital development capability (HUMCAP), and market information capability (MKTINFOCAP).

4. Regression Results

As mentioned above, we examined firms with commercialization project experience. The sample consists of 115 companies and the quantitative analysis was based on the answers to a survey we carried out. For the final model, we conducted a preliminary stepwise regression by entering all of the variables in the model. Then, we added a backward stepwise regression that eliminates variables with low explanatory power from the saturated model.

As a result of Chi-square test, X^2 is 85.406 with a significance level of 0.00. Thus, we could not reject the global null hypothesis that the exploratory variable is independent. Using the Hosmer-Lemeshow test for the goodness of fit, we found p-value to be 0.793, indicating that the null hypothesis is rejected. We also found that the model has an appropriate level of goodness of fit.

The results of the logistic regression analysis including all the variables are shown in Table 2. If there is additional development to improve the completeness of the transferred technology, alternative technology that can compete with the transferred technology in the market, or uncertainty in the market, the results are found to have a positive relationship with the likelihood of a failed commercialization. On the contrary, complementary technology, cooperation with the technology provider, market size, CEO's willingness to commercialize, and the funding capability of the firm are found to have positive effects on successful commercialization results.

The best fitting result of the logistic regression model that applied backward stepwise regression is displayed in Table 3. The backward stepwise regression compares the –2log likelihood values of the model with all of the variables and with omitted variables to find the variable with the lowest explanatory power. Here, in the best fitting model, we deleted a total of 16 variables throughout the 17 steps of analyses, and the final model includes 13 variables, as shown in Table 3.

As a result of the backward stepwise regression, we found that additional technology development and alternative technology increase the likelihood of commercialization falling within the 1% significance level. This is because additional technology development after the technology transfer requires not only funding and human capital, but also correctly timed business development into the market. We suggest that the additional resource input due to the development of further technology would decentralize the business concentration leaving the firm possibly unable to enter the market with the correct timing. When there is a complementary technology, firms will choose to shift to the complementary technology in the case of failure, and there are also other issues such as price competitiveness or technological competitiveness that become critical factors in the commercialization process. We also found the intuitively convincing fact that when the firm has already a complementary technology which, when combined with the transferred technology, can enhance its value, then the firm's commercialization is likely to succeed.

Among the project-specific variables, duration of the commercialization project has a positive influence on commercialization. Shorter durations of the project lead to higher probability of commercialization to fail.

Table 2 Coefficients of logistic regression model

	B	Std.Dev	Wald	Sig	Exp(B)
ADDTECH	-3.142	1.295	5.886	.015**	0.043
COMPTECH	5.039	1.629	9.572	.002***	154.294
ALTTECH	-5.65	1.986	8.094	.004***	0.004
RELTECH	-0.297	0.779	0.146	0.703	0.743
DURATION	0.088	0.058	2.296	0.13	1.092
RDINPUT	0.057	0.2	0.081	0.776	1.058
MNGINPUT	-0.172	0.434	0.156	0.693	0.842
FUNDING	0.068	0.29	0.055	0.815	1.07
SOURCECOOP	2.871	1.033	7.73	.005***	17.658
GOVSUPPORT	0.007	0.977	0	0.994	1.007
MKTSIZE	3.087	1.059	8.496	.004***	21.902
MKTUNC	-2.977	1.019	8.537	.003***	0.051
COMPINT	0.395	0.561	0.496	0.481	1.484
ENTREGINT	0.22	0.674	0.107	0.744	1.246
MKTPROINT	0.755	0.812	0.863	0.353	2.127
ENVREGINT	0.407	0.722	0.317	0.573	1.502
IPPROINT	0.021	0.953	0	0.982	1.021
CEOAGE	0.926	0.654	2.008	0.156	2.525
CEODEG	0.702	0.592	1.408	0.235	2.018
CEOREL	-0.129	0.651	0.039	0.843	0.879
CEOEXCOMM	0.917	1.243	0.544	0.461	2.502
CEOWILL	1.827	0.986	3.431	.064*	6.214
FIRMAGE	0.003	0.074	0.002	0.966	1.003
FIRMSIZE	-0.213	0.999	0.045	0.831	0.808
FIRMEXCOMM	-0.102	0.998	0.01	0.919	0.903
CORETECHCAP	-0.693	0.809	0.733	0.392	0.5
FUNDINGCAP	1.607	0.676	5.66	.017**	4.989
HUMCAP	-1.978	0.89	4.943	.026**	0.138
MKTINFOCAP	-0.662	0.786	0.711	0.399	0.516
Constant	-24.634	146.549	0.028	0.867	0

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The probability of failure also increases when the target market size decreases, or uncertainties in the market become larger. Also, CEO's willingness to commercialize and the funding capability have positive relationships with the success of commercialization.

One caveat is that, when the firm is able to acquire human capital with a high level of expertise, the likelihood of a successful commercialization decreases. This aspect requires further investigation and we recommend future studies to categorize the human capital in more details, particularly by making a distinction between research and development employees and marketing employees.

Table 3 Result of stepwise logistic regression model

	B	Std.Dev	Wald	Sig.	Exp(B)
ADDTECH	-2.714	1	7.364	0.007***	0.066
COMPTECH	3.978	1.109	12.867	0.000***	53.397
ALTTECH	-4.799	1.503	10.194	0.001***	0.008
DURATION	0.088	0.042	4.446	0.035**	1.092
SOURCECOOP	2.109	0.643	10.76	0.001***	8.241
MKTSIZE	2.529	0.717	12.448	0.000***	12.546
MKTUNC	-2.34	0.717	10.645	0.001***	0.096
ENVREGINT	0.911	0.603	2.286	0.131	2.487
CEODEG	0.642	0.42	2.336	0.126	1.901
CEOWILL	1.137	0.566	4.037	0.045**	3.118
CORETECHCAP	-0.503	0.566	0.79	0.374	0.605
FUNDINGCAP	1.384	0.518	7.147	0.008***	3.99
HUMCAP	-2.124	0.708	8.997	0.003***	0.12
Constant	-10.102	3.27	9.542	0.002	0

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

IV. Interview Case Results

To understand the commercialization process from an industry perspective, we also conducted in-depth on-site interviews. We sampled four companies in different industries, markets, and technologies, and at different stages in the technological development cycle. The results of the qualitative case studies confirm the quantitative analysis derived from the logistic regression model.

The first case is Firm A, a case that shows how alternative technology and market uncertainty are associated with commercialization. Firm A specializes in organic light emitting diode (OLED) products such as ultraviolet (UV) chips or chip-on-board modules. The firm has been investing more than 15% of annual revenue into its R&D department. Firm A was transferred the relevant technology for OLED fluorescent emitters from University E. Its

CEO, a Stanford University graduate, had previously worked at IBM and LG Electronics, in particular in the departments related to customized LED modules and chips. A professor at University E, a former IBM manager, and Firm A formed a consortium to jointly receive support from the South Korean government, which drastically increased their technological competitiveness. The consortium developed a 'nano zinc sulfate-based fluorescent emitter,' patented the technology, and transferred it to the sole ownership of Firm A. The patented technology increased the efficiency of light derivation by using nano zinc sulfate as a source compared to the conventional light derivation technologies.

Although Firm A had a technological edge, it made little efforts to understand the market's characteristics and neglected the importance of marketing. The market was highly competitive and its competitors were also rapidly developing different types of fluorescent emitters with high level of technological intensity. In view of this situation, we could infer that severe competition from the different forms of technologies prevented Firm A from successful commercialization. Firm A initially embraced the technological advantage over its competitors yet failed to commercialize the technology at a competitive price level. The CRI[3] of products by Firm A ranged from 80 to 90 while that of its competitors was below 70. However, because the products of Firm A outperformed the others, the price was relatively high, resulting in the products to be uncompetitive. Differences in CRI did not offset the differences in the prices of products; customers tended to stay with alternative technologies, forgoing the gains in efficiency. The lack of price competitiveness was partly due to a lack of marketing expertise. Firm A had no marketing-related personnel who could research the market and make market-oriented decisions. The lack of marketer caused the firm A to neglect market uncertainty as well as competing for alternative technologies.

The second case is Firm B, a manufacturer of robotics automation devices and automatic guided vehicles (AGVs) that can be operated in logistics and storage transportation processes. The CEO had relevant knowledge of the field before founding the firm because he had previously worked for Samsung Airline where he accumulated relevant experience in the distribution lines of cargo. A Korean GRIs transferred to Firm B its recently-developed infrared-based tracing of objects from a robotic sensor. Whereas conventional sensor technologies of AGVs are based on wires, magnets, or laser, an infrared-based tracing sensor has a higher visual resolution, lower error rates and a greater accuracy.

[3] Performance of general OLEDs is measured by a Color Rendering Index (CRI) which is a quantitative measure of the ability of the light source compared with an ideal light-source or natural sunlight.

At first, the infrared technology seemed more competitive than the existing technology, yet Firm B overlooked two important factors in the commercialization process: complementary technology and market size. One downside of the infrared technology is the necessity of complementary vision sensors installed on warehouses ceilings. So, to make infrared tracing and vision sensors compatible, Firm B had to develop a complementary vision sensor technology. However, lacking expertise, Firm B earmarked excessive resources to develop such a complementary vision sensor technology. Another problem was the market size. To install the infrared-based AGV, the warehouse needed solid metal ceilings, uncommon in Korea. Only a limited number of large-size warehouses were built with metal panel ceilings, so the market for infrared-based AGVs was relatively small.

The third case is Firm C, a producer of lithium and special secondary batteries, such as $Li{-}SOCI_2$, $Li{-}SO_2$, and $Li{-}MnO_2$ based batteries. The technology Firm C obtained from the Anonymous Technology Center, a GRI, was a 'zinc-air battery production method from accumulated negative electrodes.' If the zinc-air production technology was embedded in the metal battery, the battery lifetime could be prolonged at a lower voltage. Firm C was able to mass-produce commercial zinc-air based batteries after the technology transfer and the battery could store up to 120% of the battery power compared to that of competing for secondary air batteries.

However, Firm C confronted two issues: one is related to the additional technology development required by zinc-air based battery production technology and the other is related to market uncertainty. Firstly, since the zinc-air battery product lifecycle was in its the initial phase, it necessitated additional technology development. For example, safety and specification issues made mass-production of zinc-air batteries difficult. The batteries needed to be safe even at extreme conditions (-40 or +165 Celsius), however secure maintenance in those conditions required additional research and development. Also, since mass production was not yet available for the wide range of specifications of the battery sizes and purposes, sizing and packaging technologies became an urgent need.

Secondly, although Firm C anticipated that the market would soon become mature, the market did not actually respond until Firm C had abandoned the commercialization project. The initially small market size and growth rate did not support the mass production of zinc-air batteries. Therefore, the burden of additional research and development and a lack of market understanding forced Firm C to abandon its commercialization project.

The fourth case is Firm D, established since 1969 in the fiber materials and apparel production industry. With diverse fiber materials, Firm D develops and produces clothing, and cooperates with many global apparel companies such as the French conglomerate Eider, or the Korean fashion brand LG

Fashion. The technology originated from one of the fiber research institutes, a GRI, relates to wool production. The technology enabled Firm D to recycle at room temperature eco-friendly wool that can be used into conventional clothing. This patented technology was noted as an innovation with its eco-friendly impact because it is difficult to recycle fiber from mass colorized and dyed clothes. Due to its environmental friendliness, the technology was supported by the South Korean government.

However, huge market uncertainty and the lack of funding capability stopped Firm D from successfully commercializing the transferred technology. The initial plan was to first produce intermediate products (material to be later turned into clothes) in order to generate the initial funding necessary for the mass production of completed clothing products. Although the technology was appealing to the supply side of production, the intermediate and final demand side was not as large as the supply because end-customers of clothing did not favor the idea of recycled clothes unless the clothes were of firsthand quality. However, the multiple reprocessing of clothing necessary to create a firsthand quality would hardly offset the cost savings of the new patented technology. Rather, multiple reprocessing stages would incur both variable and fixed costs and additional fees for vendors. Since the final demand was insufficient to create intermediary demand, the lack of the expected funding source meant that there was no other choice for the production cycle to temporarily stop. Because parts of the production site were no longer in operation, Firm D could not achieve economies of scale, resulting in higher prices for their recycled wool. Given this, the price of the recycled products ended up 2.5 times higher than those of competing end products.

Table 4 Summary of firm cases

	Firm A	Firm B	Firm C	Firm D
Year of establishment	2006	2002	1987	1969
Transferred technology type	OLED and fluorescent emitters	Robotics automation technology and AGVs	Battery manufacturing technology	Fiber materials production technology
Industry	Lighting industry	Robotics control system industry	Special lithium-air battery industry	Fiber industry
Main reason for unsuccessful commercialization	Severe competition in the LED market	Lack of complementary technology	Immature entry into the market	Lack of funding
	Lack of marketing knowhow and marketer	Lack of understanding about the market size	Lack of market understanding	Lack of price competitiveness

V. Conclusion

In this paper, we sought to understand how the commercialization process of small and medium-sized enterprises operates. We tracked patented technologies discovered at PROs such as universities and government-subsidized research institutes and then transferred to private firms. Using binomial logistic regression models, we investigated the factors determining the success or failure of commercialization. Additionally, we included detailed case studies that failed or halted because we believe these can be canonical examples that support the empirical results.

The model dentifying the causes of commercialization success or failure included many variables. The dependent variable was a dichotomous success/failure variable; as independent variables, we included the technology-specificity, the commercialization project-specificity, the target market, the institutional context (rules/regulations), the CEO-specificity and the firm-specificity.

The logistic regression model analysis we carried out produced the following results. The more additional technology development, alternative technology, and uncertainty in the market, the more the commercialization was likely to fail. On the contrary, complementary technology, cooperation with the technology provider, market size, willingness of the CEO to commercialize, and the funding capability of the firm are found to have positive effects on successful commercialization results. Also, the case analyses of four representative firms confirmed three major causes of failure. In particular, firms are sensitive to market uncertainty and the funding situation, and they need to plan strategically by taking into account technological characteristics such as alternative, complementary, and additional technologies. The empirical results of the quantitative analysis indicate that failed commercialization is caused by a complex mix of such variables.

Although we believe this study produced rigorous results, it is not without limitations. The study is based on commercialization cases from PROs in a limited region of South Korea. This national-level data can hardly be entirely generalizable to the global mechanisms of technology commercialization. Another data-based limitation is that we have had to use cross-sectional data due to the unavailability of records. Moreover, our model only specifies the success or failure of commercialization as a single operationalization – a product/service launch in the market. Considering these limitations, further studies and boundary conditions should be considered for a better understanding of global commercialization mechanisms.

This study also provides policy implications. First, it is generally assumed that government policy promoting additional developments after the technology had been transferred from PROs is crucial for the commercialization of technologies. However, according to the result of this study, additional developments of the transferred technologies by private firms increase the probability of a commercialization failure. This is because the development of additional technologies for private small and medium-sized firms requires additional time, funding and human capital. These may cause decentralized resource inputs and result in poor coordination during the market entry process. To solve this issue, additional technology development of low R&D intensity should not be allocated to the private sector. Rather, additional developments that can enhance the completeness of technologies should be conducted by PROs. After the technological suppliers have increase the completion stage of technologies to be transferred to the private sector, the private sector should be in a position to commercialize the transferred technology into an applicable product.

Another implication of your study is that government should support and promote the market understanding in order to reduce market uncertainty. Government support to help firms analyze market situations more effectively will likely lead to better performance of small and medium-sized firms. For example, we suggest supporting marketing and technology management staff. This is because the majority of small and medium-sized firms lack marketing personnel and managers of technology who could help to internally reduce market uncertainty. As can be seen from the logistic regression model, the greater uncertainty of the target market and the smaller market size are associated with a higher probability of commercialization failure. Also, the cases analyzed support the idea that the estimation of market trends and risks is highly associated with successful commercialization.

Our last policy implication for commercialization is an obvious one: financial capital. As observed in the logistic regression model, higher firm funding capabilities increase the likelihood of successful commercialization. The case of Firm D shows the direct effect of funding availability as well as funding capability. Yet, unlike technological development, commercialization is directly related to the revenue and profit of firms, and the government should seek ways to help firms via indirect supports such as the financing of technology through venture capital companies, technology guarantees or conditional loans.

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