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Analysis of Success Factors for Technology Commercialization using Meta-Analytic Structural Equation Modeling

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ABSTRACT

The purpose of this study is to identify core influencing factors of technology commercialization at a firm level in Korea and to propose a comprehensive model of a successful technology commercialization process. The data was collected from 70 studies selected through a systematic literature review, and two meta-analytic methods were applied to analyze these data. First, we analyzed the data by a meta-analysis(MA) method and identified six key factors influencing the success of the technology commercialization. The results of meta-analysis showed 0.3672 of correlation coefficient as overall average effects size which corresponded to a high side of medium effect. Next, we conducted a meta-analytic structural equation modeling(MASEM) to test relationships among these variables and to present a conceptual model of technology commercialization. The adjusted model showed a better fit to the data and significant path coefficients, and thus was adopted as the final research model of technology commercialization of the present study.

Keywords: Technology Commercialization, Influencing Factor, Success Factor, Meta-Analysis, Meta-Analytic Structural Equation Modeling

1. Introduction

Technological innovation is considered fundamental for a country's economic growth, and technological progress is a leading key factor in technological innovation. In many countries, an enormous budget is competitively allocated to research and development (R&D) to develop new technologies. As R&D progressed, the main research task in the early days was to transfer the technologies developed by universities and research

institutes to firms. As the new technologies accumulated over time, much attention has been focused on technology commercialization in recent years. The research related to technology transfer and commercialization has been conducted by different disciplines (e.g., economics, management, marketing, and engineering) and from various theoretical perspectives (e.g., organization theory, resource-based view, institutional theory, and agency theory) (Djokovic & Souitaris 2008; Garcia & Calantone 2002; Perkmann et al. 2013). Some researchers emphasized how commercialization channels might be different (Clarysse et al., 2011; Mustar et al., 2006), whereas others focused on identifying factors that influenced the success of technology commercialization

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(Arvanitis et al., 2008; Casper, 2013; George et al., 2002; Siegel et al., 2003).

As the research on technology commercialization became increasingly popular over the past decade, many empirical studies have been accumulated. In connection to this, some efforts have been made to synthesize the results of the precedent individual studies to present an integrated result (Song et al, 2008; Crook et al, 2011; Chung & Hyun, 2018). Across many research areas, meta-analysis (MA) has proven to be a very useful technique in synthesizing empirical studies to present an integrating result from a wide variety of settings (Landis, 2013). Recently, meta-analytic structural equation modeling (MASEM) has also been recommended, which combines the statistical techniques of meta-analysis (MA) and structural equation modeling (SEM) to synthesize the correlation or covariance matrices and to test a hypothesis model on the pooled correlation or covariance data (Jak, 2015).

This study was planned with two study questions: “what are the core influencing factors of technology commercialization at the firm level in Korea?” and “what is a comprehensive model of technology commercialization process?”. In order to find the answers to these questions, we reviewed the prior studies and synthesized the results of the empirical studies by applying two statistical methods of MA and MASEM.

II. Literature Reviews

A. Literature reviews

Resource-Based view (RBV) was most commonly presented as a theoretical background in numerous precedent studies of technology commercialization. In RBV, organizations are heterogeneous in relation to their resources and capabilities which determine their performance (Barney, 1991; Teece et al., 1997). The resources that firms own and control are difficult-to-imitate, non-substitutable, and can create a competitive advantage (Peteraf, 1993; Ravichandran & Lertwongsatien, 2005). In review of prior research,

we found that many of the previous studies focused on a firm's specific competencies as the influencing factors of technology commercialization.

Romjin & Albaladejo (2002) emphasized the importance of corporate owned R&D as an important source of innovation and Yam et al. (2004) divided the learning capacity, R&D capacity, resource allocation capacity, manufacturing capacity, marketing capacity, organizational capacity, and strategic planning capacity into the factors of technological innovation ability. Choe (2016) observed that the competitive usage of knowledge asset had a positive impact on the performance of an organization. Moon (2017) confirmed in his study that a CEO's technically oriented functional background affected the firm's technological innovation performance.

Absorptive Capacity was defined as a firm's ability to value, assimilate, and apply new knowledge (Cohen & Levinthal, 1990). Zahra & George (2002) expanded absorptive capacity to four dimensions of acquisition, assimilation, transformation, and exploitation. Zahra & Hayton (2008) presented the impact, importance, and necessity of absorption capacity in enhancing commercialization performance or corporate performance. A technology commercialization capability refers to the ability to directly apply the technology to the production and sales activities of the company by digesting and improving the technology. Nevens et al. (1990) described the technology commercialization capability as a competitive advantage to win competitors through cost reduction, quality improvement, and new technology acquisition. In a recent study, Choe (2017) concluded that the level of advanced manufacturing technology positively contributes to the improvement of a firm's production performance.

Relational capital of social capital theory promotes communication and information sharing among trading partners, promotes knowledge exchange, and further contributes to organizational performance by influencing knowledge creation in combination of knowledge (Nahapiet & Ghoshal, 1998). Based on the relational capital, it is possible to establish an inter-organizational cooperation system and external networking, and this relationship will have an important influence on the success or failure of technology commercialization.

The precedent studies presented the above various factors based on RBV as the theoretical background.

B. Influencing Factors as Variables

In order to derive the key success factors of technology commercialization by meta-analysis, the following procedures were used as did Markus & Larissa (2016). Firstly, we took various influencing factors from precedent studies and reduced the number of factors by merging together the factors with different names but with the same meaning (e.g., “R&D capability” and “R&D

competency”) and then, further reduced the number of factors by creating constructs and definitions that were comprehensive enough to unite factors in a similar category.

For example, the factors of total research expenses, number of researchers, quality of inventor, and research fund support were combined to construct a more comprehensive factor, R&D competency (RND).

In the such process, the external environmental factors such as government policy and market condition were excluded from consideration because the subject of this research focuses on influencing factors at the firm level. Finally six influencing factors were derived as independent

Table 1. Variables in the present study

	Variables	Attributes	References
Independent	R&D competency (RND)	Number of researchers, Quality of inventor, Total research expenses, Research fund support	Berchicci(2013) Becheikh et al. (2006)
	CEO competency (CEO)	Entrepreneurial spirit, Executive competency, Chief Executive Support,	Coulthard (2007) Romijn and Albaladejo (2002)
	Absorptive capacity (ACAP)	Acquisition - speed & quality of learning, Assimilation - interpretation & comprehension, Transformation - conversion & Internalization, Exploitation - implementation & use	Zahra and George (2002) Roper and Xia (2014)
	Commercialization competency (COMM)	Product developing ability, Establish project strategy, Manufacturing ability, Production ability, Competitor Analysis, Identify customer needs, Sales competitiveness,	Camison and Villar (2014) Chen (2009) Laird and Sjoblom (2004) Lin et al. (2006)
	Technology resources (TECH)	Intellectual property, Technical Assets, Technical perfection, Technology excellence, Technical specificity,	Ahmadi et al. (2014) Spann et al (1993) Yam et al (2004)
	Social Capital Resources (SCR)	Cooperative Partnerships, External network, Diffusion of information, Organizational flexibility, Organizational Culture,	Bengtsson and Kock (2000) Hagedoorn (1993) Sung and Carlsson (2003)
Dependent	Performance of technology commercialization (PTC)	Increase of Sales amount, Increase of operating profit, Increase market share, Increase of new product launch,	Cote et al., (2005). O'Sullivan and Abela (2007) Zahra and Nielsen, (2002)

variables in the present study: R&D competency, CEO competency, Absorptive capacity, Commercialization competency, Technology resources, and Social capital resources (see Table 1).

In the precedent studies, the performance of technology commercialization was decided by business performance including sales amount increase, operating profit increase, and/or firm's judgement on technology commercialization. So, the performance of technology commercialization was decided as a dependent variable of this study by combining its attributes by the meta-analysis method. At last, six independent variables and one dependent variable were finally fixed as the variables of this study (see Table 1).

III. Study One: Meta-Analysis

A. Meta-Analysis (MA)

Meta-Analysis is a comprehensive research methodology that systematically and quantitatively synthesizes the diverse research results of individual studies with the same subject. For meta-analysis, the preceding studies to be analyzed should be quantitative research. The results of individual studies are converted into a standardized effect size and synthesized by applying a meta-analysis statistical method (Cooper, 2010). As meta-analysis uses more samples, it can improve the precision and accuracy of estimates and the increased precision and accuracy also lead to greater statistical power to detect effects.

As recent meta-analysis study, Song et al (2008) conducted meta-analysis on success factors in new ventures, and Frances et al (2010) utilized meta-analysis in the study of relationships between organizational performance and innovation focusing on temporal sequence. Crook et al (2011) found that human capital relates strongly to performance by using the meta-analysis method. Chung & Hyun (2018) conducted a meta-analysis in which a broad range of influencing factors were covered as variables of technology commercialization. In this study, as a further step, a meta-analysis was conducted by narrowing the focus on the firm's

competency as variables of technology commercialization in Korea based on Resource-Based view (RBV).

B. Data

The precedent studies to be analyzed in this study were identified via a thorough search of the literature of technology commercialization. First, we searched the existing studies through RISS (Research information service) which is linked with major academic databases in Korea such as KISS (Korean Academic Information), DBpia (Nuri Media), Korea Scholar, Kyobo, and e-Article (Korean Academy of Sciences). As a result, 4,543 references (1,392 journals, 3,151 theses) were found through the database using the key words of *technology transfer*, *technology commercialization*, *success factor*, *influential factor*, and *determinant*. Next, we checked the reference section of the prior studies and excavated 37 papers additionally. So, a total of 4,580 studies were listed. We eliminated the studies which titles and abstracts were not relevant to the research topic. The papers in which the full text could not be secured were also excluded. As the result, 336 papers were obtained. As the next step, we chose only the empirical studies which provided statistical analysis for the variables of a firm's competencies representing RND, CEO, ACAP, COMM, TECH, and SCR. At the end, 70 studies were selected as the final data to be analyzed by meta-analysis. The total combined from 70 studies were 17,435 samples.

C. Methods

Coding - Before starting to code, we set coding standards for data extraction, created coding manuals and coding tables, and then coded the results from the selected precedent studies. Coding items consisted of researcher, title, issuing institution, publication year, source of data, number of samples, method of research, influencing factors as variables, and statistics of research results. The data was coded by two researchers in order to ensure reliability of the evaluation between coders. Through the coding process, the items with

mutual differences were finalized upon consensus through thorough discussion between the evaluators.

Effect size calculation - For meta-Analysis, the statistics of research results presented in various forms should be converted into standardized effect size. The correlation coefficient (r) is the effect size (ES) for this study. The individual study's correlation coefficients(r) were all converted to Fisher's Z using the following formula (1). Fisher's Z was used to calculate the mean value of the analysis result, and then it was converted back to Pearson's correlation coefficient 'r' using the below formula (2) for ease of interpretation (Borenstein et al., 2009).

$$\text{Fisher's } Z = 0.5 \times \ln\left(\frac{1+r}{1-r}\right) \quad (1)$$

$$r = \frac{e^{2z} - 1}{e^{2z} + 1} \quad (2)$$

Weighted mean effect - In calculation of the mean of effect sizes (ES) from individual studies, a method was used of calculating the average value of the given inverse weights reflecting the large and small sample sizes. Because each study has different characteristics, weights must be given to reflect the characteristics (here, the sample size) so that the average effect size can be calculated properly. In general, the weight is the inverse of the variance, and the larger the sample, the larger the weight.

Meta-Analysis model - There is a fixed effects model and a random effects model as the calculation method for meta-analysis. The fixed effect model assumes the homogeneity of the population of all studies, while the random effect model assumes the heterogeneity of the population and acknowledges the between-study variance. Because the study design and sample of the precedent research varied from study to study, heterogeneity of the population was estimated, so the meta-analysis in this research was conducted using random impact models.

Statistical Software - Analysis was performed using R version 3.3.2 (2016-10-31) statistical software.

D. Results

When we synthesize the precedent studies, the issue of representativeness of the sampled studies may arise if we only cover some studies. This is called a publication bias. In the meta-analysis, a good way to show publication bias is through a funnel plot. When this funnel picture is symmetrical about the vertical line, it can be concluded that there is no publication bias. A funnel plot of this study is presented in Figure 1, which shows some degree of asymmetry.

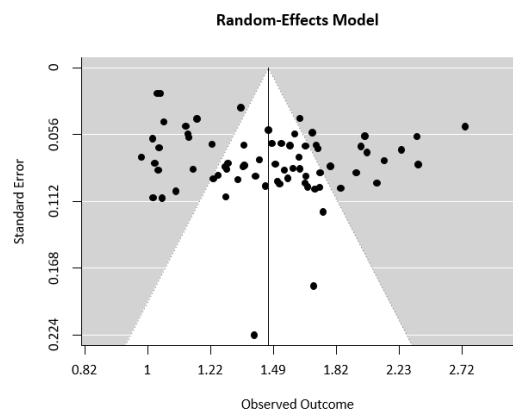


Figure 1. Funnel Plot

If a publication bias is noticed, the next step is to see how much bias is involved. In this study, Rosenthal's fail-safe N calculation was used and the result was shown in Figure 2. Rosenthal (1979) asserted that if the number of fail-safe N is above a certain level, the study is generally credible and he presented the criterion for this N as $5k + 10$ (k: number of studies). In this study, Rosenthal's criterion is $5 * (70) + 10 = 360$, and the number of fail-safe N is 49,969, which is much more than 360. This implies that 49,969 additional studies with negative (-) effect should be added to the analysis

Fail-safe N Calculation Using the Rosenthal Approach
Observed Significance Level: <.0001
Target Significance Level: 0.05
Fail-safe N: 49969

Figure 2. Fail-safe N calculation

in order for the overall average effect to be statistically insignificant. ($p > 0.05$). Therefore, we can claim that this study is reliable.

In meta-analysis, it is important to know the average effect size, but understanding the overall pattern of effect sizes is also very important. The heterogeneity of the effect size represents the extent of the effect size distribution of each study. Table 2 shows the results of the homogeneity test. The total variance (Q) was 1,255.58, which was significant at $p < .0001$, and I^2 showed 94.5% indicating large heterogeneity (Higgins and Green, 2011)¹⁾, which means that the random effects model is appropriate for this meta-analysis.

This study conducted Meta-Analysis on 70 precedent studies and the overall average effect size was calculated

using the random effect model. As shown in Table 3, the overall effect size is .3672, the lower limit of the 95% CI is .3106, the upper limit is .4213, and the significance level is statistically significant at $p < .0001$. This can be regarded as the quite large effect size according to the effect size criterion proposed by Cohen (1988)²⁾.

When a study included multiple estimates, the average effect size of each variable was computed so that only one average effect size of each variable per study was used as the data to be analyzed in a meta-analysis. This allowed us to avoid nonindependence of the data.

In this way, a total of 238 effect units were used for meta-analysis of six variables and the results were shown in Table 4. The size of the effects was in the

Table 2. Test of Homogeneity

k	Q	$df (Q)$	p	T^2	I^2
70	1,255.58	69	< 0.0001	0.0679	94.5%

Note: k = number of effect unit, Q = total variance, T^2 : variance of the true effects
 df =degrees of freedom($k-1$), I^2 : the proportion of true variance

Table 3. Overall Average Effect Size

Model	K	ES_r	95% CI		Z	p
Random Effects Model	70	0.3672	0.3106	- 0.4213	11.19	< 0.0001

Note: k =Number of Study, ES_r = Effect Size, CI = confidence interval, Z =Z-Score, p =p-value

Table 4. Effect Size of Variables

Variable	k	ES_r	95% CI		Q	T^2	I^2
RND	38	0.2981	0.2002	- 0.3900	1223.08	0.1923	97.0%
CEO	34	0.3462	0.2585	- 0.4282	592.69	0.0766	94.4%
ACAP	46	0.3986	0.3216	- 0.4704	1106.39	0.0878	95.9%
COMM	48	0.4400	0.3634	- 0.5107	1110.39	0.0973	95.8%
TECH	35	0.3283	0.2567	- 0.3963	409.22	0.0484	91.7%
SCR	37	0.4066	0.3156	- 0.4903	740.86	0.0988	95.1%

Sum of $k=238$, Test of heterogeneity: $Q=5634.41$, $df=237$, $p < 0.0001$

Note 1: k =Number of effect unit, ES_r = Effect Size, CI = confidence interval, Q = total variance,
 T^2 : variance of the true effects, I^2 : the proportion of true variance, df =degree of freedom, p =p-value

Note 2: R&D = R&D competency, CEO = CEO competency, ACAP = Absorptive capacity, COMM = Commercialization competency,
 TECH = Technology resources, SCR=Social Capital Resources

1) I^2 represents the percentage of the variation in effect estimates that is due to heterogeneity rather than sampling error. $I^2 = 25\%$: small heterogeneity, $I^2 = 50\%$: medium heterogeneity, $I^2 = 75\%$: large heterogeneity. A value greater than 50% can be considered substantial.

2) Cohen (1988) interprets the correlation coefficient effect size (ES_r) in a meta-analysis as a small effect size ($ES_r \leq .10$), a medium effect size ($ES_r = .25$), and a large effect size ($ES_r \geq .40$) respectively.

following order: COMM (.4400) > SCR (.4066) > ACAP (.3986) > CEO (.3462) > TECH (.3283) > RND (.2981).

E. Discussions

The results of meta-analysis showed that overall average effects size was .3672 of correlation coefficient (ESr), corresponding to the high side of medium effect size. This is meaningful in that it is the average effect size calculated by combining the results of 70 studies with 17,435 samples. In a subgroup analysis, six variables all were identified as the important influencing factors of technology commercialization at the firm level in Korea. Among them, Commercialization competency, Social Capital Resources, and Absorptive capacity were the core factors which effect sizes are large ($ESr \geq .40$). The other three factors of CEO competency, R&D competency, and technology resource were also important for technology commercialization with the level of effect sizes over than a medium effect size ($ESr = .25$).

The result of this research can provide a meaningful reference to enterprise and government policy makers. Although three core factors are the firm's resources, special attention and support on these core factors are needed not only from the enterprise but also from the government. While firms focus on strengthening their core competencies, if the government also provides technology commercialization policies focusing on these key factors, such collaborations will lead technology commercialization in Korea to be successful.

In Study One, we combined the effect sizes of the existing studies by using the Meta-Analysis (MA) method, identify core influencing factors of technology commercialization, and drew overall conclusions based on the pooled results. Next, in Study Two, we conducted meta-analytic structural equation modeling (MASEM) to test relationships among the variables derived in Study One under a hypothesized model of technology commercialization process.

IV. Study Two: MASEM

A. Meta-Analytic Structural Equation Modeling (MASEM)

As the second study in the present research, the Meta-analytic structural equation modeling (MASEM) was used as the statistical analysis method. MASEM combines the statistical techniques of meta-analysis (MA) and structural equation modeling (SEM) to synthesize correlation or covariance matrices and to fit a hypothesized model on the pooled correlation or covariance data. MASEM is a fairly young field of research, and it seems to be growing in popularity, both in substantive and methodological research (Jak, 2015).

Integration of MA and SEM is hardly surprising, given at least two compelling reasons (Landis, 2013). First, by creating an input correlation matrix of values generated through MA, researchers are afforded the opportunity to test structural models not tested in any primary study (Viswesvaran & Ones, 1995; Becker & Schram, 1994). This is a truly attractive feature of integrating MA and SEM as one can empirically test the viability of a structural model by combining the available evidence from the potentially disparate literature. Second, as noted in treatments of SEM (Barrett 2007; Kline 2011), strong inferences from tests of structural models are dependent upon a sufficiently large sample. Although primary studies can certainly achieve reasonable sample sizes, meta-analytic correlations are typically generated from samples that far exceed these minimum values. That is, parameter estimates and fit statistics will be more stable than values generated from any single sample (i.e., primary study).

B. Research Model and Hypothesis

As technology progresses, shorter product life cycles and intensified competition have encouraged technology commercialization activities (Lichtenthaler & Ernst, 2007). It is necessary to understand that technology commercialization is a complex process, and its success is dependent on many factors. Some studies often present

just a number of factors, but it is not sufficient to concentrate on just a few factors when the complex combination of these factors is of the utmost importance (Conceição et al., 2002).

The CEO is an essential driver in managing technology commercialization and achieving success. Although there have been many studies on the variables of top management, the main variables have traditionally been considered innovations, initiatives, leading, and risk orientation (Covin & Slevin, 1991; Wiklund & Shepherd, 2003). Burgelman et al. (2009) emphasized the importance of technological entrepreneurship in creating new resource combinations to realize technological innovation and integrating technical and commercial domains in a profitable way. *CEO competency (CEO)* in this study comprises of attributes associated with entrepreneurial spirit and executive competency. As it is assumed that CEO affects various variables throughout the process of technology commercialization, the following hypotheses are suggested.

- H1a:** CEO competency will positively influence R&D competency.
- H1b:** CEO competency will positively influence Absorptive competency.
- H1c:** CEO competency will positively influence Technology resource.
- H1d:** CEO competency will positively influence Commercialization competency.
- H1e:** CEO competency will positively influence Social Capital Resources.

From reviewing the previous studies, R&D investment in small and medium-sized enterprises (SMEs) is considered to be the most important determinant of innovation capability (Lin et al., 2006; Keizer et al., 2003; Shefer & Frenkel, 2005). The R&D at the firm level plays a very important role in product and process innovation and enhances the possibility of technological innovation by increasing intellectual assets such as patents. On the other hand, some previous studies suggest the importance of a firm's internal R&D in shaping their ability to import, comprehend, and assimilate external knowledge (Vanhaverbeke et al., 2008; Huizingh, 2011). *R&D competency (RND)* is, in this study, defined as

an influencing factor involving four attributes; namely, the number of researchers, quality of inventor, total research expenses, and research fund support. And the following hypotheses are suggested.

- H2a:** R&D competency will positively influence Absorptive competency.
- H2b:** R&D competency will positively influence Technology resources.
- H2c:** R&D competency will positively influence Commercialization competency.

From the network perspective, firms can form mutual-cooperation networks to share complementary resources and thereby gain a competitive advantage (Powell et al., 1996). According to Hagedoorn (1993), inter-firm cooperation such as joint research & development, patent sharing, development cooperation, and technology transfer cooperation complement the internal technical basis and it has a positive effect on technological innovation. Zahra (2010) suggested that social capital is an essential resource in building intimate relationships, which in turn is very helpful for promoting active social activities, establishing knowledge management and sharing systems, and raising a sustainable competitive advantage. In this study, *Social Capital Resources (SCR)* represents attributes of cooperative partnerships, external network, diffusion of information, organizational flexibility, and organizational culture. And the following hypotheses are suggested.

- H3a:** Social Capital Resource will positively influence Absorptive competency.
- H3b:** Social Capital Resource will positively influence Technology resources.
- H3c:** Social Capital Resource will positively influence Commercialization competency.

Cohen & Levinthal (1990) offered the most widely-cited definition of absorptive capacity, viewing it as the firm's ability to value, assimilate, and apply new knowledge. Frishammar et al. (2012) presented that the potential ACAP promotes organizational external learning activities, and the acquisition and utilization of technology licenses have a positive impact on the performance of technology commercialization.

In this study, Absorptive Capacity (ACAP) consists of attributes of acquisition with speed & quality of learning, assimilation by interpretation & comprehension, transformation as internalization & conversion, and exploitation of use & implementation. The following hypotheses are drawn from reviewing the previous research.

H4a: Absorptive Capacity will positively influence Technology resources by valuing and assimilating internal & external knowledge.

H4b: Absorptive Capacity will positively influence performance of Technology commercialization.

Base on the Resource-Based-View, Zahra & Nielson (2002) studied the effect of a company's internal and external sources on technology commercialization. Their report concluded that a company's strong internal technological resources were important for a successful technology commercialization. Ahmadi et al. (2014) examined the influence of asset complementarities on the first product commercialization and found that technology resource-capability has a positive relationship with the first product positional advantages. *Technology resources (TECH)* in this study includes the quantity & quality of intellectual property of the firm with attributes of technical assets, technical perfection, technology excellence, and technical specificity. The following hypotheses are suggested.

H5a: Technology resources will positively influence Commercialization competency.

H5b: Technology resources will positively influence the performance of Technology commercialization.

A technology commercialization capability of a firm refers to the ability to acquire and integrate the necessary technology, to quickly release new products to the market, and to apply the technology of the product to various markets (Chen et al., 2009). Nevens et al. (1990) emphasized the importance of the ability to apply developed technologies to multiple markets. Zahra and Nielsen (2002) suggested the importance of a firm's production capacity and its ability to introduce new products faster than its competitors. In this study, *Commercialization competency (COMM)* refers to product developing ability, establishing project strategy, manufacturing ability, competitor analysis, identifying customer needs, and sales competitiveness. In this regards, the following hypothesis is suggested.

H6a: Commercialization competency will positively influence Performance of Technology Commercialization.

In this study, we designed the following research model (see Figure 3) to provide theoretical relationships among the influencing factors in the technology commercialization process as suggested in the hypotheses.

C. Methods

Statistical Analysis Method - There are two MASEM approaches proposed by Viswesvaran and Ones (1995) and Cheung and Chan (2005). Sheng et. al. (2016) reviewed 126 published articles that used the MASEM approach in the past 20 years and offered the

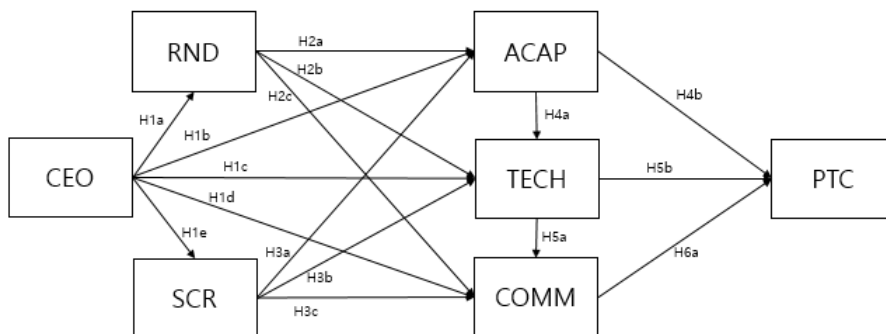


Figure 3. Proposed model of Technology Commercialization

comprehensive recommendations regarding the planning, collection, analysis, and interpretation of the studies that utilized the method of MASEM. And they encouraged researchers to use the Cheung and Chan (2005) approach because it avoided potential issues that were sometimes inevitable for the Viswesvaran and Ones (1995) approach such as heterogeneity issue, covariances versus correlations, and nonpositive definite matrices. The present study adopted the recently developed Cheung and Chan (2005)'s Two-Stage SEM (TSSEM) approach to test the research model of this study.

Data - One of the major issues associated with running the MASEM analysis was generating a full input correlation matrix. As there are seven (7) variables in this study, a seven (7) by seven (7) correlation matrix was created, which consisted of twenty-one (21) correlation coefficients between variables for each study. Ideally, studies always report the correlations between all variables. However, often not all correlations are given in a paper. So, the data in the matrix are typically combined with the correlations of variables from different studies. In this regard, Sheng et. al. (2016) suggested that the matrix would be populated entirely by correlations generated by a single meta-analysis team. This guarantees that the same decision process (e.g. search terms, inclusion criteria) would have generated all of the correlations in the matrix. Following the recommendation, all correlations on this study were derived from the same 70 studies with 17,435 samples used in meta-analysis for the study one in the previous chapter. The number of studies and samples for each

cell of matrix are shown in Table 5.

Random Effects Model - As large heterogeneity was proved in meta-analysis of the previous chapter, the random effects model was adopted for MASEM in this present study.

Procedure of Analysis -There are two stages in conducting TSSEM of MASEM. In the first stage, the correlation matrices are pooled together. In the second stage, the pooled correlation matrix is used to fit structural equation models (Cheung, 2015).

Stage 1 analysis - The main objective of the stage 1 analysis is to pool the correlation matrices together to test for homogeneity of correlations, and to create an asymptotic covariance (ACOV) matrix. The necessary input is a series of correlations matrices from individual studies. After the stage 1 analysis, a vector of pooled correlations and its ACOV is available.

Stage 2 analysis - The weighted least squares (WLS) estimation was used to fit the hypothesized structural equation model to the pooled correlation matrix that was estimated in stage 1. The weight matrix in the WLS procedure is the inverse matrix with ACOV of the pooled correlation coefficients from Stage 1. This ensures that correlation coefficients that are estimated with more precision in Stage 1 get more weight in the estimation of model parameters in Stage 2. The precision of a Stage 1 estimate depends on the number and the size of the studies that reported the specific correlation coefficient. A likelihood ratio (LR) statistic and other various well fitting indices are used to judge whether the proposed structural model is appropriate, while standard errors (SEs) are used to test the significance of individual parameter estimates

Table 5. Number of studies on Correlation

Unit: k (N)

Variable	RND	CEO	ACAP	COMM	TEC	SCR
CEO	18 (3,899)					
ACAP	20 (4,555)	18 (4,164)				
COMM	26 (5,417)	21 (4,064)	27 (5,978)			
TECH	29 (9,166)	15 (2,977)	16 (3,596)	27 (5,569)		
SCR	18 (3,957)	16 (2,835)	24 (4,564)	21 (4,202)	13 (2,625)	
PTC	38 (12,698)	34 (7,617)	46 (13,145)	48 (11,745)	35 (8,622)	37 (7,573)

Note: K = Number of Studies, N = Number of samples

(Cheung, 2015).

Software to conduct MASEM - All data analyses in the present study were conducted using metaSEM (Cheung, 2011) and OpenMx (Boker et al., 2011) packages in R version 3.5.1. statistical software.

D. Results

Results of Stage 1 Analysis - In the stage 1 analysis, the pooled correlation matrix was estimated and the ACOV matrix of the pooled correlation coefficients was created, which will be used to fit the hypothesized structural equation model in the stage 2 analysis. As the results of the analysis, Table 6 presented the Q value representing the total variance, T^2 value representing the absolute value of the estimated study level variances, and I^2 representing the percentage of

the actual variance. From the stage 1 analysis, the Q statistics were significant ($Q_{(283)} = 2040.17, p < .0001$), and I^2 of the eighteen correlation coefficients showed very large heterogeneity (.75 - .93) and the I^2 of the remaining three presented a medium size of heterogeneity (.52, .70, .72). These values indeed indicate significant heterogeneity in the correlation matrices at the study level which means that a random-effects model is more appropriate for this data set.

Results of Stage 2 Analysis - In the stage 2 analysis, the proposed model was tested to fit to the pooled correlation matrix calculated in stage 1 analysis, and the results were presented in Table 7. The chi-square of the hypothesized structural model was significant ($\chi^2_{(5)} = 31.82, p < .000$). The chi square is a traditional fit index of SEM model. For models with about 75 to 200 samples, the chi square test is generally reasonable measure of fit, but for models with more samples (400

Table 6. Results of stage 1 analysis

No.	Variables		Estim.	sigif.	S.E.	T^2	I^2
1	RND	CEO	0.31	***	0.071	0.036	0.902
2	RND	ACAP	0.44	***	0.052	0.021	0.850
3	RND	COMM	0.37	***	0.056	0.038	0.910
4	RND	TECH	0.38	***	0.057	0.020	0.843
5	RND	SCR	0.32	***	0.047	0.019	0.829
6	RND	PTC	0.31	***	0.048	0.036	0.904
7	CEO	ACAP	0.49	***	0.049	0.024	0.863
8	CEO	COMM	0.45	***	0.030	0.009	0.695
9	CEO	TECH	0.55	***	0.058	0.012	0.757
10	CEO	SCR	0.45	***	0.033	0.004	0.516
11	CEO	PTC	0.36	***	0.051	0.050	0.930
12	ABS	COMM	0.52	***	0.029	0.009	0.715
13	ABS	TECH	0.57	***	0.048	0.013	0.766
14	ABS	SCR	0.47	***	0.044	0.021	0.849
15	ABS	PTC	0.40	***	0.036	0.025	0.874
16	COMM	TECH	0.42	***	0.056	0.029	0.885
17	COMM	SCR	0.43	***	0.041	0.023	0.857
18	COMM	PTC	0.39	***	0.035	0.030	0.896
19	TECH	SCR	0.45	***	0.074	0.038	0.906
20	TECH	PTC	0.36	***	0.049	0.042	0.917
21	SCR	PTC	0.38	***	0.034	0.024	0.868

$K = 70$ ($N = 304$), $Q : 2040.167$, degree of freedom: 283, $p < .0001$

Note 1: K = Number of Studies, N = Number of observed statistics, Corr. = Correlation coefficient,

Note 2: Significance codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

or more), the chi square is almost always statistically significant (Kenny, 2014). Considering the huge number of samples (= 17,435) in this study, it was more reasonable to test the proposed model with an alternative measure of fit. More importantly, the proposed model provided an acceptable fit to the data (RMSEA .017, SRMR .054, TLI .938, CFI .985, AIC 21.822).

It should be noted that a good-fitting model is not necessarily a valid model. The parameter estimates were examined and showed that the core paths

(*TEC-COMM* and *TECH-PTC*) were statistically not significant (.142, $p = .247$; .151, $p = .114$). Although it showed good-fitting, the proposed model was nonsensical (see Figure 4). In addition, a few more paths were statistically not significant (*CEO-COM*, *SCR-TECH*, *RND-TECH*). Therefore, we decided to find an alternative model based on the theoretical basis and modify the proposed model.

Analysis of modified model - On closer review of the theoretical basis, we noted the function of absorptive

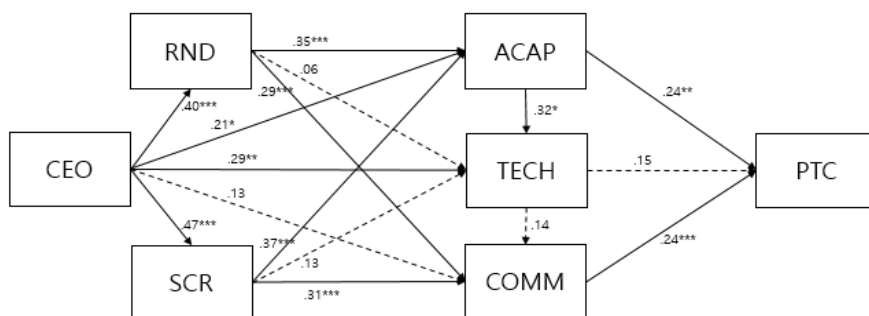


Figure 4. Proposed model with path coefficients.

Note: '***' 0.001 '**' 0.01 '*' 0.05. The dotted paths indicate non-significant.

Table 7. Path Coefficients of proposed model

Hypothetical Path	PC	SE	LB	UB	z	p
CEO → ACAP	0.212	0.084	0.048	0.376	2.535	0.011 *
SCR → ACAP	0.369	0.061	0.249	0.489	6.032	0.000 ***
RND → ACAP	0.347	0.066	0.218	0.475	5.288	0.000 ***
CEO → COMM	0.126	0.081	-0.034	0.285	1.547	0.122
SCR → COMM	0.312	0.065	0.186	0.439	4.833	0.000 ***
RND → COMM	0.287	0.074	0.141	0.432	3.855	0.000 ***
TECH → COMM	0.142	0.122	-0.098	0.381	1.159	0.247
ACAP → PTC	0.240	0.076	0.092	0.389	3.175	0.001 **
COM → PTC	0.239	0.055	0.130	0.348	4.312	0.000 ***
TECH → PTC	0.151	0.096	-0.036	0.339	1.580	0.114
CEO → SCR	0.469	0.032	0.406	0.533	14.439	0.000 ***
CEO → RND	0.398	0.061	0.279	0.518	6.514	0.000 ***
ACAP → TECH	0.320	0.141	0.045	0.596	2.279	0.023 *
CEO → TECH	0.291	0.106	0.084	0.499	2.750	0.006 **
SCR → TECH	0.134	0.148	-0.156	0.424	0.904	0.366
RND → TECH	0.056	0.110	-0.159	0.272	0.512	0.609

Model fit: $\chi^2_{(5)} = 31.82$, $p < .000$, RMSEA .017, SRMR .054, TLI .938, CFI .985, AIC 21.822

Note 1: PC = Path Coefficient, SE = Standard error, LB = Low Bound of 95% Confidence Interval, UB = Upper Bound of 95% Confidence Interval, z = z value, p = p value. Significance codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

capacity (ACAP) in the whole process of technology commercialization. Stock et al. (2001) suggested that absorptive capacity has a positive effect on new product development performance because it plays a role in acquiring external knowledge and applying it to product development. Theoretically, ACAP is classified into two kinds: potential absorptive capacity (PACAP) and realized absorptive capacity (RACAP) (Zahra & George, 2002). Potential Absorptive Capacity (PACAP) would influence studying and assimilation of technology outside and Realized Absorptive Capacity (RACAP) would transform and utilize the technology and lead it through a commercialization process. Indeed, RACAP has been linked to COMM developing and manufacturing new products in many domains. Thus, we amended the hypotheses *H4a* and *H5a* as follows

H4a: Absorptive Capacity will positively influence Commercialization competency by transforming and utilizing technology resource.

H5a: Technology resources will be positively influence Commercialization competency by mediation of Absorptive Capacity.

We conducted the MASEM analysis one more time with the adjusted model and the result is presented in Table 8.

The Goodness-of-fit indices of the adjusted model shows an even better fit to the data: $\chi^2_{(5)} 20.03$ ($p < .001$), *RMSEA* .0126; *SRMR* .0491; *TLI* .9654; *CFI* .9918, *AIC* 10.0273) than the proposed model. Also, this model showed more meaningful significant path coefficients (*TECH-ACAP* .243, $p < .01$; *ACAP-COMM* .267, $p < .001$), providing further support for this mediation model. The adjusted model with path coefficients is depicted in Figure 5, which shows a reduction of non-significant paths from four of the proposed models to two in the adjusted model. Therefore, the adjusted model was finally adopted as the research model of this study.

E. Discussions

Zahra and George (2002) classified ACAP into two kinds: potential absorptive capacity (PACAP) and

Table 8. Path Coefficients of Adjusted model

Hypothetical Path			PC	SE	LB	UB	z	p	
CEO	→	ACAP	0.148	0.096	-0.040	0.337	1.544	0.123	
SCR	→	ACAP	0.238	0.078	0.086	0.390	3.069	0.002	**
RND	→	ACAP	0.240	0.074	0.095	0.386	3.244	0.001	**
TECH	→	ACAP	0.243	0.094	0.059	0.427	2.595	0.009	**
ACAP	→	COMM	0.267	0.062	0.145	0.389	4.281	0.000	***
CEO	→	COMM	0.153	0.063	0.029	0.276	2.426	0.015	*
SCR	→	COMM	0.215	0.066	0.086	0.345	3.256	0.001	**
RND	→	COMM	0.152	0.081	-0.006	0.310	1.884	0.060	.
ACAP	→	PTC	0.178	0.074	0.033	0.323	2.409	0.016	*
COMM	→	PTC	0.223	0.057	0.111	0.334	3.918	0.000	***
TECH	→	PTC	0.245	0.074	0.100	0.390	3.310	0.001	***
CEO	→	SCR	0.478	0.032	0.416	0.540	14.995	0.000	***
CEO	→	RND	0.433	0.058	0.320	0.546	7.525	0.000	***
CEO	→	TECH	0.316	0.100	0.120	0.511	3.156	0.002	**
SCR	→	TECH	0.333	0.094	0.148	0.518	3.531	0.000	***
RND	→	TECH	0.185	0.079	0.030	0.339	2.344	0.019	*

Note 1: PC = Path Coefficient, SE = Standard error, LB = Low Bound of 95% Confidence Interval, UB = Upper Bound of 95% Confidence Interval, z = z value, p = p value. Significance codes: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1
Model fit: $\chi^2_{(5)} 20.03$ ($p < .01$), *RMSEA* .0128, *SRMR* .0491, *TLI* .9654, *CFI* .9918, *AIC* 10.0278

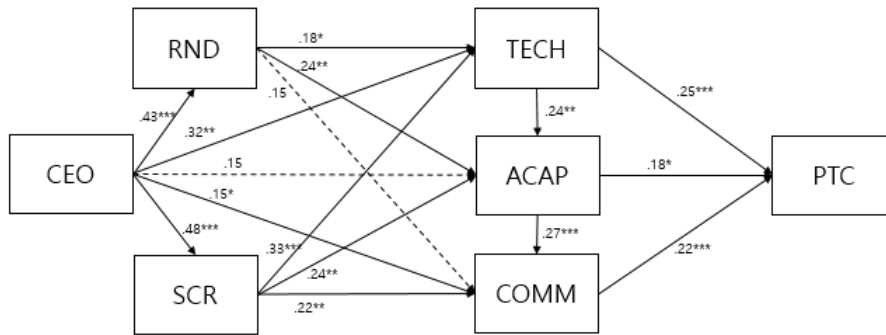


Figure 5. Adjusted model with path coefficients.

Note: '***' 0.001 '**' 0.01 '*' 0.05. The dotted paths indicate not significant.

realized absorptive capacity (RACAP). The PACAP would influence studying and assimilating technology and RACAP would transform and utilize the technology and lead it through a commercialization process. In the proposed model, ACAP was mediated well between RND and TECH, so it is assumed that PACAP was functioned to study and assimilate the technology developed internally or transferred from an outside research institute. On the other hand, in the adjusted model, ACAP was also mediated well between TECH and COMM. In this case, RACAP was functioned to transform and utilize the technology for developing and manufacturing new products in the process of technology commercialization. Thus, it would be theoretically more ideal for PACAP to mediate between RND and TECH, and for RACAP to mediate between TECH and COMM. However, due to the data of the present study not being able to be divided into PACAP and RACAP, we were not able to test the combined model at the present study.

The adjusted model reflecting the amended hypotheses was adopted as the final model of this study. The summary of hypotheses verification is presented in Table 9 in which the hypothesis of CEO influencing various factors (*H1a*, *H1b*, *H1d*, and *H1e*) through the process of technology commercialization were all supported, with the one exception of *H1c* which had failed. The results showed that CEO would indirectly influence ACAP through RND and SCR. In case of *H1d*, the path coefficient from CEO to COMM showed limited influence (.152) although it was statistically

significant ($p < .05$). The analysis indicates that CEO would be indirectly influencing COMM by mediation of SCR.

RND is well associated with ACAP (*H2a*), but its influence on COMM is not significant (*H2c* had failed). The results showed that RND influenced COMM indirectly by the mediation of ACAP. The influence of RND on TECH (*H2b*) was not strong (.185), contrary from expectations. It is assumed that RND would be well associated with TECH when ACAP is mediated between RND and TEC referring to the analysis of the proposed model. If the ACAP data can be divided into PACAP and RACAP, we can test the linkage of RND-ACAP-TEC, however, the data cannot be divided in this study.

SCR seems to influence TECH, ACAP, and COMM respectively, so *H3a*, *H3b*, and *H3c* were all supported. TEC is well associated with ACAP (*H5a*) and also influences PTC strongly both directly and indirectly (*H5b*). ACAP associates well with COMM (*H4a*) and also influences PTC (*H4b*), but direct influence seems to be limited (.178). The analysis showed that COMM significantly influences PTC, so *H6a* is supported.

The total effect, direct, and indirect effect were calculated and presented in Table 10. The fact that CEO plays the most important role throughout the process of technology commercialization (TC) is not surprising. CEO competency refers to entrepreneurial spirit, leadership, and executive competency. The characteristics of the entrepreneur's personal resources and the role of the entrepreneur are crucial to the

Table 9. Summary of Hypotheses Verification

	Hypotheses	coef	p value	concl.
H1a	CEO will positively influence RND	0.433	0.000***	support
H1b	CEO will positively influence ACAP	0.148	0.123	failed
H1c	CEO will positively influence TECH	0.316	0.002**	support
H1d	CEO will positively influence COMM	0.153	0.015*	support
H1e	CEO will positively influence SCR	0.478	0.000***	support
H2a	RND will positively influence ACAP	0.240	0.001**	support
H2b	R&D will positively influence TECH	0.185	0.019*	support
H2c	R&D will positively influence COMM	0.152	0.060.	failed
H3a	SCR will positively influence ACAP	0.238	0.002**	support
H3b	SCR will positively influence TECH	0.333	0.000***	support
H3c	SCR will positively influence COMM	0.215	0.001**	support
H4a	ACAP will positively influence COMM by transforming and utilizing TECH	0.267	0.000***	support
H4b	ACAP will positively influence PTC	0.178	0.016*	support
H5a	TECH will be positively influence COMM by mediation of ACAP	0.243	0.009**	support
H5b	TECH will positively influence PTC	0.245	0.001***	support
H6a	COMM will positively influence PTC	0.223	0.000***	support

Note: coef. = path coefficient, concl. = conclusion. significance: '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

Table 10. Total effects, Direct, indirect of Variables

	CEO	RND	SCR	TECH	ACAP	COMM
RND	.433 (.433, .000)					
SCR	.478 (.478, .000)					
TECH	.555 (.316, .239)	.185 (.185, .000)	.333 (.333, .000)			
ACAP	.501 (.148, .353)	.285 (.240, .045)	.319 (.238, .081)	.243 (.243, .000)		
COMM	.361 (.153, .196)	.228 (.152, .076)	.300 (.215, .085)	.065 (.000, .065)	.267 (.267, .000)	
PTC	.327 (.000, .327)	.147 (.000, .147)	.205 (.000, .205)	.303 (.245, .058)	.237 (.178, .059)	.223 (.223, .000)

Note. Numbers are total effects. Numbers in brackets represent direct effect and indirect effects.

performance of technology startup companies (Wiklund and Shepherd, 2005). CEO is an essential driver in managing technology commercialization and achieving success. The *TECH-ACAP-COMM-PTC* model reveals that TECH as the input and COMM as the process are core factors influencing PTC. However, COMM alone is not sufficient in the process of TC but also ACAP is an essential element in bringing TC to success by mediating TECH and COMM.

Among the six factors, SCR is another factor to pay close attention to. Social Capital Resource (SCR) includes internal & external network, organizational

culture, and cooperative partnerships. The high quality of technology is an essential factor for TC and R&D is also important for developing the technology. However, the technological innovation can be reinforced by acquiring technology and knowledge from outside firms, without relying solely on internal technology resources (Cassiman and Veugelers, 2006). The Technical Cooperation Network will expand the resource base of participating companies by enabling them to utilize technologies already developed by partner organizations, which in turn will improve innovation performance (Lee et al., 2001). That is, SCR is playing a very important

role by enabling firms to acquire technology and knowledge from outside firms or research institutes. This study shows that SCR is closely associated with TECH, ACAP, and COMM respectively as well as strongly influenced by CEO. The analysis implied that SCR is a very important factor for a successful TC, and it is the CEO that can strengthen SCR. In addition, SCR requires mutual cooperation and multilateral cooperation among various stakeholders in the process of TC. The success of internal & external cooperation can be achieved only by the mutual effort of all stakeholders involved in the TC process.

The results of this study present that it is essential to acquire high quality technology either developed by the firm internally or transferred from outside research institutions by using SCR and digest & transform the technology with ACAP to design and manufacture the sellable goods to the market. This will result in a fruitful performance of technology commercialization.

V. Conclusions

This research started to address two important study questions: “what are the core influencing factors of technology commercialization at the firm level in Korea?” and “what is the comprehensive model of technology commercialization process?”. In order to figure out the answer, two meta-analytic approaches were conducted. Through systematic literature review, 70 prior studies with 17,435 samples were collected for meta-analysis.

By the study one, the meta-analysis (MA) identified three core factors of Commercialization competency, Social Capital Resources, and Absorptive competency among six important influencing factors of technology commercialization. The overall average effects size was .3672 of correlation coefficient (ES_r), corresponding to the high side of medium effect size.

The study two was designed to set a comprehensive model of technology commercialization by using a meta-analytic structural equation modeling (MASEM).

A proposed model of *TEC-COMMPTC* was tested but it failed to acquire a significant path coefficient. The adjusted model of *TEC-ACAP-COMMPTC* showed a better fit to the data and significant path coefficients, so that it was adopted as the final research model for technology commercialization at the present study.

This study has implication for identifying key success factors for technology commercialization at the firm level in Korea. And then, a comprehensive model of technology commercialization was presented, which revealed the relations among the influencing factors in the process of technology commercialization. These results can provide meaningful reference to the enterprise and government policy makers. While companies focus on strengthening their core competencies, if the government also provide policies focusing on these key factors, such collaboration will lead technology commercialization in Korea to be more successful.

The next implication is that meta-analysis structural equation modeling (MASEM) was applied to verify the hypothesized models in this study. Using MASEM, the statistical results from multiple primary studies were used to test a hypothesized model that explains the relationships between a set of variables. By combining meta-analysis (MA) and structural equation modeling (SEM), some of the difficulties in the separate fields may be overcome. MASEM is a fairly young field of research, and it seems to be growing in popularity, both in substantive and methodological research.

The other implication can be the verification of absorptive capacity theory. Zahra and George (2002) classified absorptive capacity into potential absorptive capacity and realized absorptive capacity and the realized absorptive transform and utilize the knowledge. In the adjusted model of this study, the absorptive capacity was mediated well between technology resources and commercialization competency. So, the absorptive capacity theory was verified by the empirical study of MASEM.

This study focused on the subject of technology commercialization at the firm level in Korea. Therefore, it is necessary to expand the subject of research to the industry or region levels in future studies. The scope

of study also needs to be expanded to global level in order to generalize the result.

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