Organizational Composition and R&D Performance in Science and Technology Government-funded Research Institutes

과학기술분야 출연연 인력 다양성과 성과간의 관계분석

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Abstract

This study used a resource-based perspective to analyse the effects of organizational composition on the R&D performance of science and technology government-funded research institutes (GFRIs). We assumed that the composition of each GFRI would eventually be regarded as absorptive capacity and act as a moderating variable between R&D investment and performance. We used a panel generalized least squares (GLS) model with fixed effects to analyse panel data from 115 Korean GFRIs between 2011 and 2015. Our findings show that R&D investment of GFRIs has a direct and positive effect on performance. We also analysed how organizational composition can moderate the effect of R&D investment on performance. The findings provide evidence that organizational composition plays a moderating role between R&D investment and performance. Finally, this study discusses policy implications, its limitations, and also highlights future research directions.

Keywords : Government-funded research institutes, GFRI, research and development, organizational composition, absorptive capacity, government policy

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Ⅰ. Introduction

Over the past 50 years, Korean government-funded research institutes (GFRIs) in the science and technology field have contributed scientific and core technological development in mainstream industries in Korea. As such, GFRIs have helped to implement government-led economic development strategies (Lee et al., 1996). Indeed, in 2015, GFRIs spent USD 4.14 thousand million, which is about 25% of the government's total R&D budget, on R&D. Moreover, GFRIs are the nation's largest research group, employing 11,617 researchers. In this context, many Korean researchers have conducted studies on the determinants and efficiency of GFRIs' research results (Choi et al., 2011; Kim and Lee, 2014; Nam et al., 2008; Won et al., 2003). These studies have mainly focused on evaluating GFRIs' research outcomes in terms of efficiency and have considered, for example, the calculation of input–output, the structure of research implementation, and the evaluation methodology of research results. In other words, the research has focused on the appropriateness of performance and the level of outcome utilization in accordance with input.

R&D investment has been considered an important research topic at both the R&D unit level such as for firms and GFRIs and the national level. At the national level, studies have mainly used the endogenous growth theory (Aghion and Howitt, 1990; Aghion et al., 1998; Griffith et al., 2004; Lucas, 1988; Romer, 1990) and the national innovation system (NIS) (Edquist, 2001; Lundvall, 1992; Nelson and Winter, 1982) to investigate the effects of R&D investment on economic growth as an output in accordance with inputs such as R&D investment. In these studies, performance creation, such as through technological innovation based on R&D investment, is treated as a 'black box' (Kline and Rosenberg, 1986). This research uses, as its evidence, a number of evolutionary economic studies that show that the relationship between R&D investment and economic growth is driven, not by a linear model, but by the complex interactions and networks of various innovators and institutional environments (Casper and Soskice, 2004; Casper and van Waarden, 2005; Coriat and Weinstein, 2004; Edquist, 1997; Nelson, 1993; Nelson and Rosenberg, 1993). However, qualitative aspects, such as the nature of R&D practitioners and the various factors involved in the transformation of R&D investment into performance, have not been sufficiently investigated.

The lack of research is similar to firm level studies, although the effects of the determinants and performance of R&D investment have been discussed in detail

(Belderbos et al., 2004; Bönte, 2003; Callen and Morel, 2005; Chambers et al., 2002; Griliches, 2000; Han and Manry, 2004; Hirschey, 1982; Hirschey and Weygandt, 1985; Kostopoulos et al., 2011; Kotabe et al., 2002; Lev and Sougiannis, 1996; Sougiannis, 1994). Nonetheless, some studies related to the performance of R&D have shown that human resources play an important role in forming a competitive advantage and securing sustainable competitiveness (Brown and Eisenhardt, 1995; Faems and Subramanian, 2012; Liu et al., 2009; Verona, 1999). However, the organizational factors of R&D units that influence the effects on performance have received relatively little attention. Indeed, R&D activity is not simply a process of inputting, such as financial capital, and producing outputs, but of human capital (Kaufman and Sternberg, 2010).

This perspective is also discussed in the resource-based view (RBV) (Barney, 1991; Barney et al., 2001; Wernerfelt, 1984) and should be recognized as an important organizational resource that affects organizational performance. In other words, valuable, rare, inimitable, non-tradable, and non-substitutable characteristics possessed by organizational members have an important effect on organizational outcomes as assets or capabilities (Barney, 1991). Thus, it is necessary to focus on qualitative characteristics such as organizational composition as well as R&D personnel because the latter has been utilized as a quantitative aspect in terms of scale. This is in accord with the notion that composition has been overlooked in discussions about R&D personnel (Keller, 1996).

Therefore, this study regards the organizational composition of GFRIs as an absorptive capacity (Cohen and Levinthal, 1990) from the perspective of human capital, because researchers in the R&D process play a real role in generating creative ideas and using internal and external knowledge (Cohen and Levinthal, 1990; Faems and Subramanian, 2012; Liu et al., 2009). Consequently, we attempt to overcome the limitations that are overlooked in the organizational perspective by previous research, which approaches the subject from the viewpoint of simple input and output.

From the empirical perspective, this study differs from previous studies in that many other studies about R&D investment and organization use firm level or national level rather than GFRIs. Korea has established 25 GFRIs in the form of technical fields or research institutes based on legal grounds, and access to these GFRIs' data is very limited. As mentioned earlier, the Korean government recognizes that GFRIs, along with universities and corporations, play a strategic role in the development of innovative technologies in the nation and securing future growth engines to improve economic performance. Therefore, research on GFRIs in Korea has been acknowledged as important, but it is difficult to obtain appropriate data for research because of the closure of GFRIs. In this study, we conducted surveys with the cooperation of the

National Research Council of Science and Technology (NST), which manages the 25 GFRIs, and obtained 5 year panel data, including R&D investment and performance data, of GFRIs. We first identify the direct impact of R&D investment on GFRIs' performance and then analyse the indirect impact of GFRIs' organizational composition as a moderating variable on the relationship between R&D investment and GFRIs' performance. The results enrich our understanding of the relationship between R&D investment and GFRIs' performance, and identify the moderating effect of organizational composition as absorptive capacity.

This study is structured as follows: In the following section, we hypothesize the effect of R&D investment on GFRIs' performance as a baseline through a theoretical discussion of R&D investment and performance. We then hypothesize the effect of the organizational composition of GFRIs on performance in terms of the RBV and absorptive capacity. In the research methodology section, we address how we constructed the empirical model, the data set, the variable, and the research method. In section 4, we present our results, and in the final section, we discuss the results and offer a conclusion.

II. Theoretical Framework and Hypotheses' Development

1) The Effect of R&D Investment on GFRIs' Performance

Many theoretical perspectives can explain why each nations allocate a large amount of its budget to GFRIs in order to conduct R&D for achieving economic growth. First, according to the endogenous growth theory (Aghion and Howitt, 1990; Aghion et al., 1998; Lucas, 1988; Romer, 1990), a nation's economic growth is not an outcome of forces that are external to the economic system; instead, economic growth is an endogenous outcome of the economic system.

Unlike the explanations provided by the endogenous growth theory on the relationship between R&D investment, human capital investment, and economic growth, as suggested by neoclassical economics (Edquist, 2001; Lundvall, 1992; Nelson and Winter, 1982), neo-institutionalism and evolutionary economics explain the relationship between R&D investment and the economy from the perspective a national innovation system (NIS). While research based on neo-institutionalism advocated a monotone idea that higher R&D and human capital investment leads to economic growth, studies based on evolutionary economics have argued that various innovative entities, complex interactions, and networks are subordinated by institutional environments and are, thereby, deeply

influenced (Casper and Soskice, 2004; Casper and van Waarden, 2005; Coriat and Weinstein, 2004; Edquist, 1997; Nelson, 1993; Nelson and Rosenberg, 1993). This approach was adopted because neoclassical economics simply explained economic growth by R&D investment as a quantitative relationship of input–output. In addition, because the processes of technological change and innovation were treated as 'black boxes' (Kline and Rosenberg, 1986), it was not enough to merely identify various factors.

The relationship between R&D investment and performance has been actively pursued, not only at the national level, but also at the firm level. From the perspective of the RBV, firms should utilize their resources effectively in order to achieve innovative performance (Leiblein and Miller, 2003). In other words, many firms can improve performance by investing in R&D because it can provide core competencies through productivity improvements and technological development. Thus, many studies have confirmed the positive effects of R&D investment on firms' performance such as amount of sales and productivity improvements through empirical analysis (Cohen and Klepper, 1996; Griliches, 1990, 2000; Hall and Ziedonis, 2001; Hirschey, 1982; J Acs and Audretsch, 1989; Kleinknecht and Reijnen, 1992; Kondo, 1999; Pakes and Griliches, 1980, 1984; Shefer and Frenkel, 2005).

Based on these theoretical and empirical arguments, we propose that R&D investment in GFRIs will have a positive impact on performance. Many studies (Acs and Audretsch, 2003; Choi et al., 2011; Johnson and Evenson, 1997; Kim and Lee, 2014; Nam et al., 2008; Pakes and Griliches, 1984; Won et al., 2003) have generally used the number of papers and patents as proxies for performance. Of course, this perspective is also related to how we view the process of innovation through R&D. In other words, as Pakes and Griliches (1984) suggested, knowledge can be regarded as an intermediary achievement derived from R&D investment. According to Pakes and Griliches (1984), the knowledge production function consists of R&D investment that corresponds to input and prior patents, and leads to the improvement of productivity, which is the output of a firm's technological innovation. Although the output of technological innovation through R&D investment is technological innovation itself, from the perspective of a measurement for empirical research, papers and patents have been used in many studies as proxy variables for knowledge output based on appropriateness and efficiency (Acs and Audretsch, 2003; Johnson and Evenson, 1997). Thus, with regard to GFRIs in this study, the outcomes generated through R&D investment are transferred to firms and universities through a form of knowledge such as papers and patents (Campbell and Guttel, 2005). This knowledge is then converted into economic performance such as a growth in sales.

Consequently, for the first hypothesis, based on these theoretical and empirical

discussions, we propose that R&D investment and GFRIs' performance have a positive relationship. This hypothesis is a baseline for the next proposal that GFRIs' organizational composition moderates the relationship between R&D investment and performance.

Hypothesis 1 (H1): GFRIs with high levels of R&D investment achieve greater performance than those that engage in comparatively low levels of R&D.

2) Organizational Composition as Absorptive Capacity and Performance

The RBV considers a firm as a portfolio of core competencies (Prahalad and Hamel, 2006) and a firm combines internal and external innovative resources strategically in order to achieve and improve performance (Barney, 1991; Wernerfelt, 1984, 1995). Thus, an organization such as a firm can secure a sustained competitive advantage and improve its performance by arranging and combining various internal resources effectively (Barney, 1991). In terms of the factors that constitute a firm's core competencies, human resources substantially affect performance (Barney, 1991; Barney et al., 2001; Wernerfelt, 1984). In other words, human resources can be considered one of the assets that achieve organizational goals and contribute to an organization's performance (Barney, 1991; Barney et al., 2001; Bryson et al., 2007). In this context, many researchers have categorized human resources as a representative type of resource, together with financial, physical, and technological resources (Barney, 1991; Bozeman and Moulton, 2011; Bozeman and Straussman, 1990; Fry et al., 2004; Grant, 1991; Lee and Whitford, 2012; da Mota Pedrosa et al., 2013; Rainey and Steinbauer, 1999; Russo and Fouts, 1997). Human resources can be regarded as one of the bundles of heterogeneous resources possessed by an organization; moreover, these bundles are organized differently for each organization (Penrose, 1995). Thus, an organization's performance can vary depending on the composition and utilization of its resources. According to prior studies, the attributes of human resources, such as education and research experience, and the level of education, other than the attributes of physical resources such as the amount of R&D investment and research equipment, have a positive effect on performance (Bowman, 1992; Lee et al., 2005).

The purpose of this study is to investigate the effect of the organizational composition of GFRIs as absorptive capacity on performance because the researchers who work in GFRIs possess R&D knowledge and specific capabilities. In other words, GFRIs' employees, collectively, are the resource that provides the core competence and are also the entity that carries out the actual R&D. This means that human resources are

intangible assets that are an inherent part of any organization. Furthermore, these assets have embodied capabilities that cannot be imitated, transferred, or replaced, unlike financial and physical resources (Wright and McMahan, 1992). Based on these discussions, GFRIs' diverse organizational composition can act as a unique competence in quantitative and qualitative aspects, and may ultimately have an effect on the performance of R&D.

Absorptive capacity is the ability to recognize the value of knowledge by assimilating and applying other firms' experience (Cohen and Levinthal, 1990). In many prior studies, a high level of absorptive capacity has been associated with actively exploring and acquiring valuable information, and creating new value by combining various resources within an organization, thereby enhancing competitiveness, and ultimately contributing to performance improvement (George et al., 2001; Mellat-Parast and Digman, 2008; Mowery et al., 1996; Spanos and Voudouris, 2009; Yang et al., 2006). Most determinants of absorptive capacity were analysed by Cohen and Levinthal (1990) as the key factors of the level of prior-related knowledge and effort (Cohen and Levinthal, 1990; Tsai, 2001; Van Den Bosch et al., 1999; Veugelers, 1997). In this context, prior-related knowledge is existing knowledge available within an organization that increases the ability to assign meaning to, internalize, and use, new knowledge. Strength of effort refers to the amount of energy that a member of an organization uses to solve a problem (Caloghirou et al., 2004; Kim, 1998). A high level of effort enhances the interactions among members to promote organizational-level knowledge transformation and creation, and increase absorptive capacity (Cohen and Levinthal, 1990; Lane et al., 2006; Lane and Lubatkin, 1998). From these organizational perspectives, all prior-related knowledge is embedded in an organization's human resources. In other words, GFRIs' organizational composition targeted in this study can be an important factor for determining the level of absorptive capacity as an organization's unique capability. This is because, with regard to GFRIs, R&D in itself is an organizational purpose and a routine task.

Although organizational aspects have been recognized as important factors that determine the formation and level of absorptive capacity, there are not many studies on the organizational factors that influence absorptive capacity formation. Many researchers have conducted empirical studies to determine the level and impact of absorptive capacity by measuring R&D intensity (Cohen and Levinthal, 1990; Escribano et al., 2009; George et al., 2001; Kostopoulos et al., 2011; Rothaermel and Alexandre, 2009; Stock et al., 2001; Tsai and Wang, 2008; Tsai, 2001; Xia, 2013; Zahra, 1996; Zahra and George, 2002; Zahra and Hayton, 2008), patent numbers (Austin, 1993; Cohen and Levinthal, 1990; Zahra and George, 2002), and questionnaires that directly address the

level of an organization's absorptive capability (Bagchi et al., 2014; Chen, 2004; Clausen, 2013; Lund Vinding, 2006; Spithoven et al., 2011). Such measurements have also been used for studies on performance determinants and studies involving efficiency analyses of GFRIs. Prior studies of performance analysis that investigate public research organizations such as GFRIs have focused primarily on the type or duration of R&D, or environmental characteristics (Choi et al., 2011; Kim and Lee, 2014; Nam et al., 2008; Won et al., 2003). In addition, only studies that have examined the effects of characteristics such as human resource attributes and organizational structure have analysed the impact of the size of the workforce in quantitative terms (Bowman, 1992; Parikh, 2001; Werner and Souder, 1997).

Based on these theoretical and empirical discussions, this study aims to identify the moderating effects of organizational composition in terms of absorptive capacity on the relationship between R&D investment and GFRIs' performance. This is an attempt to overcome the limitations of organizational structure, which has been neglected in terms of core competence and absorptive capacity, and to consider the inherent characteristic of human resources from the perspective of the RBV. Van Den Bosch et al. (1999) indicate that organizational structure is one of the important factors that determine absorptive capacity. Moreover, the level of absorptive capacity differs depending on the type of organizational structure because knowledge processes and methods differ (Burton et al., 1998; Volberda, 1999).

Consequently, we focus on the organizational composition of the researchers who are the human resources of GFRIs. Firstly, we assume that GFRIs' organizational composition in terms of absorptive capacity has a significant impact on the relationship between R&D investment and performance.

Hypothesis 2 (H2): GFRIs' organizational composition in terms of absorptive capacity moderates the relationship between R&D investment and performance.

Considering organizational composition in detail, it can be assumed that the higher the proportion of total R&D personnel related to GFRIs' workforce composition, the higher the absorptive capacity. In other words, as the proportion of R&D personnel increases, absorptive capacity, which is the practical ability to perform R&D, is improved. Thus, the creation of new knowledge through R&D, the generation of innovative ideas, and the possibility of improvement can be increased (Keller, 1996). In this study, we assume that the ratio of R&D personnel, which is one of the elements of GFRIs' organizational composition, positively moderates the relationship between R&D investment and performance in terms of absorptive capacity.

Hypothesis 2-1 (H2-1): R&D investment is more strongly associated with GFRIs' performance when the ratio of researchers in terms of absorptive capacity via organizational composition is higher.

Additionally, the higher the education level of an R&D workforce, the more is its knowledge and know-how (Carter, 1989; Lund Vinding, 2006; Mangematin and Nesta, 1999; Veugelers, 1997). Thus, we assume that the higher the percentage of researchers who have PhD degrees in GFRIs' organizational composition, the greater the positive influence on R&D investment and performance in terms of absorptive capacity.

Hypothesis 2-2 (H2-2): R&D investment is more strongly associated with GFRIs' performance when the ratio of PhD researchers in terms of absorptive capacity via organizational composition is higher.

The types of job and positions of R&D personnel are also important. In other words, R&D personnel differ depending on whether their jobs are full-time or part-time. In general, full-time researchers have more knowledge and know-how than part-time researchers and have greater responsibilities for R&D work (Michie and Sheehan Quinn, 2001; Pfeffer, 1994). Consequently, we assume that a high ratio of full-time researchers, as part of GFRIs' organizational composition, positively affects the relationship between R&D investment and GFRIs' performance.

Hypothesis 2-3 (H2-3): R&D investment is more strongly associated with GFRIs' performance when the ratio of full-time researchers in terms of absorptive capacity via organizational composition is higher.

The positions held by R&D personnel can also have a significant impact. For example, a manager in an organization makes strategic decisions and manages subordinates rather than undertaking R&D. In this regard, we assume that the relationship between R&D investment and performance can be negatively influenced by the ratio of researchers in GFRIs who act as managers rather than researchers. In other words, it is important to identify the researchers in GFRIs who perform actual R&D, which is the main goal of R&D and constitutes the daily workload. Thus, the greater the amount of bureaucratization, the higher the ratio of managers in the organization and the more likely it is that the organization will experience a negative impact on performance.

Hypothesis 2-4 (H2-4): R&D investment is more strongly associated with GFRIs'

performance when the ratio of managers in terms of absorptive capacity via organizational composition is lower.

Finally, the proportion of female researchers in GFRIs' organizational composition can influence the relationship between R&D investment and performance. Research on the relationship between the proportion of women in an organization and performance has been mostly based on the diversity theory (Jehn et al., 1999; Pfeffer, 1985; Schneider, 1987). However, the results of the empirical analysis are not consistent with positive (Ali et al., 2011; Carter et al., 2003; Catalyst, 2004; Cox and Blake, 1991; Erhardt et al., 2003) or negative impacts (Adams and Ferreira, 2009; Earley and Mosakowski, 2000; Shrader et al., 1997). We assume that a high proportion of female researchers in GFRIs positively affects the relationship between R&D investment and performance, because female researchers can generate new ideas and bring creativity from a different perspective to that of male researchers, and they can form mutually competitive and complementary relationships with male researchers.

This proposition reflects the creative and exploratory nature of R&D, which is an intrinsic part of GFRIs. In other words, R&D is the process of creating new knowledge, and such a process requires various approaches to collaboration. Taking these characteristics into account, heterogeneous organizations are superior to homogeneous organizations in that they offer better alternative considerations and exploratory capabilities (Cox and Blake, 1991; Eisenhardt and Schoonhoven, 1990). This is especially because R&D organizations, such as GFRIs, aim to solve complex and unconventional problems; and in such a context, a more effective solution can be obtained from personnel with various human attributes (Bantel and Jackson, 1989; Murray, 1989). Jackson (1992) also argued that organizational heterogeneity is more effective in non-organizational work that requires creativity rather than routine. In fact, the proportion of female researchers in the GFRIs covered by this study is less than half and is between 2.3% and 26.5%. Thus, based on the above discussion, we focus on the proportion of female researchers.

Hypothesis 2-5 (H2-5): R&D investment is more strongly associated with GFRIs' performance when the ratio of female researchers, in terms of absorptive capacity via organizational composition, is higher.

Ⅲ. Research Methods

1) Model and Data

Figure 1 presents this study's conceptual framework. First, we assume that R&D investment in GFRIs directly affects performance. In addition, we hypothesize that GFRIs' organizational composition in terms of absorptive capacity moderates the relationship between R&D investment and performance.

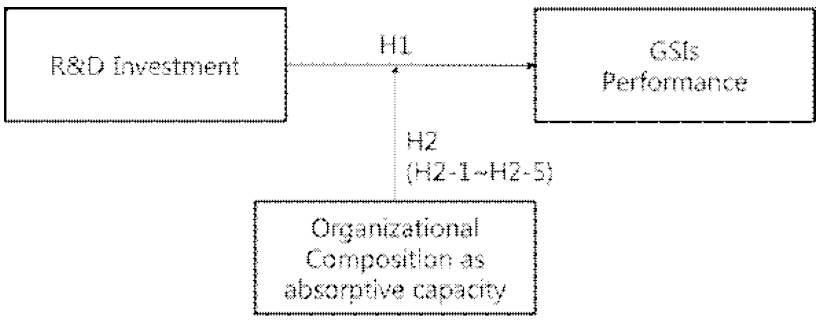

Figure 1. Conceptual Framework

For the purpose of empirical analysis, this study considers the budget and personnel status data of 25 science and technology GFRIs from 2011 to 2015. The data were obtained from a survey of the Korea Institute of Science and Technology Evaluation and Planning (KISTEP) and were combined with R&D statistics provided by the National Research Council of Science and Technology (NST). KISTEP is responsible for planning, evaluating, and coordinating national science and technology policy in Korea. The NST has 25 science and technology GFRIs and its purpose is to foster GFRIs, distribute the research results, and support small and medium-sized enterprises (SMEs) through the GFRIs. The NST publishes a range of information on its 25 GFRIs which provide details of the GFRIs' R&D budgets, personnel, and performance information. In sum, this study combines data about surveyed GFRI researchers drawn from a KISTEP questionnaire with data about GFRIs drawn from the NST. The final data used in the empirical analysis are based on five years of data from 23 GFRIs, since two of the 25 GFRIs had errors or missing data. The final number of observations was 115.

2) Variables and Measures

Table 1 shows the classification, definition, and measurement of the variables used in

this study.

Table 1. Definition of Variables and Data Sources

Category		Variables	Definition	Data source
Dependent variable	GFRIs' performance	SCI paper	ln (number of SCI papers)	NST's R&D Statistics
		patents	ln (number of PCT patents)	
Independent variables	R&D Effort	R&D Investment	n (Amount of R&D budget)	
Moderating Variables	Organizational composition as Absorptive Capacity	Ratio of researchers	No. of researchers /Total employees in GFRIs	KISTEP Survey
		Ratio of PhD researchers	No. of PhD. researchers/ total researchers	
		Ratio of FTE (Full-time employee) researchers	No. of FTE of researchers/ total researchers	
		Ratio of managers	No. of researchers with a manager position/ total researchers	
		Ratio of female researchers	No. of female researchers/ total researchers	
Control variables	Age	Age	ln (age)	NST's R&D Statistics
	Size	No. of employee	ln (No. of employee)	

This study measures GFRIs' performance as a dependent variable by the number of papers and patents because GFRIs' mission is to conduct research and development for identifying new natural phenomena, developing new technologies, and improving existing technologies. Many prior studies have used papers (Griliches, 1984; Wang and Huang, 2007) and patents (Acs et al., 2002; Ahuja and Katila, 2001; Griliches, 1984; Hitt et al., 1991; J Acs and Audretsch, 1989) for empirical analysis to measure R&D output. Hence, we used the number of Patent Cooperation Treaty (PCT) patents and the number

of papers with international applications published in journals listed in the Science Citation Index (SCI) as proxies of GFRIs' performance. As an independent variable, GFRIs' R&D investment uses the R&D budget for the year.

The moderating variable, GFRIs' organizational composition as absorptive capacity, is identified through empirical analysis and classified into five categories as we have discussed above. First, we assume that the higher the proportion of R&D personnel in GFRIs, the better the performance. This assumption, as in prior studies, is an important determinant of R&D performance outcomes because the measure of absorptive capacity is used on the same scale as the number of R&D personnel (Cohen and Levinthal, 1990; Keller, 1996). Thus, we use the ratio of the number of researchers to total GFRI employees, calculated by dividing the number of researchers by a GFRI's total employees, as one indicator of GFRIs' absorptive capacity. One of the variables related to the excellence of R&D personnel includes a high level academic degree held by an R&D researcher, which can be a positive factor for a GFRI's performance; consequently, this study uses the ratio of PhD researchers to total researchers. We can also infer that a full-time researcher has greater responsibility than a part-time researcher; thus, we use the ratio of full-time research employees to total researchers. We also use the ratio of researchers with a managerial position to total researchers. This ratio is calculated by dividing the number of researchers in a managerial position by the total researchers. Finally, we assume that the higher the ratio of female researchers, the more positive the impact on the relationship between R&D investment and performance. Hence, we use the ratio of female researchers to total researchers.

We also use two control variables. First, we include the age of individual GFRIs in the control variables to control for innovation activities and performance in accordance with the age of each organization. In addition, we use total employees to control for the size of each GFRI. Further, the empirical analysis model includes the size of the R&D budget for the prior year.

2) Empirical Model

Recall that this study's purpose is to investigate the effect of GFRIs' organizational composition on R&D investment and performance in terms of absorptive capacity. Panel data analysis was used to consider not only observable variables but also the heterogeneity of unobservable GFRIs. In contrast to cross-sectional analysis, panel data analysis can provide an unbiased estimator by controlling for the unobservable heterogeneity of individuals, which is the panel's basic unit (Schmidheiny, 2014). Thus,

$$y = \alpha + \beta x + \delta + \epsilon \qquad \begin{aligned} &i = 1,2,...,N \\ &t = 1,2,...,T \\ &\varepsilon_{it} \sim i.i.d.(0, \sigma^{2_e}) \end{aligned}$$

Here, i is an individual observation of GFRIs, t is time, is the dependent variable, represents the independent variables, is an unobservable individual, and the GFRI-specific effect as a time invariant, is an idiosyncratic error term.

The pooled ordinary least squares (POLS) model assumes that δ is not a unique value of individual GFRIs; accordingly, the observed values are analysed as different GFRIs. Taking into account the time dimension in the analysis of panel data, the error term , which is time invariant and not observed, is important. The POLS model assumes that is not a unique value of individual GFRIs and that all observations are considered different GFRIs. In terms of rationality, the expected value of the error term is zero at all points in all panel data and assumes homoscedasticity. In addition, there is no contemporaneous correlation and autocorrelation in the panel data's error term. Moreover, the exogeneity of the explanatory variables is assumed. Panel analysis is generally performed by applying the POLS, fixed effects, and random effects models. When a prior assumption is violated, the POLS' estimator is not consistent. However, fixed and random effects models assume that is a unique value of individual GFRIs. It is assumed here that fixed effects are determined by fixed constants of GFRIs and that random effects are determined randomly from a particular distribution (Wooldridge, 2010). First, we investigated whether heteroscedasticity exists in the analytical model by employing the likelihood ratio (LR) test and considering autocorrelation through the Wooldridge test (Wooldridge, 2010). The LR test results showed heteroscedasticity in the panel data and the Wooldridge test demonstrated first-order autocorrelation. In addition, the results of a Hausman test (Hausman, 1978) (showed that it is appropriate to select the fixed effects model rather than the random effects model by rejecting the null hypothesis (at the 1% significance level.

Consequently, this study selected the fixed effects panel generalized least squares (GLS) model as the final analytical model, taking into account the cross-sectional and time-series characteristics of the panel data, the heterogeneity of the error term, and autocorrelation. The results of the POLS model were also presented for comparative purposes. In addition, a different time lag was applied to the dependent variables in the panel analysis. The reason was that prior studies have assumed that the performance of R&D investment is obtained at a certain time lag (Kay, 1988; Ravenscraft and Scherer, 1982). Thus, we applied one year for SCI papers and two years for PCT patents through focus group interviews held with GFRI researchers.

Ⅳ. Results

Table 2 shows the descriptive statistics such as the mean, standard deviation, and minimum and maximum values of the variables used in this study. We first analysed and confirmed the effect of R&D investment on performance and then used hierarchical regression procedures (Cohen et al., 2003) to confirm the effect of each moderating variable on a sequential basis. The results of the empirical analysis are presented together with the results of the POLS model, which does not consider inter-individual effects.

Table 3 shows the results of the POLS model. These indicate that R&D investment of GFRIs have a significantly positive effect on the number of SCI papers and PCT patents. In models 2 and 3 of Table 3, the ratio of managers ($t=-2.44$, $P<0.01$) among the five organizational composition variables of GFRIs appears to negatively moderate the relationship between GFRIs' R&D investment and the number of SCI papers. However, models 5 and 6 of Table 3 show that the ratio of managers among all the researchers has a positive moderating effect ($t=1.84$, $P<0.05$) on the relationship between GFRIs' R&D investment and the number of PCT patents. In other words, the effect of the ratio of managers among all the researchers differs in accordance with the type of dependent variable, and the ratio of researchers ($t=2.71$, $P<0.05$), PhD researchers ($t=2.43$, $P<0.01$), and full-time equivalent (FTE) researchers ($t=2.79$, $P<0.001$) all have a positive moderating effect on the relationship between GFRIs' R&D investment and PCT patent numbers, as originally assumed.

Table 4 shows the results of the panel GLS model with fixed effects. In accordance with the results of the POLS model, the GFRIs' R&D investment from model 7 through 12 positively affects the number of SCI papers and PCT patents. The results of the GFRIs' organizational composition as absorptive capacity and the moderating effect analysis are presented in models 9 and 12. First, the ratio of researchers ($t=1.91$, $P<0.05$) shows a positive moderating effect on the relationship between R&D investment and the number of SCI papers, thereby confirming hypothesis H2-1. These results are the same as that of model 6, in which GFRIs' performance is set as the number of PCT patents and the ratio of researchers ($z=3.34$, $P<0.001$) and where it has a significantly positive moderating effect. Next, we examined the moderating effects of the ratio of PhD researchers and the ratio of FTE researchers, which are variables that indicate the quality level of R&D personnel. The moderating effect of the ratio of PhD researchers ($z=1.82$, $P<0.05$) is significantly positive only for the number of PCT patents

in terms of GFRIs' performance; thus, hypothesis H2-2 is partially supported. In other words, the ratio of PhD researchers has a positive moderating effect on the relationship with R&D investment only when the dependent variable is PCT patents.

The ratio of FTE researchers, as H2-3 postulates, on the other hand, positively regulates the relationship between R&D investment for both the number of SCI papers ($z=1.68$, $P<0.05$) and the number of PCT patents ($z=3.31$, $P<0.001$). The results of the empirical analysis for hypotheses H2-2 and H2-3 indicate that the higher the level of education of the personnel in an R&D organization, the higher the level of authority and responsibility for regular employees, and the better the performance. This result is in accordance with recent efforts by many high-tech firms to secure competitive R&D personnel (Kim et al., 2015).

In other words, it is possible to say that the greater the number of researchers who are highly educated, the more stable the working conditions in an organization, and the higher the probability of obtaining good results. In particular, considering that R&D investment takes a long time to deliver some performance, the suggestion is to secure not only highly educated personnel but also a stable workforce capable of consistent research, in order to improve an organization's performance. According to the results of the POLS model, the ratio of managers, which is hypothesis 2-4, has the opposite effect on the number of SCI papers and PCT patents in terms of GFRIs' performance. Namely, the ratio of managers has a negatively moderating effect ($z=-3.91$, $P<0.001$) on the relationship between GFRIs' R&D investment and the number of SCI papers, and a positively moderating effect ($t=3.06$, $P<0.001$) on the relationship between GFRIs' R&D investment and the number of PCT patents. Thus, hypothesis H2-4 is supported when the performance of GFRIs is assumed to be determined by the number of PCT patents. Finally, the ratio of female researchers has a significantly positive effect on the relationship between GFRIs' R&D investment and the number of SCI papers ($t=1.73$, $P< 0.05$) and the relationship between GFRIs' R&D investment and PCT patents ($t=1.81$, $P< 0.05$). Accordingly, hypothesis H2-5 is supported.

Table 2. Descriptive Statistics and Correlation Matrix of Variables (N = 115)

Variables	Mean	std dev	Min.	Max.	SCI paper	patents	R&D Investment	Ratio of researchers	Ratio of PhD researchers	Ratio of FTE researchers	Ratio of managers	Ratio of female researchers	age	No. of employees
SCI paper	4.911	0.814	2.773	6.410	1.000									
PCT patents	2.639	1.065	0	4.654	0.532***	1.000								
R&D Investment	11.883	0.755	10.581	13.441	0.321***	0.332***	1.000							
Ratio of researchers	0.682	0.147	0.275	0.898	-0.165	0.140	0.189□	1.000						
Ratio of PhD researchers	0.522	0.116	0.151	0.663	0.481***	0.375***	0.020	0.245*	1.000					
Ratio of FTE researchers	0.687	0.106	0.446	0.881	0.147	0.332**	0.42***	0.326***	0.388***	1.000				
Ratio of managers	0.103	0.036	0.040	0.193	-0.085	0.113	0.212□	0.110	-0.250*	0.199□	1.000			
Ratio of female researchers	0.093	0.070	0.023	0.265	-0.205*	-0.095	-0.418***	0.027*	-0.252*	-0.054	0.068	1.000		
age	3.224	0.601	1.386	3.970	0.204□	0.094	0.333**	0.176	0.227*	0.388***	-0.408***	-0.049	1.000	
No. of employees	5.945	0.690	4.828	7.602	0.324***	0.323**	0.521***	0.269*	-0.018	0.420***	0.047	-0.389***	0.435***	1.000

Notes: †p < 0.10, *p<0.05, **p<0.01, ***p<0.001 estimated standard errors are in parentheses

Table 3. Results of POLS Analysis (Full Sample, N = 115)

Dependent Variable	SCI paper(1 year time lag)			PCT patents(2 year time lag)		
Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
age	0.013(0.018)	-0.004(-0.018)	0.010(0.022)	-0.019(0.026)	-0.035(0.029)	-0.109(0.032)***
No. of employees	-0.004(0.037)	0.100(0.042)**	-0.026(0.065)	0.010(0.051)	0.072(0.068)	0.210(0.104)**
R&D Investment	0.030(0.013)**	0.062(0.016)***	0.044(0.021)**	0.059(0.019)***	0.089(0.026)***	0.153(0.036)***
Ratio of researchers		-0.209(0.075) ***	-0.136(0.088)		0.015(0.116)	0.243 (0.128)*
Ratio of PhD researchers		0.560(0.094)***	0.625(0.119)***		0.605(0.151) ***	0.647(0.170)***
Ratio of FTE researchers		-0.24(0.159)	-0.241(0.177)		-0.231(0.255)	-0.520 (0.275)*
Ratio of managers		0.453(0.366)	0.300(0.380)		0.589(0.587)	0.161(0.599)
Ratio of female researchers		0.230(0.152)	0.429(0.260)		0.331(0.242)	1.603(0.404)***
R&D InvestmentxRatio of researchers			0.135(0.339)			0.901 (0.527)*
R&D InvestmentxRatio of PhD researchers			-0.12(0.155)			0.541(0.223)**
R&D InvestmentxRatio of FTE researchers			0.456(0.405)			1.849(0.663)***
R&D InvestmentxRatio of managers			-1.371 (0.563)**			1.496(0.813)*
R&D InvestmentxRatio of female researchers			0.475(0.288)			0.64(0.415)
constant	0.075(0.21)	0.146(0.253)	-0.097(0.297)	-0.340(0.289)	-0.673*(-0.393)	-1.270***(-0.427)
Adjusted R2	0.067	0.447	0.488	0.100	0.293	0.441
F-Value(P)	2.61**	7.77***	5.90***	3.36***	4.26***	4.82***

Notes: †p < 0.10, *p<0.05, **p<0.01, ***p<0.001 estimated standard errors are in parentheses

Table 4. Results of FE Panel GLS Analysis (Full Sample, N = 115)

Dependent Variable	SCI paper(1 year time lag)			PCT patents(2 year time lag)		
Variables	Model 7	Model 8	Model9	Model 10	Model 11	Model 12
age	0.009(0.012)	-0.014(0.01)	0.005(0.011)	-0.041(0.03)	-0.060(0.016)***	-0.053 (0.021)**
No. of employee	0.021(0.014)	0.119(0.019)***	0.009(0.026)	0.005(0.044)	-0.076(0.046)	-0.018(0.063)
R&D Investment	0.031(0.005)***	0.041(0.015)***	0.030(0.011)**	0.070(0.039)*	0.111(0.027)***	0.079 (0.047)*
Ratio of researchers		0.163(0.046)***	0.117(0.058)**		0.21(0.138)	0.037(-0.116)
Ratio of PhD researchers		0.488(0.085)***	0.489(0.081)***		0.133(0.119)	0.584(0.154)***
Ratio of FTE researchers		0.215(0.082)***	0.166 (0.098)*		0.468(-0.191)**	0.145(0.245)
Ratio of managers		0.378(0.147)**	0.345(0.275)		-0.903(0.302)***	-1.221(0.447)***
Ratio of female researchers		0.134(0.133)	0.288** (0.147)		0.059(0.186)	0.959(0.290)***
R&D InvestmentxRatio of researchers			0.215(0.113)*			1.032(0.309)***
R&D InvestmentxRatio of PhD researchers			0.161(0.101)			0.283(0.155)*
R&D InvestmentxRatio of FTE researchers			0.275(0.163)*			1.142(0.345)***
R&D InvestmentxRatio of managers			-1.395(0.357)***			1.574(0.514)***
R&D InvestmentxRatio of female researchers			0.265 (0.154)*			0.685(0.377)*
constant	0.197(0.105)*	0.283(0.107)***	0.04(0.139)	-0.458(0.291)	-0.847(0.183)***	-0.741 (0.310)**
Wald χ^2	46.06***	116.76***	183.05***	9.91**	674.35***	362.09***

Notes: †p < 0.10, *p<0.05, **p<0.01, ***p<0.001 estimated standard errors are in parentheses

V. Conclusions and Discussion

Although GFRIs have been acknowledged as one of the most important players in implementing government-led economic development and technological innovation strategies (Lee et al., 1996), many studies focus on the determinants and efficiency of GFRIs' performance (Choi et al., 2011; Kim and Lee, 2014; Nam et al., 2008; Won et al., 2003). These studies have mainly focused on efficiency in terms of macroscopic aspects such as input–output framework, GFRIs' research structure, and evaluation methodologies of research performance. In this context, although there is a need to extend the research issues such as R&D organizational composition (Burton et al., 1998; Volberda, 1999), the empirical research has not been fully examined.

Thus, we tried to clarify the moderating effect of organizational composition in terms of absorptive capacity on the relationship between GFRIs' R&D investment and performance, based on theoretical and empirical discussions.

We first investigated whether GFRIs' R&D investment affects performance. We then classified GFRIs' organizational composition as absorptive capacity into five types. First, we assumed that the ratio of R&D personnel in GFRIs moderates the relationship between R&D investment and performance overall. In addition, we assumed that the higher the level of education such as the ratio of researchers with PhDs to the total number of R&D personnel and the higher the level of authority and accountability such as the number of FTE researchers the more positive the moderating influence on the relationship between R&D investment and performance. We also assumed that the higher the proportion of managers who only manage a team rather than carry out R&D, the more negative the effect of R&D investment on GFRIs' performance. This assumption is made because GFRIs are advanced bureaucratic organizations and R&D is carried out in accordance with governmental policy; however, the direction of R&D performance is changing and research can be conducted in accordance with a vertical structure. Finally, we examined how the ratio of female researchers to the total researchers in GFRIs has a moderating effect on the relationship between R&D investment and performance. This variable suggests that it is desirable to identify the roles of female employees because they are important in terms of organizational diversity. In particular, we contribute to an expansion of the scope of related research because major studies related to gender composition in organizations have been limited to specific groups such as top management teams (TMTs) at the firm level (Adams and

Ferreira, 2009; Ali et al., 2011; Carter et al., 2003; Catalyst, 2004; Cox and Blake, 1991; Earley and Mosakowski, 2000; Erhardt et al., 2003; Shrader et al., 1997) in term of diversity theory.

The results of the empirical analysis are summarized as follows. First, GFRIs' R&D investment has a positive effect on performance. This result is consistent with prior research (Bound et al., 1982; Hall and Ziedonis, 2001; Kondo, 1999; Pakes and Griliches, 1984). In contrast to previous studies, which mainly set firms as research level and measured the performance of R&D investment as the amount of sales or improvement in productivity (Cohen and Klepper, 1996; Griliches, 1990, 2000; Hall and Ziedonis, 2001; Hirschey, 1982; J Acs and Audretsch, 1989; Kleinknecht and Reijnen, 1992; Kondo, 1999; Pakes and Griliches, 1980, 1984; Shefer and Frenkel, 2005), we set GFRIs as the unit of empirical analysis. Therefore, it is meaningful that we set the numbers of SCI papers and PCT patents as dependent variables and find that R&D investment can be positively influenced by the R&D process itself rather than economic performance.

The results show that the higher the ratio of researchers, PhD researchers, and FTE researchers, who have more authority and responsibility, the more positively moderated is the relationship between R&D investment and performance. This asset represents the overall competence of an organization and consists of expertise, experience, skill, and culture (Hall, 1992). The ratio of female researchers also positively affects the relationship between R&D investment and performance. Interestingly, the ratio of managers in GFRIs produced conflicting results regarding the numbers of SCI papers and PCT patents. In other words, this ratio appears to have a negatively moderating effect on the number of SCI papers and a positively moderating effect on the number of PCT patents. These findings can be interpreted in terms of the attributes of the policies implemented by the Korean government for GFRIs during the period of the analysis, because, based on the policy paradigm of the 'Creative Economy' from 2011 to 2015, the Korean government emphasized that GFRIs should provide technical knowledge and commercialization in order to support SMEs. Such support was in the form of patents, for example, which reduced the gap between SMEs and the market, rather than academic support in the form of SCI papers. Thus, we believe that the results seem to reflect some of the policies on GFRIs.

The results provide the following implications for the policy direction of the Korean government, which currently emphasizes the macro approach for GFRIs. The Korean government has established GFRIs' policies and roles at the national level in accordance with the technological portfolio, investment scale, and level of R&D. However, there is

a lack of research and policy considerations about the organizational composition, personality, and characteristics of the workforce that undertakes R&D. Consequently, in order to improve the performance that is derived from R&D investment, the directions of GFRIs' operational and developmental policies need to be considered not only in macro-level terms but also in combination with the characteristics of organizations and researchers.

Nonetheless, this study has the following limitations. First, despite using five years of data of 25 science and technology GFRIs, the number of observations is 115 due to data limitations. Second, because the missions and R&D specialties of each GFRI are discriminatory, R&D performance can differ. For example, Lichtenberg and Siegel (1991) suggested that the effects of R&D on performance may differ in terms of basic, applied, and developmental effects. However, in this study, it has proved difficult to distinguish the main R&D stage of each GFRI and to reflect these in the analysis.

Finally, we can consider that future studies will need to investigate the cognitive aspects of GFRIs' researchers. In other words, researchers' understanding of organizational missions and roles can affect performance in terms of their levels of commitment to tasks. Thus, unlike empirical analysis that focuses on the physical aspects of GFRIs, future research must focus on the cognition and characteristics of individual researchers who comprise the GFRIs and who conduct R&D through interviews and surveys.

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