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# An analysis of the optimal research and development investment level of contractor using the panel threshold regression model

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**ABSTRACT**

This study explores the threshold effect between R&D investment and firm performance in the construction industry, focusing on optimizing R&D spending in this capital-intensive sector. Unlike industries with shorter innovation cycles, construction requires long project durations, high costs, and regulatory compliance, making strategic R&D allocation essential. Using the panel threshold regression model (PTRM), the study analyses data from 136 Korean construction firms with over 100 employees and in-house R&D centres. Threshold values of 0.47% for R&D project cost and 2.25% for researcher ratio are identified, beyond which investment efficiency declines. PTRM is suitable for detecting nonlinear effects, though future studies should test alternative models for greater reliability. While firm-specific financial factors are controlled, external influences such as market dynamics and government policies are not considered. A five-year lag is assumed between R&D investment and outcomes, aligning with South Korea's planning norms, but alternative lags are recommended for further study. The findings offer practical insights for SMEs in managing R&D and financial constraints, with relevance extending beyond Korea to developing nations seeking to close technological gaps. Future research should refine sector-specific benchmarks and consider firm size variations for more applicable R&D strategies.

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**KEYWORDS**
Threshold impact; panel threshold regression model; R&D investment; Korean contractor

## Introduction

According to the definition provided by the Organisation for Economic Co-operation and Development (OECD 2015), research and development (R&D) refers to 'creative activities carried out in a systematic way to newly accumulate all knowledge, including human, cultural, and social knowledge, or to devise new applications using the accumulated knowledge'. R&D investments are a critical matter that play a significant role in enhancing products (Aw et al. 2011) and generating value for the company and its shareholders. Therefore, they constitute a substantial portion of intangible assets and intellectual capital for the industry as a whole, and specifically for the firm. As a result, R&D investment might be considered a significant source of economic growth at the country and government levels (Lakhal and Dedaj, 2019). Additionally, R&D investment has a crucial correlation with the long-term profitability of firms, enhancing business competitiveness. Thus, it has been recognized as deserving the attention of the firm's top management. Companies must enhance their comprehensive competitiveness, expedite independent technical innovation, and elevate corporate value to sustain continuous growth in the competitive international business market. R&D investments in intangible assets have emerged as a crucial topic due to the heightened emphasis on the value these assets bring to businesses (Safitri et al. 2019).

The construction industry has increasingly been required to pursue innovation through R&D initiatives. With the advent of the Fourth Industrial Revolution (Industry 4.0), the integration of advanced technologies such as BIM, IoT, and AI has positioned innovation as a key driver of competitiveness and market sustainability. However, implementing these digital technologies demands substantial R&D investment, and in the construction sector, such investment is often accompanied by considerable risks—namely, uncertain returns on investment, challenges in resource allocation, and the project-based nature of firms, which limits long-term planning.

Compared to the manufacturing or technology sectors, R&D in construction is distinguished by long investment cycles, high capital intensity, and relatively low short-term returns. These characteristics inherently increase financial risk and make it more difficult for construction firms to maintain consistent R&D investment strategies. In particular, contractor-led projects face several financial and operational constraints—such as delayed payments, rigid contract structures, and narrow profit margins—that limit the capacity for long-term innovation efforts (Deep et al. 2024). Moreover, due to the industry's reliance on subcontractors for specialized expertise, R&D efficiency is often affected by the quality of collaboration between subcontractors and general contractors. Deep et al. (2023) emphasize that inefficiencies in these relationships can negatively impact productivity and decision-making. Therefore, construction R&D strategies should not only consider investment levels but also promote collaborative innovation frameworks to improve implementation outcomes and long-term impact. These technologies are not only

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enablers of innovation but also represent significant cost burdens that require careful financial and strategic decision-making. As construction firms face increasing pressure to adopt such technologies to stay competitive, identifying the optimal level of R&D investment becomes a critical managerial and financial concern. In addition, contractor-led R&D efforts in the construction industry present their own unique challenges. Unlike manufacturers, many construction firms lack structured in-house R&D systems and operate under business models that emphasize short-term project profitability over long-term innovation (Regona et al. 2022). This often leads to hesitation in engaging with uncertain, long-cycle R&D initiatives, particularly due to financial risks, limited technical workforce, and delayed returns. These structural and organizational barriers highlight the importance of establishing a more efficient and data-driven approach to optimize R&D investment strategies in the construction sector. Construction firms often struggle to determine the appropriate level of R&D investment due to the dual risk of overinvestment and underinvestment. Excessive R&D spending can strain financial resources and threaten firm stability, particularly in capital-intensive and low-margin environments like construction. On the other hand, insufficient investment can lead to technological stagnation and loss of competitive advantage. These contrasting risks highlight the need to identify a precise investment threshold that balances innovation gains with financial sustainability.

R&D investment stands out as the primary source of such innovation (Hampson 2014; Turner et al. 2021). Different studies have been conducted on the correlation between R&D investment and productivity, profit, and company growth. According to Tassey (1983), who concentrated on high-tech technology as a sample, R&D investment may continuously increase a firm's value and performance by demonstrating a positive link between corporate R&D spending and company performance. However, investing in an R&D project alone does not increase a firm's value; rather, the degree of contribution to the company valuation is determined by how efficiently it is used (Xin and Sun 2019). Contractors tend to prioritize construction projects that yield immediate profits for the firm, rather than R&D projects, which are characterized by high sunken costs, long-term cycles, and high risks. These traits may hinder the development of an effective and balanced operational plan for a company. Specifically, small to medium-sized construction firms encounter difficulties in determining the most effective allocation and duration of their resources towards achieving optimal performance from investments in R&D projects. Contrarily, in developing countries where the construction sector has not yet reached full maturity, individual firms tend to allocate resources disproportionately towards R&D efforts. This inclination stems from their pursuit of swiftly acquiring advanced technology and narrowing the gap with leading industries within a condensed timeframe (Darko et al. 2018).

The objective of this study is to assist construction companies in developing optimal R&D investment strategies by determining the threshold investment levels for key R&D factors. Specifically, this study aims to identify the non-linear relationship between R&D investment and firm performance, recognizing the point at which additional investment yields diminishing returns. To achieve this, the research analyses the correlation between R&D investment and company performance (profit rate), focusing on two critical R&D factors: R&D project cost and researcher ratio. Using a threshold regression model, this study examines the impact of varying R&D investment levels on firm profitability within the South Korean construction industry. The findings are intended to provide a data-driven framework for construction firms, enabling them to allocate R&D resources more efficiently and maximize their competitive advantage. While this study focuses on Korean construction firms, its findings have broader implications for other countries with similar industry structures. South Korea represents a highly industrialized economy with a strong emphasis on R&D investment, making it a relevant case study for nations experiencing rapid technological growth and increased R&D expenditures. The findings may also be applicable to emerging economies seeking to optimize their R&D investments within the construction sector. Moreover, since construction firms globally face similar challenges in balancing project-based investment cycles with long-term innovation strategies, the insights from this research can serve as a reference for international construction companies aiming to refine their R&D allocation strategies. Korean firms can serve as ideal examples for exploring the impact of R&D investment in terms of the scale of investments made into R&D. This is attributed to Korea's status as a highly representative case transitioning from a developing to a developed nation with vigorous technological advancements (Lee and Ki 2017; Kim and Park 2020).

Various criteria are utilized in assessing the effectiveness of R&D. Additionally, a company's profit rate is determined not only by R&D performance but also by various other complex interactions, so it cannot be solely attributed to R&D investment. However, the profit rate serves as a crucial metric for evaluating the current company value, irrespective of the company's size or history. Since all companies periodically disclose their profit rates, the results of R&D investment using companies' profit rate can be considered objective, whether it is positive or negative. For the establishment of an optimal R&D strategy, the panel threshold regression model is used to analyse the threshold impact of R&D investment. In addition, empirical analysis is conducted, including basic statistics and multicollinearity tests for variables selected as major determinants of the performance (profit rate) of R&D investment in the Korean construction industry.

The remainder of this paper is organized as follows. The Literature Review section examines existing research on the relationship between R&D investment and firm performance, with a particular focus on the construction industry. The Research Methodology section describes the research design and methodology, focusing on variable selection and the panel threshold regression model. The Research Data section presents the empirical analysis results, while the Analysis section discusses the key findings and their implications. The Discussion section explains the main conclusions and implications of the study, and finally, the Conclusion provides a summary of the entire research and suggestions for future studies.

## Literature review

### *R&D and firm performance: general business sector*

Previous studies have highlighted the critical role of R&D investment across various industries and business sectors, emphasizing its impact on organizational competitiveness and long-term sustainability (Konno and Itoh 2018; Vrontis and Christofi, 2021). The significance of R&D for organizational competitiveness has spurred the development of supportive and evaluative systems aimed at optimizing R&D strategies. Various studies have indicated that appropriate investment in R&D can yield beneficial outcomes, such as bolstering the country's GDP and employment growth rates, alongside enhancing corporate sales, productivity, and profitability. In the USA, the National Science Foundation has been regularly evaluating its R&D program since 1950, and many US firms utilize R&D metric systems to assess the efficiency of their R&D investments (Lucking et al. 2019). In Germany, Hud and Hussinger (2015) investigated the effects of R&D expenditure on small and medium-sized businesses during the most recent financial crisis. They demonstrated how R&D may result in additional business opportunities over the long term.

In the realm of R&D investment, major research has concentrated on the governmental role, including regulations and support mechanisms such as subsidies. Alam et al. (2019) emphasized that the relationship between R&D investment and company growth is highly dependent on the external environment. Through the estimation and elasticity testing of more than 400 companies across various emerging countries, they scrutinized the impact of government intervention on the relationship between a firm's R&D expenditure and growth. They asserted that, particularly in emerging economies, safeguarding R&D outcomes at the national level is crucial to ensure the continued development of the national economy along the right trajectory. Regardless of the business sector, research pertaining to R&D has predominantly focused on the governmental role or the overarching national strategies for R&D implementation, rather than on the specific corporate or industrial level (Becker 2015; Choi and Lee 2017; Hu et al. 2022). Yu et al. (2016) endeavoured to comprehend the impact of government support on R&D investment in the construction and related industries, such as the energy sector. Their findings revealed that governmental subsidies exert a substantial influence on augmenting private firms' R&D expenditure. Moreover, they observed that the magnitude of this impact is further modulated by the ownership structure or size of the firm. Additionally, Xu et al. (2014) investigated how government-led R&D collaborations with universities or research institutes enhance companies' new development initiatives, utilizing data from more than 270 Chinese companies. From the perspective of companies striving for maximum profits and sustainable growth, accurately evaluating R&D performance is crucial for establishing appropriate resource allocation (reinvestment) strategies within limitations (Lev and Zarowin 1999; Lakhal and Dedaj, 2019). Excessive expenditure in R&D may raise the issue of companies' accounting stability, which is not always due to the complexity of cash flows and the high level of uncertainty. Thus, companies and industries need to accurately appraise R&D performance to effectively utilize limited resources, and various studies have been conducted accordingly (Konno and Itoh 2018; Salimi and Rezaei 2018; Xin and Sun 2019).

While prior studies have firmly established the importance of R&D investment in driving corporate growth and innovation across various industries, they often centre around manufacturing and technology-driven sectors where structured R&D systems are more prevalent. However, these frameworks are not always applicable to industries like construction, which operate under markedly different business models and face unique structural and financial constraints. The next section explores these sector-specific challenges, focusing on why the construction industry requires a more tailored approach to R&D investment.

### *Construction sector-specific challenges in R&D*

While R&D is widely recognized as a driver of innovation across industries, the construction sector faces distinct challenges and opportunities. Construction firms often operate under project-based models with narrow profit margins and limited long-term planning, making R&D investment riskier compared to other sectors. Moreover, unlike manufacturing or IT industries where technological innovation can be continuously applied and refined across standardized products, the construction sector is largely composed of one-off projects. This makes it difficult to reuse developed technologies across multiple projects, particularly for small and medium-sized firms that lack scale. Additionally, construction firms tend to prioritize short-term project profitability over long-term innovation strategies. As a result, sustained R&D investment is often seen as risky and unattractive, except among large-scale firms with dedicated R&D units. These conditions create a structural disincentive for long-term innovation and highlight the need for tailored R&D models that account for the unique dynamics of the construction sector. However, when effectively managed, R&D in construction can enhance productivity, improve project quality, and foster competitive advantage through technology adoption such as BIM, modular construction, and digital twin technologies. These characteristics highlight the need for sector-specific R&D strategies that reflect the unique risk-return profile of construction firms. Gambatese and Hallowell (2011), who focus on the construction sector, contended that technological innovation is crucial to long-term company performance. However, compared to other business sectors, investment by construction companies alone in R&D projects tends to be insufficient to achieve competitive high technologies. Wang et al. (2017) examined the impact of policy and market conditions on corporate R&D investment in China. They found that uncertainties in policy and market conditions can negatively influence decisions regarding R&D investment. However, they argued that the size and scope of companies' R&D investment vary depending on the amount of government support (subsidies) received by the company. Xu et al. (2019) also conducted research to investigate the influence of market conditions and government intervention, which could either constrain or support R&D investments by private companies. Using 6,595 firm-year observation samples, they argued that market valuation can enhance companies' expenditure on R&D projects, but there is no specific evidence indicating that government support significantly affects R&D investment levels.

However, as seen in Table 1, research from the perspective of private companies that directly invest in R&D has been relatively insufficient. Limited research (Saad and Zantout 2014; Ahuja and Novelli 2017; Dranev et al. 2017; Shi 2019) has been conducted to determine the correlations between over-investment and the appropriate R&D level from the company or industry perspective. According to the findings of these studies, R&D investment is generally understood to have a positive effect. However, there are also numerous studies indicating that there is no significant correlation or, in some cases, a negative relationship between increasing R&D investment and company performance, particularly in cases of over-investment (Lee and Wu 2016; Lin et al. 2017). Limited previous studies have derived the relationship with the linearity of the S curve, but few studies have quantitatively evaluated the appropriate level of R&D investment. Although previous studies have examined the relationship between R&D investment and firm performance, most have relied on linear models or broad, sector-wide generalizations. These approaches often lack a structured threshold analysis tailored to the unique characteristics of the construction industry. Moreover, the bulk of existing research has focused on manufacturing and technology sectors, leaving a significant gap in understanding how R&D investment functions within project-based industries such as construction. While prior literature recognizes the importance of R&D in enhancing firm performance, it rarely offers a clear methodology for identifying the point at which further investment becomes inefficient.

To fill this gap, the present study adopts a panel threshold regression model to quantify the optimal level of R&D investment for construction firms. This approach not only builds on the existing R&D literature but also provides practical guidance for firms seeking to improve their investment efficiency, maximize returns, and manage financial risk. Furthermore, while some previous studies acknowledge the complex R&D challenges specific to construction firms, these insights remain largely conceptual or are derived from case studies outside Korea. Considering Korea's distinctive industrial landscape—marked by a strong focus on corporate-led innovation and dominance by large conglomerates—it is crucial to examine how R&D investment patterns unfold within the Korean construction sector. The following section investigates national trends and private-sector dynamics in Korea's R&D landscape, with particular emphasis on how these align with or diverge from the global patterns previously discussed.

## R&D investment in Korea

Korea has adopted a strategy as a late-industrialized country by maintaining a high level of R&D investment to strengthen its technological capabilities and narrow the technological gap with advanced economies. As illustrated in Figure 1, Korea's R&D intensity—measured as R&D investment as a percentage of GDP—is the highest (4.9%) among major economies, exceeding that of the United States (3.5%), Japan (3.3%), Germany (3.1%), and the EU average (2.1%). This exceptionally high investment level reflects Korea's national strategy to strengthen its technological capacity and catch up with advanced economies.

While the government implemented policies to promote high levels of R&D investment (Park and Yuhn 2012), Korea has simultaneously relied heavily on large private conglomerates known as Chaebol[1], for actual R&D execution (Byun et al. 2018; Lee and Jeon 2018). Among major industrialized countries in 2021, South Korea had the second-highest share of private-sector R&D investment, reaching 79.1%, just 0.1% behind Japan. Specifically, out of Korea's total R&D expenditure of USD 74.2 billion in 2021, USD 58.6 billion (79.1%) came from the private sector, which is more than seven times the government's contribution of USD 8.8 billion (11.9%). Accordingly, in Korea's R&D investment, private enterprises are playing a dominant role in shaping the national R&D landscape. According to the Korea Institute of Science and Technology Evaluation and Planning (KISTEP, 2022), Korea's total R&D investment in 2021 reached 74.2 billion USD, marking a 4.5% increase (3.2 billion USD) from the previous year, with an annual growth rate close to 5%. The distribution of R&D expenditure shows that public research institutes account for 11.9%, universities for 9.0%, and private corporations for 79.1% of the total investment. Figure 2 illustrates this breakdown, highlighting the predominant role of private firms in driving Korea's R&D sector.

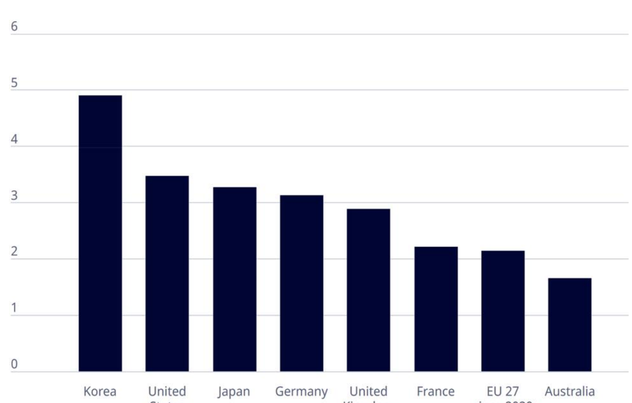


**Figure 1.** GDP spending on R&D (% of GDP, 2021).
*Source:* OECD (2022).

In recent years, corporate R&D investment has evolved beyond simple technology development to become a strategic response for survival and long-term growth in the global market. This is not a phenomenon confined to a specific country or industry, but a widespread global trend. According to the WIPO Global Innovation Index (WIPO 2024), R&D spending by the world's top 2,500 corporate R&D investors—who account for 90% of global corporate R&D expenditure—increased more than 4.5 times, from EUR 279.6 billion in 2003 to EUR 1.27 trillion in 2022. According to the studies by Bočková and Meluzín (2017), this trend is particularly prominent among large corporations, where economies of scale and technological concentration reinforce sustained R&D investment. South Korea reflects this global pattern, with its industry dominated by large firms that continue to invest heavily in R&D despite high financial risks. Many Korean companies, even after acquiring advanced technologies, allocate a significant portion of their corporate capabilities and resources to R&D as a strategic means of surviving in the highly competitive global landscape. These companies rarely reduce their R&D spending, even during periods of financial difficulty (Min and Smyth 2016; Xu and Sim 2018), viewing technology development as the last line of defence to maintain long-term value.

In sectors characterized by rapid innovation and frequent deployment of advanced technologies—such as construction, automotive, and electronics—R&D plays a crucial role as a key determinant of firm value. However, R&D investment is inherently high-risk, as financial gains such as revenue or profit are not immediately realized (Hall et al. 2016; Alam et al. 2019). Research by Cohen et al. (2013) and Kim and Park (2020) indicates that R&D projects often carry a high degree of cash flow uncertainty. Moreover, compared to other types of investment, R&D is more susceptible to issues of information asymmetry between R&D departments and other operational units within firms. These characteristics explain why many large companies around the world are continuing to strengthen their R&D investment as a means of securing long-term technological advantage and enhancing firm value. In Korea in particular, R&D is increasingly positioned at the core of long-term corporate strategy, as firms aim to transition from being fast followers to becoming first movers in the global innovation landscape.

The Korean government has implemented a five-year basic plan to establish an objective R&D output evaluation system and to promote systematic management of national R&D performance through the enactment of the National R&D Project Performance Evaluation and Management Act (NABO, 2020). In parallel, it operates support programs such as the 'Construction Technology Research Project' and 'Land, Infrastructure and Transport R&D', which provide direct financial support to construction firms or encourage private investment through matching fund schemes. These programs play a crucial role in strengthening technological development capabilities, particularly for small and medium-sized construction firms or industry–academia–research consortia and help lower the entry barriers to R&D investment (Lee and Yang 2023). Furthermore, the

**Table 1.** Previous studies on R&D investment and performance.

| Research | Authors | Finding | Limitation |
|---|---|---|---|
| Enabling and measuring innovation in the construction industry | Gambatese and Hallowell (2011) | • Owner's role is crucial for innovation.<br>• R&D investment enhances project performance.<br>• Integrated teamwork fosters innovation. | • Limited diffusion of innovation.<br>• High initial investment hinders R&D adoption.<br>• Regulations and market risks obstruct innovation. |
| Uncertainty and corporate R&D investment: evidence from Chinese listed firms | Wang et al. (2017) | • Policy and market uncertainties reduce R&D investment.<br>• Policy uncertainty significantly impacts politically connected firms.<br>• Government subsidies mitigate the negative effects of uncertainty. | • Findings are limited to Chinese listed firms and may not be generalizable.<br>• Uncertainty measurement methods may not fully capture all influencing factors. |
| Market or government: who plays a decisive role in R&D resource allocation? | Xu et al. (2014) | • Market valuation boosts corporate R&D investment.<br>• Government intervention does not significantly impact R&D investment.<br>• Excessive government intervention weakens market-driven R&D allocation. | • Findings are specific to Chinese listed firms.<br>• Government intervention effects may vary across industries.<br>• Market valuation impact may be influenced by external financial factors. |
| Over-investment in corporate R&D, risk, and stock returns | Saad and Zantout (2014) | • Large firms over-invest in R&D, leading to negative stock returns.<br>• Small firms benefit from R&D investment, experiencing positive returns.<br>• Investor misjudgement causes initial overvaluation, followed by stock underperformance. | • Findings focus on U.S. firms and may not generalize globally.<br>• R&D investment outcomes vary by firm size and industry.<br>• Stock price movements may be influenced by external market factors. |
| Activity overinvestment: The case of R&D | Ahuja and Novelli (2017) | • Firms often overinvest in R&D due to uncertainty and managerial biases.<br>• Overinvestment can stem from competitive pressures and signalling strategies.<br>• Lack of clear feedback mechanisms lead to persistent R&D overinvestment. | • Findings focus on theoretical constructs rather than empirical data.<br>• Overinvestment effects may vary across industries and firm structures. |
| R&D effects, risks and strategic decisions: evidence from listed firms in R&D-intensive countries | Dranev et al. (2017) | • Higher R&D intensity increases stock returns in R&D-intensive economies.<br>• Gradual R&D investment growth is valued positively, while sudden increases reduce firm value.<br>• R&D investments lower a firm's exposure to currency risk, reducing overall volatility. | • Findings are based on select R&D-intensive countries (Korea, Finland, Israel).<br>• Limited consideration of industry-specific R&D dynamics.<br>• R&D's long-term impact on firm value remains inconclusive. |
| Overinvestment and corporate governance in energy listed companies: evidence from China. | Shi (2019) | • Free cash flow significantly drives over-investment in Chinese energy firms.<br>• Corporate governance mechanisms fail to mitigate over-investment risks.<br>• Board and state shareholding intensify the link between free cash flow and over-investment. | • Findings are limited to Chinese energy firms and may not apply broadly.<br>• Focuses mainly on free cash flow, without detailed consideration of market dynamics. |
| How do slack resources affect the relationship between R&D expenditures and firm performance? | Lee and Wu (2016) | • Absorbed slack weakens the positive impact of R&D on performance.<br>• Unabsorbed slack boosts R&D performance up to a point but then causes inefficiencies.<br>• Short-term R&D expenses are more sensitive to slack than long-term R&D capital. | • Limited to Taiwanese high-tech firms.<br>• Does not differentiate R&D types (process vs. product).<br>• Ignores external market influences on slack use. |
| The impact of financing constraints and agency costs on corporate R&D investment: Evidence from China | Lin et al. (2017) | • Financing constraints lead to R&D underinvestment.<br>• Agency costs contribute to R&D overinvestment.<br>• Government subsidies help mitigate R&D underinvestment. | • Findings focus on Chinese listed firms and may not generalize globally.<br>• Does not fully account for external market and policy influences.<br>• Optimal R&D investment level remains uncertain. |

government promotes the practical application of construction technologies by offering market-based incentives. For example, companies possessing new technologies are awarded extra points or preferential qualifications in public procurement bids. Such policy initiatives—through financial support and institutional incentives—are designed to foster technological innovation across the construction sector and ultimately stimulate voluntary R&D investment in the private sector.

In the private sector, various literatures exist on R&D evaluation at the micro-level, mainly focusing on evaluation methods (Park et al. 2013; Lee et al. 2015), procedures (Park 2010), and guidelines for projects (Lee et al. 2019). Some studies show positive correlations between R&D expenditure and company performance, while others indicate that the relationship varies depending on industry conditions, changes in variable conditions, and time differences (Yoo and Sung 2015; Alam et al. 2020; Xu et al. 2021). However, compared to the general management field, limited studies have been conducted in the construction sector to find out the optimal R&D investment level from the perspective of private companies, considering company

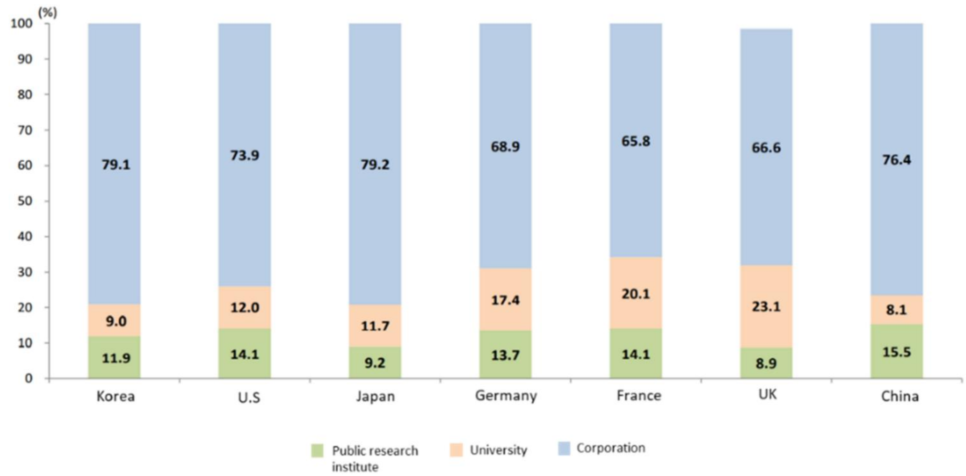


Figure 2. Ratio of annual R&D expenses by performing subjects.

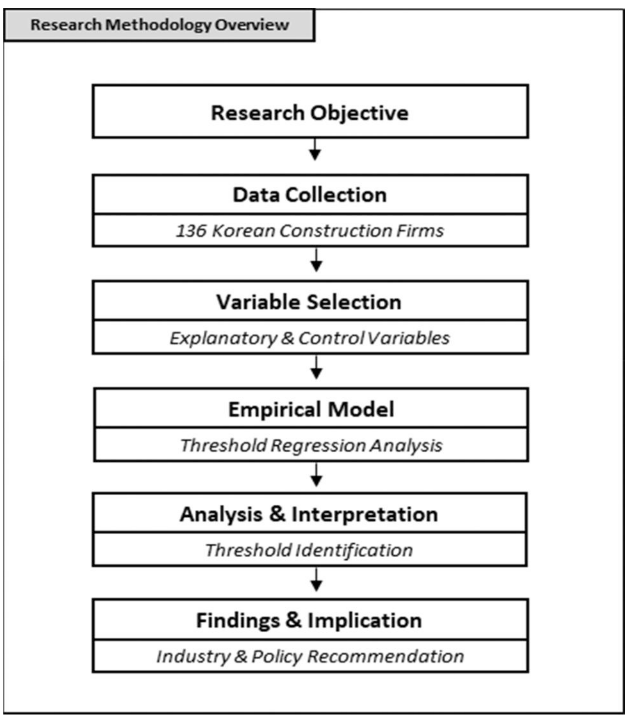


Figure 3. Research methodology overview.

management situations and the appropriate balance between R&D expenditure and financial conditions.

## Research methodology

### Research design

Considering the R&D investment capabilities and the impact of R&D on the long-term value of individual companies, this paper focuses on determining a suitable balance between R&D investment and expected company profit, with the objective of averting excessive expenditure on R&D, which could significantly affect companies' financial situations. This paper determines the optimal level of R&D investment in Korean contractors using threshold variables (R&D project cost and researcher ratio). Various market dynamics, government policies, and the global economic situation may affect the companies' performance and profit. However, in this paper, only the company's internal factors (such as company size, sales, or debt) are identified as control variables to analyse and validate the threshold regression model.

Figure 3 illustrates the overall research methodology, outlining the sequential process from research objectives to data collection, variable selection, empirical modelling, and analysis. This structured approach ensures a clear and systematic evaluation of the threshold effects of R&D investment on company performance. To achieve this, the study focuses solely on internal factors, excluding external influences such as government policies, economic cycles, and market demand. This decision aims to narrow the research scope, creating a more controlled analysis environment and minimizing potential confusion from external variables. Internal factors, which fall within a company's direct control or influence, serve as the contextual backdrop for managerial decision-making processes related to R&D investment. By excluding external variables, the study ensures a more precise analysis of how internal organizational dynamics impact R&D investment decisions and subsequent performance outcomes. Furthermore, to mitigate errors stemming from artificially partitioning the growth interval of companies' R&D investment levels (Wang and Wang 2020), Hansen's threshold regression model (Hansen 2000) is employed. This model is utilized to examine the threshold effect of R&D investment on profit rates as a performance metric, with the interval division being determined endogenously based on the characteristics of the variables.

### Application of the panel threshold regression model (PTRM)

Hansen's threshold regression model is a methodological framework used to ascertain whether the regression equation holds uniformly across all observation targets in the sample, or if the observation targets are divided into several groups, each potentially demonstrating distinct characteristics (Osei and Kim 2020; Kamal et al. 2021). Through the utilization of the threshold regression model, it becomes feasible to ascertain the nonlinearity of dependent variables, estimate the marginal effect serving as a benchmark for group separation, and analyse the correlation between dependent and explanatory variables, which may be subject to variation across different phases (Nizam et al. 2020). Following the analysis, if the estimated regression coefficient of a specific explanatory variable varies depending on the observation targets, it indicates that the explanatory variable has a marginal effect on the dependent variable (Moralles and Moreno 2020). Here, the marginal effect is also referred to as the threshold effect, where a specific explanatory variable exhibiting a marginal effect is termed a threshold variable. Additionally, it is possible to estimate the value of the threshold variable at which the marginal effect occurs, known as the threshold level.

In this study, the panel threshold regression model was specifically chosen to capture the non-linear relationship between R&D investment and firm performance, which conventional linear or polynomial regression models may fail to identify effectively. Unlike traditional regression methods, the threshold regression model allows for the identification of distinct investment phases, revealing how R&D efficiency varies at different levels. This model does not simply analyse linear correlations but instead focuses on identifying non-linear relationships and deriving specific threshold values. Rather than assuming a direct causal relationship between R&D investment and profit rate, this study emphasizes that performance changes occur at certain threshold points, highlighting the importance of optimal investment levels. Given the nature of R&D investments in construction firms—where excessive investment may lead to diminishing returns—a threshold-based approach provides more precise insights. In the panel threshold regression model, the profit rate of a company (dependent variable) will be influenced differently by control variables such as company size, EBIT (Earnings Before Interest and Tax), debt ratio, sales, growth ratio, as well as the level of R&D investment (R&D project cost and researcher ratio). Unlike the general regression model which primarily emphasizes the correlation between variables, the panel threshold regression model offers the advantage of alleviating the strong assumption of left and right symmetry inherent in the existing inverted U-shaped curve (Haans et al. 2016). This study follows the methodology proposed by Hansen (2000), incorporating the following four key steps:

**Step1. Selection of Threshold Variables:**

- The study identifies R&D project cost and researcher ratio as key threshold variables influencing firm profitability.
- These variables were selected based on prior empirical studies and their theoretical relevance to the construction sector.

**Step2. Model Specification and Estimation:**

$$y_i = \beta x_i + e_i \tag{1}$$

The panel threshold regression model is expressed as Equation (1), where $y_i$ represents the dependent variable of $i$ (Profit rate), $x_i$ represents the explanatory variables (R&D project cost and Researcher ratio), and $e_i$ denotes the error term. $\gamma$ represents the threshold. The slope coefficient is $\beta = (\beta_1 \beta_2)$ when the explanatory variables are divided into two groups based on the threshold, and they are expressed as Equations (2) and (3).

$$y_i = \beta_1 x_i + e_{1i}(q_i \le \gamma) \tag{2}$$

$$y_i = \beta_2 x_i + e_{2i}(q_i > \gamma) \tag{3}$$

In this model, the sum of squared error is

$$\mathrm{S}(\gamma) = \widehat{e_i}(\gamma)' \ \widehat{e_i}(\gamma) \tag{4}$$

At this time, S is determined by the slope coefficient $\gamma$. When a $\gamma$ value that minimizes the equation S is obtained, it represents the estimated threshold level, and the optimal threshold is expressed as Equation (5).

$$\hat{\gamma} = \arg \min \mathrm{S}(\gamma) \tag{5}$$

**Step3. Threshold Effect Estimation:**

- The threshold is estimated by minimizing the sum of squared errors (SSE).
- Bootstrap techniques are employed to compute confidence intervals for the threshold values to ensure robustness.

**Step4. Testing for Non-Linearity and Threshold Significance:**

- A supremum F-test is conducted to verify the statistical significance of the estimated threshold.
- The study also examines whether multiple threshold effects exist by testing for additional breakpoints in the data.

### Control variables and robustness checks

To isolate the effects of R&D investment, this study controls for firm-specific financial indicators, including company size, EBIT (Earnings Before Interest and Tax), debt ratio, sales, and growth ratio. These variables are included to account for potential firm-level heterogeneity and to prevent omitted variable bias. To ensure the reliability of the findings, the study conducts robustness checks:

- Alternative threshold variable specifications are tested to examine model sensitivity.
- Variance inflation factors (VIFs) and correlation analysis confirm the absence of multicollinearity issues.
- Panel fixed effects estimation is applied to control for unobserved firm-level heterogeneity.

By providing a detailed explanation of the methodology and model estimation process, this study enhances transparency and replicability, addressing concerns regarding model implementation and estimation workflow.

## Research data

### Data and variables

The R&D data of Korean construction companies utilized in this study are collected from the Korean government's statistical data (KISTEP, 2022), which is surveyed annually following the guidelines outlined in the OECD's Frascati Manual. These data represent the most reliable and comprehensive state-approved statistical information regarding corporate R&D investment. The survey targets companies that have their own research organization or department within the company. Therefore, it includes data on R&D investment from most medium to large-scale Korean construction companies.

As shown in Table 2, the dependent variable, termed the Profit Rate, is computed as the ratio of net income for a specific period to total assets. The R&D project cost and Researcher ratio are used as explanatory variables. For the analysis of company size, data for EBIT, debt ratio, sales, and growth ratio, used as control variables, are obtained from KISTEP and KisValue (a corporate information service in Korea) over the course of 18 years. The profit rate is calculated by dividing net income,

**Table 2.** Model variables.

| Variable | Description | Calculation formula |
|---|---|---|
| Dependent | Profit rate (ROA) | = Net income*/ Total assets |
| Explanatory | R&D project cost | = Funds allocated for R&D projects*/ Sales* |
| | Researcher ratio | = R&D researcher/ Total employees |
| Control | Company size (B $) | = Total assets |
| | EBIT (B $) (Earnings Before Interest and Tax) | = Net income*+ Interest*+ Taxes* |
| | Debt ratio | = Total liabilities/ Total assets |
| | Sales (B $) | = Sales* |
| | Growth Ratio | = Total asset growth*/ Total assets for the previous year |

ROA: Return On Asset.
B $: 1,000 million US dollars.
∗ : Over the course of one year.

**Table 3.** Summary statistics.

| Variable | Mean value | Standard deviation | Min | Max |
|---|---|---|---|---|
| Profit rate | 1.657 | 0.226 | 0.224 | 3.048 |
| R&D project cost | 0.494 | 0.183 | 0.138 | 1.230 |
| Researcher ratio | 2.036 | 0.319 | 0.423 | 3.442 |
| Company size | 1.819 | 1.247 | 0.228 | 20.263 |
| EBIT | 0.149 | 0.854 | 0.037 | 0.256 |
| Debt ratio | 43.250 | 0.525 | 28.667 | 56.133 |
| Sales | 6.438 | 0.303 | 0.384 | 19.166 |
| Growth Ratio | 4.293 | 0.935 | 0.659 | 13.684 |

excluding interest and taxes, by total assets; R&D project cost refers to the ratio of the amount invested in R&D projects to sales; Researcher ratio is obtained by dividing the number of researchers by the total number of employees; Company size is represented by the total assets of the companies; EBIT is equal to net income plus interest and taxes; Debt ratio is determined by dividing total liabilities by total assets; Sales represent the total sales of the companies per year; and Growth ratio serves as an indicator of how much a company's assets and capital increased compared to the ratio of total asset growth every year. The time gap between the implementation of R&D activities and the evaluation of their performance (profit rate) is set at five years. For example, using data from 2018 for R&D investments (explanatory variables) and other control variables, the analysis of the dependent variable, profit rate, is conducted using data from 2023. This assumption is based on industry-specific considerations and previous empirical findings. In capital-intensive industries such as construction, the impact of R&D investment tends to emerge over extended periods due to the long project cycles, technology integration phases, and regulatory approval processes. Studies in related industries have also indicated that R&D investment often exhibits a lag of three to seven years before yielding measurable effects on financial performance (Xie et al. 2020; Frontier Economics 2023). In addition, the five-year time lag assumption aligns with the South Korean government's mid- to long-term R&D planning framework. Every five years, the government announces a national science and technology policy direction and strategy, along with detailed evaluations of its implementation.

Initially, this paper planned to analyse 141 medium- to large-scale Korean construction companies listed on the KOSPI (a major stock market index in South Korea), employing more than 100 employees and operating in-house R&D research centre. They are continuously submitting financial statements during the analysis period (from 2006 to 2023) and providing secure financial data for empirical analysis. Therefore, the threshold regression analysis was conducted for construction companies that research and develop general construction technologies, including some advanced technologies. Construction firms that focus exclusively on high-tech construction technologies were excluded, as these companies tend to be start-ups or small-scale enterprises that invest disproportionately in technology, leading to an imbalance in R&D spending. The final number of companies subject to analysis, excluding outliers from each variable, is 136. Considering that these companies are among the largest and most systematically documented firms in the Korean construction industry, they provide a comprehensive representation of companies with structured R&D investment practices. Moreover, firms meeting these criteria are more likely to engage in substantial R&D activities, making them the most relevant for evaluating the impact of R&D investment on firm performance. Therefore, the selected sample is sufficiently robust to generalize the findings to the broader population of Korean construction firms with established financial and R&D reporting systems.

### *Empirical model validation and robustness checks*

Before analysing the threshold effect of a company's R&D investment level using Hansen's panel threshold regression model, it was tested whether it is reasonable to assume fixed effects in the model. As a result, it was confirmed that the fixed-effect model is more suitable than the probability-effect model or the pooled OLS (Ordinary Least Squares) that could replace it. Therefore, empirical analysis was conducted using the panel threshold regression model assuming a fixed effect. The following table (Table 3) presents basic statistics of various variables, including the mean and standard deviations of each variable.

These variables, obtained through various financial data of Korean contractors and KISTEP's R&D survey (KISTEP, 2022), are estimated to affect the profit rate of Korean construction companies. At the same time, simple correlation coefficients between variables and variance inflation factor (VIF) levels are also examined. The multicollinearity test based on the VIF index revealed that the correlation coefficient between variables is below 0.5, and the VIF values are less than 5, indicating the absence of multicollinearity issues. Table 4 presents the detailed correlation coefficients and VIF values, confirming that multicollinearity does not pose a concern in this study.

To ensure the robustness of the findings, the study also controls for firm-specific financial indicators, including company size, EBIT, debt ratio, sales, and growth ratio. These variables are included to account for potential firm-level heterogeneity and to prevent omitted variable bias. Additionally, a subsample analysis was conducted by dividing firms into small and large categories based on company size. Table 5 presents the results of this robustness test, confirming whether the estimated threshold effects of R&D investment hold consistently across different firm sizes. The findings indicate that the core

Table 4. Correlation coefficients and VIF values.

| | Profit rate | R&D project cost | Researcher ratio | Company size | EBIT | Debt ratio | Sales | Growth ratio | VIF value |
|---|---|---|---|---|---|---|---|---|---|
| Profit rate | 1.00 | 0.30 | 0.28 | 0.35 | 0.40 | −0.25 | 0.45 | 0.20 | 1.30 |
| R&D project cost | 0.30 | 1.00 | 0.33 | 0.40 | 0.38 | −0.20 | 0.42 | 0.27 | 1.70 |
| Researcher ratio | 0.28 | 0.33 | 1.00 | 0.25 | 0.22 | −0.18 | 0.36 | 0.24 | 1.55 |
| Company size | 0.35 | 0.40 | 0.25 | 1.00 | 0.45 | −0.30 | 0.50 | 0.30 | 2.50 |
| EBIT | 0.40 | 0.38 | 0.22 | 0.45 | 1.00 | −0.28 | 0.48 | 0.32 | 2.00 |
| Debt ratio | −0.25 | −0.20 | −0.18 | −0.30 | −0.28 | 1.00 | −0.22 | −0.15 | 3.00 |
| Sales | 0.45 | 0.42 | 0.36 | 0.50 | 0.48 | −0.22 | 1.00 | 0.38 | 2.80 |
| Growth Ratio | 0.20 | 0.27 | 0.24 | 0.30 | 0.32 | −0.15 | 0.38 | 1.00 | 1.90 |

Table 5. Robustness test: subsample analysis (company size split).

| | Small firms | | | Large firms | | |
|---|---|---|---|---|---|---|
| Variable | Coeff. | P-value | Std. coeff. | Coeff. | P-value | Std. coeff. |
| R&D Project Cost | 0.73740 | 0.155043 | 0.213027 | −1.04346 | 0.047574 | 0.330672 |
| Researcher Ratio | −0.90201 | 0.067865 | 0.242006 | 0.37821 | 0.335295 | 0.265520 |
| EBIT | 1.43758 | 0.211303 | 0.172930 | 1.29701 | 0.223491 | 0.412569 |
| Debt Ratio | −0.07577 | 0.637534 | −0.230726 | 0.08192 | 0.602108 | −0.140688 |
| Sales | 0.04014 | 0.168413 | 0.326091 | −0.02321 | 0.327652 | 0.260439 |
| Growth Ratio | −0.65267 | 0.702069 | 0.188432 | 0.61922 | 0.637025 | −0.221346 |

relationships remain stable, supporting the validity of the threshold model.

## Analysis

The panel threshold regression model is an empirical model assuming a fixed effect. Therefore, before establishing the panel threshold effect, a test of the regression model is conducted to determine the existence of the threshold. The $\rho$ value is calculated using 1,000 bootstrap repetitions as a means to approximate the F-test of the R&D project cost and the Researcher ratio, respectively. Furthermore, the existence of a threshold is tested, revealing that both explanatory variables are statistically significant at the 1% level, as shown in Table 6. The estimated thresholds ($\gamma$) for the R&D project cost (model 1) and the Researcher ratio (model 2) are 0.47% and 2.25%, respectively. This indicates that each explanatory variable is partitioned into two groups based on these thresholds (within and beyond the threshold effect).

Table 6. Threshold estimation.

| Variable | R&D project cost | Researcher ratio |
|---|---|---|
| Model | Model 1 | Model 2 |
| F value | 37.26*** | 28.71*** |
| $\rho$ value | 0.012 | 0.008 |
| Estimated threshold ($\gamma$) | 0.0047 | 0.0225 |
| 95% confidence interval | [0.027, 0.069] | [0.025, 0183] |

*, **, and *** indicate significance at 10%, 5%, and 1%, respectively.
$\rho$: value of bootstrap.
The number of bootstrapping is 1,000 times.

Table 7 shows the regression results of the two groups of explanatory variables, divided based on the thresholds of R&D project cost and researcher ratio. For Model 1, when the ratio of R&D project cost to sales for the current year is less than the threshold of 0.47%, the coefficient is 1.927, while it is 0.729 when it exceeds the threshold. Both coefficients are significant at the 5% level. This indicates that the rate of increase in actual performance begins to decrease based on the threshold of 0.47% for the ratio of R&D project cost. In other words, when the ratio of R&D project investment increases by 1%, companies can expect an approximately 1.9% (1.927) increase in profitability (profit rate), with a sustained effect up to 0.47%. However, when investment exceeds 0.47%, companies may observe a decrease in the rate of increase in performance (profit rate) by 0.7% (0.729) despite a 1% increase in the R&D expenditure rate.

In Model 2, where the researcher ratio serves as an explanatory variable, the coefficient associated with the researcher ratio is 0.521 when the proportion of researchers falls below the threshold value of 2.25%. Conversely, when the proportion exceeds 4.4%, the coefficient decreases to 0.096. Notably, both coefficients exhibit statistical significance at the 1% level. In companies where the proportion of researchers is below 2.25%, a 1% increase in the researcher ratio corresponds to a 0.5% (0.521) rise in the profit rate. However, it is revealed that in companies where the researcher ratio exceeds 2.25%, the profit rate increases by only 0.1% (0.096) under similar circumstances. This can be interpreted as indicating that in companies where the proportion of researchers exceeds 2.25%, an increase in the researcher ratio does not result in a significant enhancement in the company's performance (profit rate). Both explanatory variables display a non-linear relationship characterized by a threshold, where the profit rate tends to decline upon surpassing the threshold value. This implies that the threshold value may represent the optimal level of R&D investment.

Out of the total 136 observation targets analysed, 94 companies, which are investing in R&D below threshold levels, comprise 69% of the sample. This analysis indicates that approximately 70% of Korean construction companies have the potential to increase their investment in R&D. For these companies, increasing expenditure on R&D projects is expected to result in a significantly higher company profit rate. Additionally, 64 companies, with a researcher ratio below 2.25%, account for 47% of the total sample. For these companies, continuous performance can be expected until the proportion of researchers reaches 2.25% of all employees. In the global construction market, projects are becoming increasingly complex and large-scale. Consequently, construction companies are constantly required to engage in new technology development to complete the project within set timeframes and budgets. Korean contractors have been investing heavily in R&D to quickly acquire advanced construction technologies from developed countries, maintain technological superiority over competitors, and rapidly expand market share (Whang and Flanagan, 2024). However, according to the analysis results of the threshold model, there is actually room for further investment up to the threshold level in terms of R&D project cost and researcher ratio.

Table 7. Threshold regression result.

| | Model 1 | | Model 2 | |
|---|---|---|---|---|
| Variable | R&D project cost $\leq$ 0.47% | R&D project cost $>$ 0.47% | Researcher ratio $\leq$ 2.25% | Researcher ratio $>$ 2.25% |
| R&D project cost | 1.927** (0.198) | 0.729** (0.115) | | |
| Researcher ratio | | | 0.521*** (0.318) | 0.096*** (0.051) |
| Company size | −0.036*** (0.008) | −0.172*** (0.018) | 0.061** (0.029) | 0.118*** (0.041) |
| EBIT | 0.014 (0.023) | −0.066** (0.035) | −0.034** (0.015) | −0.063* (0.033) |
| Debt ratio | −0.012*** (0.029) | −0.048* (0.032) | −0.072*** (0.039) | −0.127** (0.067) |
| Sales | −0.043** (0.078) | −0.062*** (0.129) | 0.022* (0.027) | −0.058** (0.129) |
| Growth Ratio | 0.087** (0.060) | −0.113*** (0.072) | −0.035*** (0.077) | −0.086* (0.105) |
| Constant | 0.292** (0.048) | 0.527** (0.069) | 0.427** (0.034) | −0.923 (0.086) |
| Observation (Sample number) | 94 | 42 | 64 | 72 |
| Adjusted $R^2$ | 0.065 | 0.096 | 0.083 | 0.137 |
| F-statistics | 4.86 | 6.23 | 5.79 | 7.12 |

*, **, and *** indicate significance at 10%, 5%, and 1%, respectively.
() means Standard deviation.

Table 8. Comparison of statistics based on R&D project cost threshold.

| | R&D project cost $\leq$ 0.47% (Observation: 94) | | R&D project cost $>$ 0.47% (Observation: 42) | |
|---|---|---|---|---|
| Variable | Mean value | Standard deviation | Mean value | Standard deviation |
| Profit rate | 1.792 | 0.107 | 1.428 | 0.143 |
| R&D project cost | 0.338 | 0.114 | 0.614 | 0.063 |
| Researcher ratio | 1.904 | 0.121 | 2.276 | 0.149 |
| Company size | 2.532 | 0.168 | 1.433 | 0.267 |
| EBIT | 0.086 | 0.160 | 0.219 | 0.148 |
| Debt ratio | 45.298 | 0.172 | 30.421 | 0.203 |
| Sales | 6.175 | 0.237 | 6.729 | 0.185 |
| Growth Ratio | 3.892 | 0.093 | 4.526 | 0.171 |

Table 9. Comparison of statistics based on researcher ratio threshold.

| | Researcher ratio $\leq$ 2.25% (Observation: 64) | | Researcher ratio $>$ 2.25% (Observation: 72) | |
|---|---|---|---|---|
| Variable | Mean value | Standard deviation | Mean value | Standard deviation |
| Profit rate | 1.575 | 0.129 | 1.739 | 0.099 |
| R&D project cost | 0.408 | 0.185 | 0.621 | 0.176 |
| Researcher ratio | 1.638 | 0.144 | 2.527 | 0.115 |
| Company size | 1.739 | 0.225 | 1.983 | 0.183 |
| EBIT | 0.092 | 0.100 | 0.173 | 0.170 |
| Debt ratio | 28.386 | 0.185 | 42.392 | 0.164 |
| Sales | 4.823 | 0.133 | 8.770 | 0.147 |
| Growth Ratio | 3.482 | 0.165 | 5.393 | 0.155 |

Table 8 presents basic statistics of two company groups categorized by a threshold of R&D project cost and researcher ratio. The analysis results indicate that companies in the group with lower R&D project costs ($\leq$ 0.47%) typically exhibit lower EBIT, sales, and growth ratio. However, R&D project cost is not significantly associated with company size or debt ratio. On the contrary, growing (relatively smaller in size but higher in growth ratio) construction companies in Korea tend to allocate more expenses to R&D projects. Like the findings of Xu and Sim (2018), companies in a growth phase often exhibit a tendency to increase investment in R&D, even when they carry relatively high levels of current debt. This inclination can be interpreted as a readiness to allocate greater corporate resources towards R&D initiatives, irrespective of their immediate financial circumstances.

Interestingly, out of the 136 observation samples, 38 are conglomerate enterprises. And typically, they belong in the group with lower R&D project costs ($\leq$ 0.47%). Due to their significantly high sales volume, even if they make substantial expenditures on R&D projects, the relative proportion may appear low. These large conglomerates, commonly referred to as 'Chaebol' in Korea, tend to allocate more expenses to R&D compared to other specialized construction companies, as they can leverage synergies with their affiliates engaged in similar businesses in the construction industry and engage in technology sharing (Kim 2019; Choi et al. 2022). Even though the performance of a construction company, which invests significant capital in R&D sector, may not directly impact its profits, it can yield positive effects such as increased profit margins or revenue growth for other affiliates within the Chaebol group. For example, according to the management report (Samsung C&T 2020), Samsung C&T invested more in the R&D sector compared to other construction-related affiliates such as Samsung Engineering or Samsung Heavy Industries. However, their direct profits were not significantly higher compared to the investment costs. Nevertheless, during the same period, management indicators of other affiliates, which can be attributed to the results of R&D investments, such as profit margins, the number of new contracts, and project completion rates, noticeably improved.

As indicated in Table 9, there is minimal disparity in the company size (total assets) between the two groups of companies with a research staff ratio surpassing 2.25% and those that fall below this threshold, measuring 1.739 and 1.983 respectively. Despite similar company sizes, the debt ratios between them are 28.38% and 42.39%, showing a significant difference. However, there isn't a substantial difference in the growth rates that can be expected from a high researcher ratio, with 3.48% and 5.39% respectively. This indicates that a researcher ratio surpassing the threshold does not exert a significant influence on company size and growth, but it demonstrates a robust correlation with the company's debt magnitude. At the same time, it is not assumed that large Chaebol contractors inherently possess significantly more researchers than standalone construction competitors not affiliated with conglomerate groups. In reality, Hyundai Engineering & Construction (E&C), the second largest Chaebol construction company in Korea, employs 220 researchers (3.2%) out of a total of 6,841 employees as of 2022 (CompamyGuide 2022). Considering Hyundai E&C's R&D project cost and company size, even compared to the overall researcher average of 2.306% in the Korean construction industry, this is not a significantly high researcher ratio. Due to the fact that large Chaebol construction companies possess various construction-related affiliates, they may maintain a relatively smaller proportion of R&D employees compared to competitors not belonging to a conglomerate group with similar levels of R&D expenditure or similar size and technological capabilities. This is because they can conduct collaborative research with affiliates, enabling them to obtain assistance for any deficiencies in research personnel, experimental equipment, or patented technologies (Choi et al. 2015).

## Discussion

One of the key findings of this study is the identification of an optimal R&D investment threshold. The threshold values of 0.47% of total revenue for R&D project cost and 2.25% for the researcher ratio were derived using the panel threshold regression model (PTRM). This model identifies significant nonlinear relationships between R&D investment and firm performance, helping determine the point at which additional investment leads to diminishing returns. The statistical significance of these thresholds suggests that they serve as critical benchmarks for firms to optimize resource allocation and maximize profitability. Although these thresholds were derived from empirical data on Korean construction firms, they align with existing research indicating that excessive R&D investment in capital-intensive industries can lead to diminishing marginal returns (Saad and Zantout 2014; Ahuja and Novelli 2017). The methodology used in this study can be adapted to various industries and economic conditions. Future research could refine and expand these thresholds through cross-country comparative analyses or industry-specific adaptations. In particular, the construction sector in developing countries often operates under financial constraints, making efficient R&D investment strategies crucial for sustainability and competitiveness. Korea has emphasized R&D investment in the construction sector throughout its industrialization process, fostering technological innovation. This experience offers valuable lessons for developing nations seeking to optimize their R&D investment while balancing financial limitations.

This study highlights that establishing an optimal R&D investment threshold enables firms to minimize financial burdens while sustaining technological innovation. Rather than excessive investment, a strategic and structured allocation of R&D resources is essential. For small and medium-sized construction firms, limited financial capacity necessitates government intervention through tax incentives and financial support to enhance innovation without exacerbating financial distress. Furthermore, as the pace of technological development and market conditions differ across nations, customized R&D investment strategies tailored to each country's economic and industrial environment are necessary. Developing countries can adopt successful R&D models from advanced economies but must adapt them according to their financial and industrial context.

Despite its contributions, this study has several limitations. The findings are based on Korean construction firms, which may limit their general applicability to other countries or industries. Additionally, only two key explanatory variables—R&D project cost and researcher ratio—were considered, while factors such as patent acquisitions and inter-industry collaborations were not included. Furthermore, in real-world scenarios, different external factors including economic conditions or market competition play significant roles in shaping the impact of R&D investment on firm performance. However, this study does not explicitly account for such external influences, which may affect the robustness of the model. To improve model reliability, future research should incorporate control variables for external economic conditions, allowing for a more comprehensive analysis of the factors influencing R&D investment effectiveness. Future research should explore a comparative analysis of construction industries across different countries and incorporate additional performance indicators, such as technology adoption rates and patent filings, to enhance the depth and applicability of R&D investment strategies. This will enable construction firms worldwide to establish optimal R&D investment frameworks suited to their specific market conditions.

## Conclusion

In this paper, the correlations between R&D investment and companies' performance (profit rate) were analysed within the context of the construction industry in Korea. Subsequently, an appropriate R&D investment level determined using a threshold regression model. Based on the findings of the threshold regression model analysis, the threshold value for R&D project cost was identified 0.47% of total sales, while the threshold for the researcher ratio was established at 2.25% of total employees. The correlations between the company profit rate and both explanatory variables for R&D (R&D project cost and the Researcher ratio) indicated that the anticipated return on investment (ROI) of companies that invested above the threshold value was lower than that of companies that invested below the threshold value on a per-unit investment basis. Based on the R&D project cost, 30.9% of Korean contractors exceeded the appropriate level of R&D investment, while based on the Researcher ratio, the proportion was 52.9%. This result indicates that many companies continue to invest in R&D beyond the threshold point without accurately recognizing the decline in efficiency. In particular, this indicates that more than half of the companies persistently maintained excessive research personnel, which impacted ongoing company operations (e.g. labour costs). Such excessive investment in R&D sectors did not significantly contribute to the short-term profits of companies; instead, companies that excessively employed researchers exhibited significantly higher debt ratios.

In the global construction industry, each company adopts a distinct R&D strategy tailored to its business circumstances such as company size, debt ratio, and annual sales. Therefore, if companies accurately recognized their investment thresholds and formulate strategies, including specific R&D expenditures over a period of time or the scale of research organizations, they were able to more efficiently redistribute their limited company resources. Companies that generally engage in excessive R&D investment (more than 0.47% of sales) and maintain a high researcher ratio (more than 2.25% of total employees) can find it more advantageous to reduce R&D investment below the threshold level for short-term corporate benefits. Therefore, when investing below the threshold, investing in R&D projects (1.927) is over three times more efficient than increasing the number of researchers (0.521). However, even when continuing to invest above the threshold for continuous technological development, it is also evident through the threshold regression model that investing in R&D projects (0.729) significantly contributes more to the company's profit increase than increasing the number of researchers (0.096).

In this study, a representative evaluation method for R&D investment was employed, focusing on the analysis of threshold values using only two explanatory variables: R&D project cost and researcher ratio. Given the escalating complexity of projects and the widespread adoption of innovative technologies in the global construction industry, it is imperative to explore more diverse and nuanced evaluation criteria for R&D investments. These may include examining joint R&D projects with foreign companies or governments, as well as funding initiatives for corporate start-ups within the company. Furthermore, to obtain practical outcomes (threshold values), a broader array of control variables including EPS (Earnings Per Share) and the acquisition of technology-related patents can be additionally analysed. Alternatively, a more specific time lag can also be considered. In future research, it is anticipated that more precise evaluation results can be achieved by deriving threshold values while taking into account the business characteristics of individual companies, the market, and the construction industry.

## Note

1. Chaebol is a generic term referring to the large business groups in South Korea, such as Samsung, Hyundai, LG, and Lotte. Each consists of multiple firms, which, even though legally independent, are clustered and coordinated as a group and is owned and run by a family. Chaebols have the characteristics of family ownership, control, and management; highly diversified big number of subsidiaries under the unified central command; multivariate cross shareholding, and mutual loan guarantees among subsidiaries.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Data availability statement

The data that support the findings of this study are openly available in KISTEP at https://www.kistep.re.kr and KisValue at https://www.valuesearch.co.kr.

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