# The Effect of the Commercialization Failure of SMEs' R&D on Survival

Hyoung Sun Yoo and Ye Lim Jung

***Abstract*—While the cases of small and medium enterprises (SMEs) that succeeded in research and development (R&D) have been relatively well known and studied, there has not been sufficient research on cases of R&D failure and the consequent costs. Based upon the resource-based view, we hypothesized that commercialization failure of SME's R&D would be more severe for smaller firms lacking resources and dynamic capabilities, leading to early business closure. We analyzed 2,038 formal R&D projects implemented by South Korean SMEs with the support of a public subsidy program. We found that if an SME that implemented the R&D project failed to commercialize the outcomes of the R&D, the probability of business closure within 5 years after the completion of the project is 72% higher than if it succeeded. We also found that the commercialization failure increases the risk of business closure, particularly for smaller firms, due to a significant slowdown in sales growth. Our findings underscore the importance of the R&D planning strategies for SMEs and the need for funding agencies to improve their program segmentation and beneficiary selecting process.**

***Index Terms*— Business closure, Firm survival, R&D failure, R&D subsidy, Small and Medium Enterprises.**

## I. INTRODUCTION

INOVATION has been regarded as a key factor influencing performance of firms [1, 2]. In an environment with uncertainty and dynamic changes, innovation activities in firms are stimulated and can effectively contribute to improving performance [2]. Regarding firms with well-known success stories, innovation is commonly accepted as a key contributor to their success. Furthermore, many studies have demonstrated the positive effects of innovation activities and their success on the short- and long-term performance of firms [3, 4]. Specifically, it was confirmed that innovation activities, including research and development (R&D), have a positive impact on profitability and growth of firms [5]. Innovative firms that introduce new products and processes can increase their competitive advantage and market power [2]. Therefore, numerous firms have sought innovation to achieve better performance and will persist in this pursuit.

However, previous studies have also shown that the impact of innovation on firm performance has been inconsistent across many firms [3]. Innovation requires a change from the familiar status quo and additional resources. However, such investments carry risk and, naturally, do not guarantee success [6]. Because innovation is multi-faceted, the innovation practices and resulting outcomes observed in one firm may not function the same under different conditions [4]. Therefore, a large proportion of innovation attempts are abandoned or end in partial or complete failure [7, 8]. The cost of failed innovation affects firms in various forms and to varying degrees [9]. In particular, when a firm has smaller capabilities, the cost will be perceived to be more severe and can often even be catastrophic [10].

Preceding studies on innovation focused primarily on the impact of innovation success on firms' performance and the success factors [11, 12]. Meanwhile, relatively less attention was paid to the consequences of innovation failure [6, 13]. In particular, in the context of small and medium enterprises (SMEs), there was limited research on innovation attempts, their likelihood of failure, and the effects of those failures on the firm's future. SMEs often face the challenge of securing the necessary resources for innovation and the dynamic capabilities to adapt quickly to environmental changes [14, 15]. Moreover, smaller firms facing resource constraints may have insufficient knowledge management capabilities to learn from, transform, and apply the knowledge gained from failures for new innovations. R&D is a key innovation activity for SMEs, and it plays an important role in their growth strategy [16]. Therefore, R&D failure could have a serious impact on their growth and survival. However, there has been little research on the relationship between R&D failure in SMEs and early business closure, as well as the underlying mechanisms. Understanding these issues is critical for determining desirable innovation practices for SMEs and effective policies for supporting innovation of SMEs.

What are the potential costs of R&D failure for SMEs? Could the commercialization failure of SMEs' R&D lead to early

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business closure? If so, by what mechanisms does it occur? Could the commercialization failure of R&D be particularly detrimental for smaller firms with limited resources and capabilities? To answer these questions, we analyzed the impact of R&D failure on the survival of firms, based on data from a public R&D subsidy program that supports SMEs in South Korea. In addition, we investigated the mechanism by which the commercialization failure impacts the firms' survival. We also analyzed the effect of firm size on this relationship. We contributed to the related literature by theoretically explaining our findings and the underlying mechanism from the resource-based perspective and the dynamic capabilities perspective. Moreover, based on the results, we discussed practical implications that SMEs should heed when planning R&D and that funding agencies should consider in the process of selecting the beneficiaries of public R&D subsidies.

## II. Literature Review And Hypotheses

### A. *SMEs' R&D and Firm Performance*

R&D is regarded as the core of a firm's business strategy to maintain a competitive position in a market and it is a representative type of innovation activity [5, 17]. R&D activities of SMEs can directly lead the development of new products and processes [18]. R&D can also indirectly promote innovation performance by strengthening the firm's knowledge base, increasing absorptive capacity, and broadening opportunities for external collaboration [16]. According to the resource-based view, a firm's development of dynamic capabilities through R&D could enhance its ability adapt to changes in the competitive environment and survival probability [19]. R&D activities not only influence the growth and profitability of SMEs [5], but also positively impact their innovativeness and productivity [20]. During a recession, SMEs that are more innovative and proactive in R&D tend to experience less sales decline than others, indicating that R&D investment can be an effective strategy for survival [21].

However, R&D is costly for SMEs with limited financial assets, and weak absorptive capacity and competencies [16]. While SMEs strive to increase their revenues through R&D investments, not all of these investments lead to successful commercialization. In addition, there is a delay before the effects of R&D investment lead to improved performance, and during this time, R&D may not have a positive impact on short-term performance [22]. One factor that makes SMEs reluctant to engage in R&D activities is the burden of securing the necessary funds for performing R&D and the capacity to successfully complete R&D [7]. Therefore, for SMEs, making the decision to implement R&D may itself be momentous [16].

Moreover, the effects of SMEs' R&D activities exhibit great heterogeneity [18, 20]. This is because the relationship between a firm's R&D practices and performance can differ depending on the characteristics of the R&D activity, as well as the firm and its industry. [1]. Therefore, many previous studies have cautioned that the positive catalytic effect of R&D on performance of SMEs may only be observed under certain conditions [5]. In their analysis of Finnish companies, Deschryvere [23] observed that a positive correlation between R&D growth and sales growth existed only in the cases of firms that had continuously pursued product/process innovation. In addition, studies on start-up firms reported that though R&D can significantly stimulate initial growth, the effect was confined to new technology-based firms (NTBFs) and high-tech firms [18]. It has also been reported that the positive effect of R&D activities on corporate growth is concentrated only in fast-growing firms, whereas the impact can be negative for firms without such growth [24].

### B. *R&D Failure and Survival of SMEs*

The failure of an R&D project means the end of a value creation plan that has not reached its goals [9]. Since SMEs' R&D is focused on commercialization through the development of new products or processes, commercialization failure can be an important criterion for the failure. In fact, a not small proportion of R&D projects by SMEs suffer from R&D failures and commercialization failures. Approximately 30% of projects which had received public R&D funding from SBIR (Small Business Innovation Research) Phase II in the United States failed or were suspended for technical as well as market/commercial reasons [25]. In the case of R&D subsidy programs implemented in South Korea, the average R&D success rate in the 2010s was 93.4%, but the commercialization success rate was 49.8%.[1]

Indeed, failure can serve as a valuable asset for building future success. Failure in innovation can spur learning and lead to further innovative activities [26-28]. Drawing on lessons learned from failure, firms may progress closer to success by repeating the process of revising their strategies and objectives [6, 13]. However, it is not easy to convert the lessons from failure into success [6, 29, 30]. This is because it is difficult to discard previously acquired knowledge and the entrenched practices that had been believed to be correct [31-33]. In addition, failure of innovation may create a sense of burden and resistance to future attempts at innovation [34, 35].

According to the resource-based view, R&D can be a good means to promote the competitive advantage and growth of SMEs [36], but if the knowledge or technology generated by R&D is inappropriate or unavailable to the firm, the resources invested could act as a loss. The average annual R&D investment of South Korean SMEs was only US$176 thousand, which is paltry compared to Samsung Electronics' R&D investment of US$19.2 billion in 2022. Unlike large corporations, SMEs face limitations that may impede them from developing multiple technologies simultaneously [16]. For SMEs, each R&D project can be of critical importance. Therefore, R&D failure may deprive an SME of a singularly important innovation opportunity. Since generating new profits through R&D is crucial for SMEs, successful

[1] Korea Technology and Information Promotion Agency for SMEs, "Small and Medium Business Technology Development Project Performance Survey Analysis" 2012-2020.

commercialization could be the ultimate goal of implementing R&D [16]. Even when an SME successfully develops targeted technologies through R&D, failure in applying them to new products or processes can be a significant setback. If an SME carries out R&D but fails to commercialize the outcomes of R&D, the opportunity cost of R&D investment can worsen the financial condition of the SME even further.

From the dynamic capabilities view, SMEs require knowledge management capabilities to transform existing and new knowledge into innovative business opportunities [37, 38]. A firm’s dynamic capabilities, which restructure and utilize its resources and capabilities in response to environmental changes, help maintain its competitive advantage and enhance its innovation performance [39, 40]. Knowledge management capabilities, which have fundamentally dynamic characteristics, have a positive impact on product/process innovation by capturing necessary knowledge from a firm's internal and external sources and converting it into productive outcomes [41, 42]. Knowledge management can promote the creation of new ideas and ultimately improve R&D performance by facilitating the exchange and sharing of knowledge necessary for R&D [43]. Dynamic knowledge management capabilities interact closely with the learning process and play an important role in internalizing new knowledge obtained through R&D [44]. However, SMEs could have insufficient dynamic knowledge management capabilities compared to large corporations, and this deficiency can be even more pronounced in smaller firms [14, 15]. In other words, SMEs could lack the capability to successfully commercialize new knowledge obtained from R&D and maintain a competitive advantage. Moreover, they could lack the capacity to utilize the lessons learned from failures for new attempts.

Therefore, we assumed that commercialization failure could be fatal for SMEs which may lack the proper resources and capabilities, and that failure itself would have a great impact on the survival of a firm. In the case of SMEs, for whom a single R&D project is of immense importance, it seems probable that commercialization failure of R&D could lead to the early business closure. Accordingly, we established the following hypothesis.

*Hypothesis 1. The commercialization failure of SMEs’ R&D may increase the likelihood of the firm’s early business closure.*

Commercialization failure could prevent an SME from experiencing the positive ripple effects that are typically associated with R&D activities [34]. Especially, a slowdown in sales growth can be a direct result of commercialization failure and a reason for business closure. SMEs can acquire new products or process technologies through R&D investments, and generate additional revenue through these innovations [18]. However, if an SME fails to successfully commercialize its R&D outcomes, it will miss a crucial opportunity to generate additional revenue, reducing the potential for sales growth. Sales are the direct outcome of a firm's marketing activities and are a key indicator of its growth. A slowdown in sales growth or a decrease in sales indicates that a firm's ability to generate

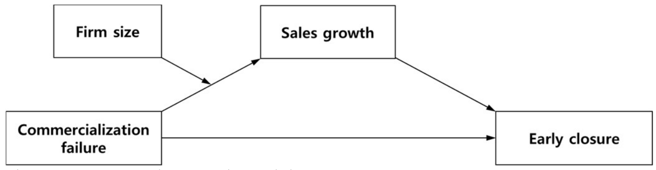


Fig. 1. Conceptual research model

profits is declining and can be a sign of a crisis in its financial stability. A considerable decline in sales can lead to business closure [45]. Therefore, we expect that the relationship between commercialization failure of SMEs’ R&D and early closure is mediated by a slowdown in sales growth. In other words, we propose a mechanism in which commercialization failure leads to a slowdown in sales growth, and through this, an SME may experience early business closure. Therefore, we established the following hypothesis.

*Hypothesis 2. The commercialization failure of SMEs’ R&D may have a positive effect on the firm’s early business closure through a slowdown in sales growth.*

The effect of a slowdown in sales growth mediating the relationship between commercialization failure of SMEs’ R&D and business closure may vary depending on firm size. When controlling for firm age, it is known that firm size has a positive impact on its net growth and reduces the rate of business closure [46]. Large firms are less affected by the commercialization failure of a single R&D project and can sustain their sales through other product lines [17]. On the other hand, for smaller firms, a single R&D attempt may have greater importance and may be pursued with more enthusiasm [47], but the impact of failing to commercialize R&D will be more considerably magnified. The smaller the firm, the narrower its product portfolio and the fewer sources of revenue it has. Therefore, in smaller firms, the failure to commercialize R&D could have a greater impact on a slowdown in sales growth and may accelerate early business closure. As a result, we have formulated the following hypothesis.

*Hypothesis 3. The effect of the commercialization failure of SMEs’ R&D on the firm’s early closure, mediated by slowed sales growth, is likely to intensify as firm size decreases.*

Fig. 1 shows the conceptual research model of this study.

## III. Research Methodology

### A. Data

We collected data on formal R&D projects performed by SMEs which were supported by the “SMEs Technological Innovation Development Program”, the largest program in South Korea for providing SMEs with R&D subsidies. The purpose of the program is to promote commercialization and scale-up of SMEs, and the program budget for 2021 reached US$372 million. The funding agency assembles an expert committee for each research area to review R&D proposals from SMEs and selects beneficiaries of the program by

TABLE I
OPERATIONAL DEFINITIONS OF THE VARIABLES

| Category | Variables | Explanations | | |
|---|---|---|---|---|
| Dependent variable | Closure | Whether the focal firm's business closed within 5 years after the completion of the R&D project (1/0) | | |
| Independent variable | Comm. failure | Whether the focal firm did not report a success of product/process innovation within 2 years after the completion of the R&D project (1/0) | | |
| Mediator | Sales growth | The slope of the linear trend line of the focal firm's sales from the project completion year to five years later, and then this value was divided by the sales in the project completion year | | |
| Moderator | Size | The total asset of the focal firm one year before the initiation of its R&D project | | |
| Control variables | ROA | The ROA of the focal firm one year before the initiation of its R&D project | | |
| | Current ratio | The current ratio of the focal firm one year before the initiation of its R&D project | | |
| | Competitors | The number of competitors in the industry to which the focal firm belongs, one year before the initiation of its R&D project | | |
| | Patents[a] | The number of active, registered patents held by the focal firm one year before the initiation of its R&D project | | |
| | Year | Year | Projects | % |
| | | 2011 | 449 | 22.0 |
| | | 2012 | 495 | 24.3 |
| | | 2013 | 535 | 26.3 |
| | | 2014 | 559 | 27.4 |
| | | Total | 2,038 | 100.0 |
| Instrument variables | R&D investment | The size of the R&D investment of the focal firm, one year before the initiation of its R&D project | | |
| | Research area | Research area | Projects | % |
| | | Biomedical | 288 | 14.1 |
| | | Electronics | 369 | 18.1 |
| | | ICT | 520 | 25.5 |
| | | Chemistry | 258 | 12.7 |
| | | Machinery | 287 | 14.1 |
| | | Others | 316 | 15.5 |
| | | Total | 2,038 | 100.0 |

[a]All unexpired patents registered globally were counted, with all patents within the same family being treated as a single entity.

evaluating their innovativeness, uniqueness, feasibility of commercialization, and research capabilities. Our analysis target included 2,038 R&D projects initiated from 2011 to 2014 and carried out for two years. On average, these projects had a budget of US$266 thousand, including subsidies and the firm's own contribution, with subsidies making up 71.0% of the total. Therefore, this program, which is one of the sub-programs of the KOSBIR (Korea Small Business Innovation Research) program operated by the South Korean government, is comparable to the SBIR Phase I in the US, although the types and ranges of support for the SBIR Phase I are much more diverse. [2] Most of the beneficiary firms belong to the manufacturing and information service industries. Although this program did not impose any limitations on conducting collaborative research with external organizations, the majority of the projects were carried out by the firm alone. Among the projects analyzed, there was no case in which one firm was the beneficiary for two or more projects in the same year.

Data on all R&D projects carried out with subsidies from the South Korean government is cumulatively recorded in NTIS (National Science and Technology Information Service) system. The commercialization performances, such as the success of product/process innovation within the firm and the technology transfer to other firms, are annually investigated by the funding agency. The performances obtained after the completion of each project are recorded cumulatively in the same system. We obtained information on the attributes and performance of the target projects from NTIS, and investigated the survival status of the firms that performed the projects. In the case of firms that had closed, the time of closure was traced.

### B. *Variables*

Table 1 presents the operational definitions of the variables considered in this study.

Business closure – We defined business closure as the cessation of ownership through bankruptcy, voluntary or involuntary liquidation. As a dependent variable, we operationalized business closure as a binary variable set to one if the focal firm underwent business closure within 5 years after the completion of the R&D project. However, closures due to mergers into other firms were excluded. We considered the time delay required for commercialization of R&D. At the same time, we considered that a business closure occurring too long after the project's completion may have less relevance to the project's commercialization failure. As a result, we basically selected a time frame of 5 years.

Commercialization failure – Firms that have successfully completed R&D projects utilize the new technologies acquired through the R&D for commercialization. Commercialization failure was measured based on the commercialization performance records of each project, which are cumulatively stored in the NTIS. Specifically, we operationalized commercialization failure as a binary variable set to one if the focal firm did not report a success of product/process innovation within 2 years after the completion of the R&D project.

Sales growth – We predicted that the commercialization failure of SMEs' R&D would lead to a slowdown of sales growth, which would mediate the early closure of the firm. Sales growth was measured by calculating the slope of the linear trend line of each focal firm's sales from the project

[2] https://www.sbir.gov/about

completion year to five years later, and then this value was divided by the sales in the project completion year. This gave a relative sales growth rate. Not all firms have sales records for those six years. For instance, if a firm goes out of business, its sales will not be recorded after it closes. In addition, there may be firms that are no longer required to disclose their financial statements. Therefore, we could only calculate sales growth for firms that had sales records for at least two years during the relevant time period. As a result, sales growth was measured for only 1,820 out of 2,038 firms.

Size – Firm size is known to have a positive effect on its business success and performances [48]. Larger firms with the resources to withstand negative internal and external shocks have a better chance of survival [49, 50]. Although sales and the number of employees are typically used as measures of firm size [46, 49], we used total assets to preserve the statistical power because 2,038 observations included balance sheet data compared to those with income statements (2,008 observations). We measured the total assets of the focal firm one year before its R&D project was initiated.

We controlled for important variables known to affect firm survival to reduce bias caused by omitted variables.

Financial performances – Financial performance is one of the key indicators that has been used to predict the bankruptcy of SMEs [51]. Aspects of a firm's financial performance, such as financial stability and profitability affect the survival of the firm [52]. As key financial indicators, we measured the return on asset (ROA) and the current ratio of the focal firm one year before initiating the R&D project.

Competitors - The intensity of competition in a market can affect a firm's innovation, growth, and survival, although there is no conclusive research consensus regarding the direction of this influence [53, 54]. Leading firms in markets with high market concentration have low market competition and therefore can achieve high levels of returns and viability. However, if the market is monopolistic or the competition is intense, SMEs may struggle to secure opportunities for growth and survival. We measured the number of competitors in the industry to which the focal firm belongs, one year before the initiation of its R&D project. Industries were classified based on the lowest classification level of the KSIC (Korean Standard Industry Classification).

Patents – Patents are considered as an indicator of a firm's competitiveness and innovativeness, and are also an important outcome of R&D subsidy program targeting SMEs [55]. In addition, the number of patents held has a considerable impact on the survival of new firms, with recent studies showing that new firms with more patents are less likely to go bankrupt [56]. We extracted the unexpired patents held by the focal firm a year prior to the R&D project's start from the Korea Intellectual Property Rights Information Service. We counted all unexpired patents registered globally. However, all patents within the same family were treated as a single entity. This created a continuous integer value used for analysis.

Year – As mentioned earlier, the R&D projects analyzed were initiated between 2011 and 2014. Considering potential annual variations in business closures, we controlled for the year in which the R&D projects were initiated.

### *C. Methodology*

The dependent variable is a binary variable set to one if the firm underwent early business closure, as extracted from a Korean credit rating agency (NICE Information Service). The success and performance of R&D projects are linked to the research area and the firm's R&D capabilities [12, 57], potentially creating a source of endogeneity in commercialization failure outcomes that may impact our results. Therefore, our estimations required a two-step process in which the first step was a probit estimating the commercialization failure; and the second was an analysis for the early business closure.

To address potential endogeneity, we created two variables to serve as instruments: (1) a categorical variable describing the research area, as defined by the KSCST (Korean Standard Classification of Science and Technology); and (2) a continuous variable describing the R&D investment, as extracted from the NICE Information Service, and transformed logarithmically. We identified projects in the area of biomedical, electronics, ICT (Information and Communication Technology), chemistry, and machinery according to the primary categories of the KSCST. Other fields such as mathematics, energy, construction, and social sciences, which have a relatively smaller number of projects, were grouped under the 'Others', and the R&D projects within this 'Others' category also carried out actual research. For the R&D investment, we measured the amount of R&D funds invested by a focal firm one year before initiating its R&D project. We estimated the propensity of commercialization failure with a probit function, as expressed in (1) below, and controlling for firm size, ROA, current ratio, competitors, and patents.

$$\hat{F} = B_{10} + B_{11} \times IV + B_{12} \times C \tag{1}$$

$$\ln(P_C/(1 - P_C)) = B_{20} + B_{21} \times \hat{F} + B_{22} \times C + E \tag{2}$$

where, $\hat{F}$ is the estimated propensity of commercialization failure obtained using instrumental variables $IV$ and control variables $C$, and $P_C$ is the likelihood of early business closure.

We analyzed the mediating effect of sales growth on the relationship between commercialization failure and business closure. Additionally, we conducted a moderated mediation analysis to determine whether the mediating effect of sales growth is moderated by firm size. We followed Baron & Kenny's method for the mediation effect analysis [58]. Given that the mediator, sales growth, is a continuous variable, we modeled it using linear regression analysis. Since sales growth was only measured for 1,820 firms, we limited our mediation effect analysis to this subset.

## IV. Results

Table 2 presents the correlation between variables and their descriptive statistics. Among the beneficiary SMEs, 15.3% experienced business closure within 5 years after the completion of the R&D projects. In addition, 42.4% of the firms failed in commercialization. Sales growth showed a wide range

TABLE II
CORRELATION BETWEEN VARIABLES AND THEIR DESCRIPTIVE STATISTICS

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 1. Closure | 1 | | | | | | | | |
| 2. Comm. failure | 0.15*** | 1 | | | | | | | |
| 3. Sales growth | -0.07** | -0.07** | 1 | | | | | | |
| 4. Size[a] | -0.13*** | 0.08*** | -0.10*** | 1 | | | | | |
| 5. ROA | -0.1*** | -0.02 | -0.09*** | 0.1*** | 1 | | | | |
| 6. Current ratio | -0.02 | 0 | -0.01 | -0.08*** | 0.02 | 1 | | | |
| 7. Competitors[a] | 0.04 | -0.04 | -0.04 | -0.24*** | -0.02 | 0.05* | 1 | | |
| 8. Patents[a] | -0.16*** | 0.02 | -0.05*** | 0.42*** | 0.01 | -0.05* | -0.09*** | 1 | |
| 9. R&D investment[a] | -0.14*** | -0.02 | -0.02 | 0.35*** | 0.09*** | -0.04 | -0.09*** | 0.28** | 1 |
| N | 2,038 | 2,038 | 1,820 | 2,038 | 2,038 | 2,038 | 2,038 | 2,038 | 2,038 |
| Unit | 1/0 | 1/0 | - | US$1,000 | - | - | firms | patents | US$1,000 |
| Mean | 0.15 | 0.42 | 0.15 | 13,073 | 0.04 | 8.78 | 871 | 8.18 | 425 |
| SD | 0.36 | 0.49 | 1.07 | 21,816 | 0.18 | 107 | 1,256 | 46.47 | 798 |
| Min. | 0 | 0 | -16.52 | 0.37 | -2.55 | 0.04 | 10 | 0 | 0 |
| Max. | 1 | 1 | 25.52 | 187,162 | 1.06 | 2,378 | 4,784 | 1,430 | 14,528 |

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$

[a]The correlation coefficients were calculated using natural logarithmic transformed values, but the descriptive statistics were reported in their original values.

from -16.52 to 25.52. The firms analyzed showed an average sales growth of about 15% over the next 5 years compared to the sales in the project completion year. For variables with high kurtosis and skewness, such as size, competitors, patents, and R&D investment, the natural logarithm was applied. Firm age was excluded from the control variables due to its high correlation with firm size ($R = 0.64$, $p < 0.001$). Although not shown in Table 2, the firms analyzed had a wide range of ages, from 1 to 61 years. The absolute value of the correlation coefficient among explanatory variables was at maximum 0.42 (size and patent) and the variance inflation factor (VIF) of the variables had a maximum of 2.12; therefore, we concluded that there was no multicollinearity problem [59].

Fig. 2 shows the survival rates of the beneficiary firms depending on the time elapsed after completion of the R&D projects. The survival rate of firms varied depending on whether or not they failed to commercialize. The commercialization success group showed a high survival rate of 89.3% up to 5 years after the projects were completed, while the commercialization failure group had a survival rate of 78.3%. As mentioned earlier, the business closure rate of the target firms was 15.3%. This closure rate is not much different from the overall closure rate of SMEs in South Korea. Supplementary Material A shows the closure rate within 8 years (i.e., the same period as within 5 years after the end of the project) of SMEs that disclosed financial statements from 2010 to 2013. The firms analyzed mostly belong to the manufacturing and information service industries. Among South Korean SMEs in these industries, the closure rate during the same period for the firms with positive R&D investment was 15.1%. In other words, there was almost no difference in the closure rate between the firms analyzed and the comparison firms. Therefore, it was confirmed that the firms analyzed are not a group with special characteristics regarding business closure, which is the dependent variable of the analyses.

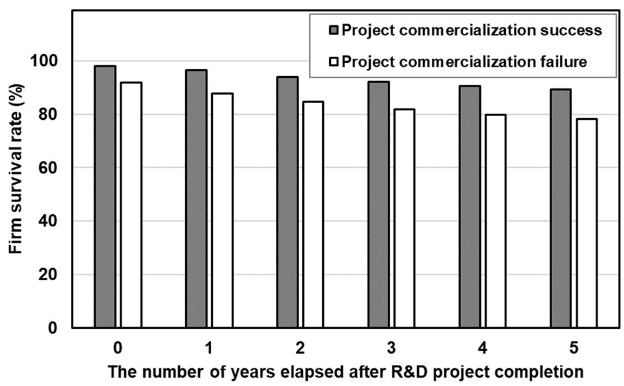


Fig. 2. Temporal evolution of firm survival, stratified by R&D project commercialization outcome

Table 3 shows the results of analyzing the effect of commercialization failure of SMEs' R&D on early business closure regarding Hypothesis 1. As shown in the table, it can be confirmed that the larger the R&D investment of a firm one year before the project, the better the firm's R&D capabilities, and the significantly lower the possibility of commercialization failure of the R&D project ($B = -0.01$, $p < 0.01$). In addition, firms that conducted R&D projects in the area of chemistry had a significantly lower likelihood of commercialization failure compared to the firms that conducted R&D projects in others area ($B = -0.09$, $p < 0.05$). When considering various control variables, commercialization failure had a significant positive impact on the early closure of the firm. Hypothesis 1 was therefore supported. Based on the average marginal effects (AME), it was found that the firms that failed to commercialize had a 72% higher likelihood of business closure within 5 years after the completion of the R&D projects compared to firms that succeeded in commercialization (AME $dy/dx = 0.72$, $p < 0.05$). Among the control variables, firm size and patents were found to have significant negative effects on business closure, and this was consistent with the findings of preceding studies [10, 46, 56]. As a result of the Wald test for the null hypothesis that the rho value, which represents the correlation between the errors of the probit equation and the reduced-form equation, is 0, it was confirmed that the endogenous regressor is not exogenous (Rho = -1.14, Wald test of exogeneity Chi2 = 6.13, $p < 0.05$). Therefore, our two-step probit model, which utilized the instrumental variables, is more reliable and provides more efficient estimates than the plain probit model.

We performed several additional analyses to check the

TABLE III
THE EFFECT OF COMMERCIALIZATION FAILURE OF SMES' R&D ON EARLY BUSINESS CLOSURE

| | Comm. failure | | Closure | | | |
|---|---|---|---|---|---|---|
| Variables | B | S.E. | B | S.E. | dy/dx | Delta-method S.E. |
| Comm. Failure | - | - | 1.96$^{***}$ | 0.21 | 0.72$^{*}$ | 0.34 |
| Size | 0.03$^{***}$ | 0.01 | -0.09$^{***}$ | 0.02 | -0.03$^{**}$ | 0.01 |
| ROA | -0.09 | 0.06 | -0.18 | 0.21 | -0.07 | 0.06 |
| Current ratio | 0.00003 | 0.0001 | -0.001 | 0.001 | -0.0002 | 0.0002 |
| Competitors | -0.01 | 0.01 | 0.03 | 0.02 | 0.01 | 0.01 |
| Patents | -0.01 | 0.01 | -0.11$^{*}$ | 0.05 | -0.04$^{***}$ | 0.01 |
| Year | Controlled | | Controlled | | Controlled | |
| R&D investment | -0.01$^{**}$ | 0.004 | | | | |
| Biomedical | -0.04 | 0.03 | | | | |
| Electronics | -0.03 | 0.03 | | | | |
| ICT | -0.03 | 0.03 | | | | |
| Chemistry | -0.09$^{*}$ | 0.04 | | | | |
| Machinery | -0.06 | 0.03 | | | | |
| Others | Ref. | | | | | |
| Constant | 0.28$^{**}$ | 0.09 | -0.67$^{***}$ | 0.22 | | |
| N | | | 2,038 | | | |
| Log likelihood | | | -2,224 | | | |
| LR Chi$^2$ | | | | | | |
| Wald Chi$^2$ | | | 821$^{***}$ | | | |
| Rho | -1.14$^{*}$ | 0.46 | | | | |
| Sigma | -0.72$^{***}$ | 0.02 | | | | |
| Wald test of exogeneity Chi$^2$ | | | 6.13$^{*}$ | | | |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

robustness of the effect of commercialization failure on early business closure. Supplementary Material B shows the effect of replacing the explanatory variables we considered with other proxy variables. First, in the model that used sales instead of total assets as firm size, commercialization failure consistently showed a significant effect on early closure (AME = 0.69, $p < 0.05$). Moreover, Hypothesis 1 was also supported in the model that applied debt ratio instead of current ratio (AME = 0.56, $p < 0.05$). In this study, we primarily measured business closure within 5 years after the completion of R&D project as our dependent variable. Supplementary Material C shows the results when we varied the time frame for determining business closure. We found that, regardless of whether this time frame was extended to 4 and 6 years, commercialization failure consistently showed a significant impact on business closure (4 years: AME = 0.88, $p < 0.05$; 6 years: AME = 0.72, $p < 0.05$). The Cox survival analysis results shown in Supplementary Material D were also strongly corroborated the results shown in Table 3. Based on these results, we can confirm that our finding regarding Hypothesis 1, the commercialization failure of SMEs' R&D could lead to early closure, is exceptionally robust.

Table 4 presents the results of our analysis on the mediating role of sales growth in the relationship between commercialization failure of SMEs' R&D and early business closure. First, the independent variable of commercialization failure was found to have a significant negative effect on sales growth (B = -0.12, $p < 0.05$). This suggests that SMEs failing to commercialize their R&D outcomes could experience slower of sales growth or even a decline in sales over the next five years compared to those that succeed in commercialization. Furthermore, sales growth was found to have a significant negative impact on business closure (AME = -0.014, $p < 0.05$),

TABLE IV
MEDIATION OF SALES GROWTH ON BUSINESS CLOSURE

| | Sales growth[a] | | Closure[b] | | | |
|---|---|---|---|---|---|---|
| Variables | B | S.E. | B | S.E. | dy/dx | Delta-method S.E. |
| Comm. failure | -0.12$^{*}$ | 0.05 | 0.18 | 0.09 | 0.02 | 0.01 |
| Sales growth | - | - | -0.10$^{*}$ | 0.04 | -0.014$^{*}$ | 0.006 |
| Size | -0.06$^{**}$ | 0.02 | -0.02 | 0.03 | -0.002 | 0.004 |
| ROA | -0.51$^{***}$ | 0.15 | -0.52$^{*}$ | 0.23 | -0.07$^{*}$ | 0.03 |
| Current ratio | -0.0002 | 0.0002 | -0.02 | 0.01 | -0.002 | 0.002 |
| Competitors | 0.01 | 0.02 | -0.02 | 0.03 | -0.002 | 0.004 |
| Patents | -0.01 | 0.02 | -0.19$^{***}$ | 0.04 | -0.03$^{***}$ | 0.01 |
| Year | Controlled | | Controlled | | Controlled | |
| Constant | 0.71$^{***}$ | 0.20 | -0.93$^{*}$ | 0.36 | | |
| N | 1,820 | | 1,820 | | | |
| F | 4.74$^{***}$ | | | | | |
| Adj. R$^2$ | 0.02 | | | | | |
| Log likelihood | | | -464 | | | |
| LR Chi$^2$ | | | 54.14$^{***}$ | | | |
| Tsur's D[c] | | | 0.04 | | | |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$
[a] $Me\ (Sales\ growth) = B_{30} + B_{31} \times X(Comm.failure) + B_{32} \times C + E$
[b] $Y\ (\ln(P_C/(1-P_C))) = B_{40} + B_{41} \times X + B_{42} \times Me + B_{43} \times C + E$
[c] Tsur's discrimination coefficient

TABLE V
MODERATION OF FIRM SIZE ON THE MEDIATING EFFECT OF SALES GROWTH

| Variables | Closure[a] B | S.E. | dy/dx | Delta-method S.E. | Sales growth[b] B | S.E. | Closure[c] B | S.E. | dy/dx | Delta-method S.E. |
|---|---|---|---|---|---|---|---|---|---|---|
| Comm. failure | $0.20^{*}$ | 0.09 | $0.03^{*}$ | 0.01 | $-0.14^{**}$ | 0.05 | $0.19^{*}$ | 0.09 | $0.02^{*}$ | 0.01 |
| Size | -0.02 | 0.03 | -0.003 | 0.004 | $-0.06^{**}$ | 0.02 | -0.06 | 0.03 | -0.007 | 0.004 |
| Comm. Failure * Size | 0.05 | 0.06 | 0.01 | 0.01 | $0.17^{***}$ | 0.03 | 0.04 | 0.06 | 0.01 | 0.01 |
| Sales growth | - | - | - | - | - | - | $-0.52^{***}$ | 0.12 | $-0.07^{***}$ | -0.02 |
| Sales growth * Size | - | - | - | - | - | - | -0.09 | 0.05 | -0.01 | 0.01 |
| ROA | $-0.52^{*}$ | 0.21 | $-0.07^{*}$ | 0.03 | $-0.50^{***}$ | 0.15 | $-0.57^{*}$ | 0.24 | $-0.08^{*}$ | 0.03 |
| Current ratio | -0.02 | 0.01 | -0.003 | 0.002 | -0.0003 | 0.0002 | -0.02 | 0.01 | -0.002 | 0.002 |
| Competitors | -0.02 | 0.03 | -0.003 | 0.004 | 0.003 | 0.02 | -0.02 | 0.03 | -0.003 | 0.004 |
| Patents | $-0.19^{***}$ | 0.04 | $-0.03^{***}$ | 0.01 | -0.01 | 0.02 | $-0.18^{***}$ | 0.04 | $-0.02^{***}$ | 0.006 |
| Year | Controlled | | Controlled | | Controlled | | Controlled | | Controlled | |
| Constant | $-1.00^{***}$ | 0.20 | | | 0.05 | 0.11 | $-1.05^{***}$ | 0.20 | | |
| N | 1,820 | | | | 1,820 | | 1,820 | | | |
| Log likelihood | -467 | | | | | | -455 | | | |
| LR Chi² | $48.47^{***}$ | | | | | | $71.88^{***}$ | | | |
| Tsur's D[d] | 0.03 | | | | | | 0.05 | | | |
| F | | | | | $7.08^{***}$ | | | | | |
| Adj. $R^2$ | | | | | 0.03 | | | | | |

$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$

[a] $Y\left(\ln\left(P_C/(1-P_C)\right)\right) = B_{50} + B_{51} \times X(Comm.failure) + B_{52} \times Mo(Size) + B_{53} \times XMo + B_{54} \times C + E$

[b] $Me\ (Sales\ growth) = B_{60} + B_{61} \times X + B_{62} \times Mo + B_{63} \times XMo + B_{64} \times C + E$

[c] $Y = B_{70} + B_{71} \times X + B_{72} \times Mo + B_{73} \times XMo + B_{74} \times Me + B_{75} \times MeMo + B_{76} \times C + E$

[d] Tsur's discrimination coefficient

indicating a mediating effect. When taking sales growth into account, commercialization failure no longer had a significant impact on business closure (AME = 0.02, p > 0.05), suggesting that sales growth fully mediates the relationship between commercialization failure and business closure. Therefore, Hypothesis 2 was supported, and it was confirmed that commercialization failure of SMEs' R&D would lead to a slowdown in sales growth over the subsequent five years, increasing the risk of business closure.

Table 5 presents the results of our analysis on the moderating role of firm size in the mediating effect of sales growth. First, the control variable of firm size does not control the influence of the independent variable, commercialization failure, on the dependent variable, business closure (AME = 0.01, p > 0.05). On the other hand, firm size moderates the negative effect of commercialization failure on the mediating variable, sales growth (B = 0.17, p < 0.001), and sales growth still has a significant negative effect on business closure (AME = -0.07, p < 0.001). In other words, as firm size increases, the negative impact of commercialization failure on sales growth is lessened. This means that the smaller the firm, the more pronounced the impact of commercialization failure on the slowdown in sales growth and the acceleration of business closure. Therefore, our Hypothesis 3 was supported. In summary, if SMEs failed to commercialize their R&D projects, their sales growth could slow down in the near future, increasing the likelihood of business closure. At this time, the smaller the firm, the greater the effect of commercialization failure on slowing sales growth or declining sales, which further increases the likelihood of business closure.

## V. DISCUSSION AND CONCLUSIONS

The word R&D activities can provide SMEs with an opportunity to increase their market competitiveness and grow rapidly by building capacity and enhancing performance. At the same time, however, for SMEs, R&D is a risky and costly endeavor with no guarantee of success. While the cases of SMEs that succeeded in R&D are relatively well known and studied, not much research has been devoted to cases of failure and the consequent cost. This study was driven by an interest in the worst situation that SMEs can face when their R&D attempts end in failure, namely early business closure. We investigated R&D subsidy projects performed by South Korean SMEs and analyzed the impact that the commercialization failure of these formal R&D projects had on the business closure of SMEs. In the following, we discuss our key findings, contributions, implications, and limitations of this work.

### A. *Key Findings*

First, we found that commercialization failure of SMEs' R&D can have a significant impact on their early business closure. After accounting for various factors that could influence SMEs' survival, we determined that commercialization failure of an R&D project is a substantial factor affecting early business closure (making the probability of business closure 72.4% higher). The R&D projects that we analyzed were conducted with the aid of government subsidies, and the firms' own contribution comprised only 29.0% of the total budget on average. Moreover, on average, the total budget of the R&D projects was only 5% of the firms' total assets. In other words, the burden on firms was much smaller in these cases compared to R&D projects for which the firm is responsible for the entire budget. Nonetheless, the commercialization failure of the formal R&D project had a significant impact on the survival of the firms. Compared to large corporations, SMEs typically maintain a narrower business portfolio and their R&D projects are often tied to short-term product targets. According to a survey[3], South Korean SMEs take an average of 16.4 months to progress from R&D planning to technology commercialization (4.5 months for R&D planning, and 6.3 months for R&D execution, 5.6 months for commercialization). In this context, if a firm fails to commercialize the technology developed through two years of R&D within an additional two years, this could lead to considerable loss for the firm, and we conclude that it can even threaten the firm's survival.

Second, we found that commercialization failure of SMEs' R&D can lead to early business closure due to a slowdown in sales growth in the near future. As mentioned earlier, SMEs' R&D is likely to focus on short-term target products. However, if these two years of crucial efforts do not result in commercialization, the opportunity to secure additional sales may be lost, leading to an immediate slowdown in sales growth. This slowdown in sales growth or decline in sales can negatively impact a firm's financial stability, ultimately increasing the likelihood of its closure.

Third, we found that smaller firms, with their limited resources and dynamic knowledge management capabilities, are more severely impacted by a slowdown in sales growth due to the failure of R&D commercialization. Given the greater significance of a single R&D investment and a narrower product portfolio and revenue sources, these firms are more vulnerable to sales deceleration, potentially leading to early business closure.

### B. Theoretical Contributions

This study provides several important theoretical contributions to research. First, we contribute to the literature on the innovation of SMEs [1, 23]. Previous studies have mainly focused on successful cases and their success factors, while less attention has been paid to innovation failures, their costs, and the mechanisms behind them [6]. We extend the knowledge to the opposite side of success by providing empirical evidence on the relationship between R&D failures and early closures in SMEs. Our robust evidence clearly demonstrates that failures in innovation can be crucially detrimental to SMEs. This confirms, from the resource-based view, that the inefficient use of a firm's resources and capabilities can adversely affect its competitive advantage and sustained growth [19]. Our findings draw important implications for broadening the scope of future research on SMEs' innovation. By shifting the focus towards failures in innovation, future studies can further enrich the associated theories and yield insightful conclusions.

Second, we contribute to the recent literature on the failures of innovation by presenting a specific mechanism through which R&D failures in SMEs influence early closures [10, 13]. We examined the mediating effect of slowdown in sales growth while presenting the mechanism, and it provides insight into why innovation failures can be more detrimental for smaller firms. From the dynamic capabilities view, the provided mechanism offers a more detailed and systematic theoretical explanation of the effects of R&D failures on the survival of SMEs, particularly those lacking knowledge management capabilities [14].

### C. Practical Implications

The results of this study demonstrate that for SMEs, the hidden costs resulting from commercialization failure of R&D can lead to the firm's early business closure. Indeed, business closure may not signify the end. New success can sprout from failure. Entrepreneurs can use the lessons learned from closures to start new businesses that will be more innovative and grow faster [8, 60]. Nonetheless, one cannot pursue a path of failure for the purpose of acquiring the lesson. If a firm cannot handle the shock of failure, it will be in a position where it no longer has the time to utilize the lessons as a foundation for success. The pain of business closure is far from negligible, and embarking on a new start can be exceptionally challenging [61]. Therefore, before trying to learn from failure, the priority ought to be to preemptively recognize potential causes of failure and avoid them.

There can be many reasons why SMEs fail in R&D and commercialization [9]. According to a survey[4], South Korean SMEs cited lack of resources and capabilities, such as funding (43.9%), manpower (14.8%), and equipment (14.2%), as the most important reasons. Other key reasons included the lack of preceding technological research (10.7%), changes in market conditions (6.5%), and earlier development by competitors (4.6%). This indicates that a lack of objective awareness of available internal resources and capabilities and inadequate analysis of external competitors and changes in the market environment can cause commercialization to fail. This is not irrelevant to the failure of R&D planning. SMEs ought to be acutely aware that the cost of hasty planning can be their early business closure. Before embarking on an R&D venture, SMEs should carefully analyze their internal capabilities and external environmental changes, and establish an R&D plan that enhances the likelihood of successful commercialization.

Furthermore, SMEs should recognize that there are many types of innovation strategies, among which R&D is only one [62]. SMEs should also consider the opportunity cost of conducting R&D. Government subsidies can enhance the efficiency of R&D activities for SMEs, but sometimes imitation may prove to be the more efficient choice. External knowledge can also be an important complement to their in-house R&D. Moreover, other forms of innovative practices, such as human resource management, can sometimes serve as an alternative to R&D [16].

From a policy perspective, public funding agencies need to be more careful in selecting beneficiary firms for government subsidies. Public R&D subsidies could provide SMEs with limited resources with great opportunities to innovate [47, 63]. R&D subsidies can enhance a firm's absorptive capacity, promote external collaboration, and increase its growth potential [64]. According to a study by Smith, et al. [65], receiving a public R&D subsidy could have a positive

[3] Ministry of SMEs and Startups, "Survey on Technology of SMEs", 2021

[4] Ministry of SMEs and Startups, "Survey on Technology of SMEs", 2021

significant effect on long term survival of small firms. Additionally, R&D subsidies could positively affect a firm's commercialization behavior and performance [64]. However, many preceding studies have already reported that it is only within a limited condition that the R&D activities of SMEs exert positive effects [18, 23, 50, 66]. While it is highly likely that positive effects would be achieved in firms that continue to innovate, firms based on new technology, firms belonging to high-tech industries, and firms with fast growth, it is difficult to expect such effects from unprepared firms. The same could be said of the effect of public R&D subsidies on SMEs. Moreover, our findings showed that when R&D projects initiated with government subsidies fail, this could accelerate the business closure of SMEs. Therefore, funding agencies should refrain from R&D support policies that blanket-target all types of firms and should make greater efforts to select beneficiaries whose proposals that are well-planned and highly likely to succeed. For example, as an auxiliary tool, it would be helpful to establish and apply a system using advanced machine learning techniques to predict which firms will have a high probability of success, instead of relying only on the qualitative judgment of expert committees [57]. This can be a means of increasing the efficiency of government R&D investment, and also a means to prevent firms that are not yet ready for innovation from prematurely undertaking costly and risky attempts that may lead to early business closure.

On the other hand, this approach may render the selection process conservative, which can lead to the error of screening out innovative and disruptive ideas with a low probability of success. In addition, selecting as beneficiaries that already have sufficient capabilities and can operate without government subsidies may result in the undesirable outcome of depriving opportunities from firms that need public help [67]. However, these potential problems can be lessened if the subsidy program is subdivided into separate tracks by industry, size, and R&D stage. In particular, for small and young firms, it would be effective to reinforce support at the planning stage to help promote more substantial and successful R&D.

Despite all efforts by firms and public agencies, not all R&D projects will be successful. Some will inevitably fail. The pain of failure is great, but the process of learning from failure is necessary for the benefit of society as a whole [32]. Both governments and firms should be aware that the failure of public R&D projects could potentially signal an early business closure. Moreover, follow-up management and support need to be provided to empower SMEs to learn from their failures to fuel new endeavors, rather than ending in failure. As commonly done with cases of success, it would be helpful to establish and operate a system that allows information on cases of failure to be shared to serve as a guide for subsequent businesses, on the condition that private information is not exposed.

### D. Limitations and Future Works

First, it should be noted that we limited our analysis target to only the public R&D projects performed by South Korean SMEs that received government subsidies. According to a survey[5], public funding accounts for an average of 12.8% of the total R&D investment of South Korean SMEs. Thus, among the R&D activities of SMEs, there is a high share of private R&D, which is not disclosed and is difficult to track statistically. The cost of failure in SMEs' R&D can vary greatly depending on factors such as the type and scale of R&D, the source of funding, and the economic conditions. As a result, further research is needed on the costs of failure for SMEs conducting R&D under various conditions in multiple countries. Based on this, we should also explore strategies to minimize R&D failure of SMEs and the consequent costs.

Second, in order to investigate the effect of commercialization failure of SMEs' R&D on early business closure, we controlled for the important variables that could affect a firm's closure. However, there may be other factors that we were unable to measure, such as the founder's competence, the communication skills of the project leader, the level of collaboration among researchers, and the firm's internal culture, that could influence both the commercialization failure and business closure. In addressing the endogeneity, we employed the research areas and R&D investment as our instrumental variables. For a more comprehensive understanding of the effect of commercialization failure on business closure, future studies need to broaden the scope of control and instrumental variables.

Third, we only focused on whether commercialization failed, considering the ultimate purpose of SMEs' R&D. Moreover, we only considered early business closure as the cost of the failure. However, the performances of R&D activity can be evaluated in various ways, such as the success of project management, achievements in intellectual property rights, and an increase in absorptive capacity. Likewise, the cost of failure can also be assessed from different perspectives, including various types of business closure and decreased financial performance. For a deeper understanding of the impact of SMEs' R&D failures on their performance, it will be necessary to consider more diverse dimensions of failure and performance.

Fourth, we categorized the research areas based on the KSCST. While it serves as the main classification system for differentiating the research areas of Korean R&D projects, it does not explicitly distinguish emerging research fields like data science. If a classification system that can identify advanced research areas is utilized in the future, it would enable more interesting comparative analyses of the effects found in this study.

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