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Article

How Can Funding Drive Firm's Performance in the In Vitro Diagnostics Industry?

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Abstract: Due to the increased need for the efficient use of public funds and the importance of private investment, there have been many studies on the effects of these factors on corporate performance. However, few studies have been conducted based on an integrated perspective. In addition, most studies have investigated cases in leading countries and have rarely studied latecomer countries. Therefore, this study investigated the step-by-step effects of government support on firm performance (innovation performance, venture capital (hereafter VC) investment, and financial performance) based on the data on in vitro diagnostic (hereafter IVD) firms in Korea. In particular, we demonstrate the sequential effects of these variables with a time lag. The results of the panel regression analysis indicate that government R&D support improved the innovation performance of IVD firms, but this increased innovation performance did not attract VC investment. Meanwhile, VC investment has a positive impact on a firm's financial performance. These findings have policy implications and suggest that government support plays a pivotal role in a company's innovation performance, and thus continuous investment is required. However, innovation performance negatively affects short-term financial performance, and thus technology commercialization should be supported.

Keywords: government R&D support; venture capital; firm's performance; in vitro diagnostics industry

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1. Introduction

Various studies have been conducted on the necessity and effects of public R&D support. Many studies have reported that government R&D support improves industry-wide innovation performance, which leads to the development of national competitiveness. Accordingly, many countries are actively investing in R&D [1–5]. However, since government spending on R&D does not always show up as a corresponding achievement, government R&D support using public finances has to be utilized efficiently, which is one of the main challenges for policymakers [6]. Therefore, various studies have investigated the relationship between government support and the performance of firms. Another factor that greatly affects a company's performance is private investment. VC investment grows companies through fund investment in companies, innovation inducement, and technology commercialization [7–9].

Although there are various studies on the effects of government support and private investment on the performance of firms separately, few studies have presented their relationship from an integrated perspective [10,11]. In addition, it is hard to find studies analyzing the effect of investment in latecomer countries rather than leading countries.

Therefore, this study aims to provide an integrated view of the two through an analysis of the Korean IVDs industry.

The IVDs market in Korea is the best target to study the effects of government support and VC investment on the performance of firms in the context of latecomer countries. The importance of in vitro diagnostics (IVDs) has been emphasized in response to outbreaks of infectious diseases [12]. With the COVID-19 pandemic hitting the world, timely and extensive diagnostic tests have emerged as a key factor in responding to infectious diseases [13]. Based on testing results, countries can implement infection control measures, such as contact tracing, isolation, and treatment. Furthermore, governments can gain essential data for public health decision making through diagnostic testing. Despite the need for diagnostic testing, there is a high market uncertainty in non-outbreak periods, so continuous government investment is essential to support the IVDs market [14]. Therefore, the Korean government has maintained continuous large-scale support for IVD companies to foster the industry [15,16]. Although the IVDs market in Korea is continuously growing, it is still relatively small and is mostly composed of small- and medium-sized enterprises (SMEs) without a global leading company, meaning it is classified as a latecomer country [17]. Furthermore, the IVDs market is largely dependent on technology. Without continuous innovation, such as developing and improving diagnostic testing technologies, IVD firms are easily eliminated from the market. Therefore, continuous R&D investment is needed for the growth and survival of IVD firms [18]. However, due to the nature of infectious diseases, firms are hesitant to increase R&D expenditure because it is difficult to predict when demand will occur [19]. Therefore, a small number of large firms that can make continuous investments occupy most of the market, and numerous SMEs divide the rest between them [20].

In our analysis, we used the multi-year panel data of Korean IVD companies. Eight models were constructed using a total of seven variables, including two regulation variables that represent government R&D support, VC investment, and the innovation and financial performance of Korean IVD firms. With this dataset, a panel regression analysis was conducted.

This paper is organized as follows. Section 2 provides an overview of past studies and formulates hypotheses about the relationship between government subsides, VC investment, and the performance of firms. Section 3 describes the data and research methods. Section 4 shows the results of this study. Finally, Section 5 presents our conclusions and their political implications.

2. Research Background and Hypotheses

Since the publication of the well-known study by Arrow [21], research on the need for government R&D support has been continuously conducted, and the need for government R&D support for companies is also widely recognized. Public R&D policies can be divided into three categories: funding, tax deduction, and joint R&D support [22]. In some cases, direct funding simply replaces private R&D investment, but in most cases this support stimulates private R&D investment [23,24]. The government's R&D subsidies also support companies facing financial difficulties to maintain national R&D capabilities [25]. Companies that are in financial turmoil tend to be passive in terms of R&D investment to reduce expenditure that does not turn into immediate profits in a period of high uncertainty. Therefore, the government's R&D investment is essential to maintain national competitiveness in these periods.

Another factor that greatly affects a company's performance is private investment. VC investment has a great influence on national growth, such as GDP growth, along with government investment [26]. In some studies, it is claimed that the influence of VC on national growth is higher than that of government investment [27]. VC investment is important not only because it provides tangible support, such as funding for companies, but also intangible assets, such as experience, knowledge, and networks [28–30].

There are many studies that analyze the effect of government support and VC investment. However, few have investigated the relationship between them. Therefore, this study attempted to examine the linkage between government support, VC investment, and firm performance.

2.1. Relationship between Government R&D Subsidies and Firm's Innovation Performance

Government support is delivered in various ways, such as direct funding and tax incentives. Nilsen, Raknerud, and Iancu [31] studied the effects of various R&D investment types, including direct funding, tax incentives, loans, and advisory services in Norway. All of them had a positive effect on the firms' product or technological innovation, and tax incentives were more effective than the others. Additionally, in an analysis of 3113 Slovenian firms, tax incentives were found to be more efficient at increasing corporate R&D expenditure than direct funding, which simply replaced firms' R&D spending [32]. In a study on 3799 firms in Germany, it was confirmed that firms that received government subsidies increased R&D expenditure and that this had a positive effect on firms' patenting behavior [33]. According to a study using innovation surveys in 2010, Turkey and Poland increased R&D subsidies to improve firms' innovation performance, resulting in improved performance in both countries [34]. In a study on the R&D investment of new energy vehicle firms in China, it was found that government subsidies increased the R&D intensity of firms [35]. In a study by Ghazinoory and Hashemi [36] on Iran's biotechnology, information and communication technology, and electronics firms, it was found that direct funding increased the R&D employment of firms. Rather than increasing R&D activities, most of the R&D subsidies were used to increase the number of researchers and pay R&D wages. Studies analyzing research and development subsidies have found that research grants increase the R&D spending of companies while development grants simply replace the spending of the company [23]. A study of 612 manufacturing and service companies in Italy also found that companies participating in government R&D assistance programs filed more patent applications than those that did not [37].

Sometimes, government R&D subsidies promote R&D alliances between firms or organize R&D consortiums that can enhance the innovation performance of firms. In the case of the United Kingdom, SMEs could acquire information for the stimulation of their innovation activity through an innovation voucher program and this successfully increased firms' innovation outcomes [38]. A study analyzed data on 657 US clean-tech startups from 2008 to 2012. The patent activity of clean-tech startups increased 73.7% each time a government technology alliance was added [39]. Research by Feldman and Kelly [40] also confirmed that subsidized R&D projects are more likely to participate in new research joint ventures and connect with universities or other firms.

On the contrary, there are also findings that suggest that government support does not affect the innovation performance of firms. Jeong, Shin, Kim, and Kim [41] proved that government support, including tax support, financial support, and human resource support, does not affect innovative performance in the case of food SMEs. Bertoni and Tykvova [42] also found that government subsidies by themselves have no impact on a firm's number of patents. However, if private VC is combined with government subsidies, the subsidies boost the effect of VC on the innovation performance of firms. To determine which of these conflicting effects occur in the IVDs industry, we examined the following hypothesis:

H1. *Government R&D subsidies have a positive impact on firm's innovation performance.*

2.2. Relationship between Firm's Innovation Performance and Private Investment

In the many studies on the relationship between corporate innovation performance and VC investment, two main perspectives have been reported. The first perspective is that innovation performance can act as a signal to increase VC investment. Munari and Toschi [43] studied 332 nanotechnology sector firms and found that VC investment decisions are determined by the number of patents associated with the technology, especially the

core technology. Lahr and Mina [44] mentioned that VC is invested in firms with high commercialization potential following patent signals. Cavigioli [45] also mentioned that the number and characteristics of patents had a positive effect on total VC investment. As a result of studying the relationship between European firms' patents and VC investment using a linear dynamic panel model, it was also found that the patents of firms induce VC investment [46]. A study on the relationship between patents and R&D investment in the biotechnology industry conducted via a survey also revealed that patents act as strategic R&D investment factors [47]. In a study analyzing the impact of VC finance on the growth and innovation of startups in Germany, it was confirmed that firms with a large number of patent applications receive more VC investments because this demonstrates their innovative output [48]. However, the number of patents and VC investment do not increase linearly. According to a study by Kiebzak, Rafert, and Tucker [49], the relationship between the number of patents and VC investment had an inverted U-shape. It gradually increases and then decreases after a certain number of patents. In addition, the effect of patents on VC investment mainly affects initial financing. A study that surveyed more than 580 US biotechnology firms confirmed that the VC investment induced by patents increased significantly in the first financing, but did not in the second financing [50].

The second perspective is that VC investment improves corporate innovation performance. According to Kortum and Lerner's study [51] using 30 years of data on 20 industries in the US, VC investment had a positive impact on the number of patents across industries. A study by Hirukawa and Ueda [52] also confirmed that VC investment increased a company's patent propensity but did not affect productivity. Data from 2359 UK firms showed that the patent application rate was higher when receiving investment from private VC funds than when receiving public investment [53]. In a study by Faria and Barbosa [54], which studied 17 European countries, it was also confirmed that VC investment improves corporate innovation performance. In a study that tracked the innovation activities of 233 Spanish companies under VC investment, it was confirmed that patent activity increased in the first two years after VC investment and then gradually decreased [55].

In a study that analyzed the prospective relationship between the innovation performance of firms and VC investment, it was revealed that innovation takes precedence over VC investment [56]. Therefore, we tested the following hypothesis:

H2. *The technological innovation of firms has a positive impact on VC investment.*

2.3. Relationship between Firm's Innovation Performance and Financial Performance

There have been many studies that empirically analyze the factors that affect a firm's financial performance, but recently, research on the role and importance of innovation has been gradually increasing. These studies are subdivided into various types depending on the level at which innovation is captured: innovation 'outcome' measured by R&D results (research paper, patent, etc.) or technology commercialization, innovation 'activity' measured by R&D investment or R&D personnel.

While many studies resulted in the positive effect of these kind of innovation, the empirical results are mixed in reality. Shin, Kim, and Jeong [11] classified innovation in detail and studied how it leads to corporate financial performance based on data from 71 biopharmaceutical companies in the United States. According to the results of the study, a company's technical innovation performance increases its innovative capacity and desorptive capacity, which increases financial performance. An empirical study of 184 manufacturing companies in Turkey found that innovation performance had a positive effect on corporate financial performance [57].

In contrast, Gök, and Pecker [10] found a negative relationship between innovation and financial performance in an analysis of 727 manufacturing and service companies in Turkey. They also found that this negative relationship was neutralized through market performance. A study using data from 2810 Brazilian manufacturing companies found that innovation performance had a negative impact on financial performance [58].

There are also studies that suggest that innovation performance has both positive and negative effects on corporate financial performance. A study analyzing the relationship between the R&D costs and the stock prices of Korean companies found that R&D costs had a positive effect on stock prices in the short to mid-term, but R&D costs had a negative effect on corporate performance in the short term [59]. In a study analyzing the effects of R&D intensity and R&D internationalization on the corporate performance of 385 companies in Shanghai, it was confirmed that R&D intensity had a negative effect on short-term profitability and a positive effect on long-term financial performance [60]. Therefore, we tested following hypothesis:

H3. *Firm innovation performance has a positive impact on financial performance.*

2.4. Government R&D Subsidies, VC Investment and Firm's Financial Performance

There are conflicting studies on the effect of government subsidies on recipient firms' financial performance. Firstly, there are studies that claim that government support has a positive effect on corporate financial performance. Government R&D subsides reduce information asymmetry and induce commercialization, thereby increasing the financial performance of firms [61]. According to the results of a study that analyzed the performance of 4378 startups in Korea, it was confirmed that the government's financial support had a positive effect on firm performance [62]. In Pakistan's case, government financial and nonfinancial support has a significant influence on firms' sustainable competitive position and financial performance [63]. Song, Yan, and Yao [64] found that government subsidies improve the total profits of firms and lower the prices of products. In contrast, government support has a negative effect on firms' financial performance. Kim, Choi, and Byun [65] conducted a big data analysis using data from 48,309 Korean national R&D projects, and their results suggested that government support did not lead to the determinants of commercialization performance. Tingvall and Videnord [66] studied the effect of government R&D on the performance of firms in Sweden. They found that government financial support had a significant negative effect on firms' financial performance and did not affect employment or productivity.

In contrast, VC investment has a positive effect on the financial performance of firms. VC acts as a coach that can substantiate the potential of a firm and increase its financial performance [7]. Rosenbusch, Brinckmann, and Müller [9] analyzed data from 36,567 firms and found that VC investment had a small positive effect on overall performance and had a significant impact on the growth and stock performance improvement of firms. In the case of IPO firms in the US, it has been demonstrated that startups continuously perform better when they receive VC investment in the early stages of their development [67]. A study that analyzed the impact of VC ownership on 217 firms in the UK confirmed that external shareholders bring management know-how to the table, which helps firms improve their performance [68].

According to these previous studies, we assumed that government support does not directly improve a firm's financial performance. Instead, we hypothesized that VC investment induced by a firm's innovation performance increases the financial performance of the firm. Therefore, we tested the following hypothesis:

H4. *VC investment has a positive impact on a firm's financial performance.*

Overall, we have established a research framework to identify the impact of government R&D investment on IVD firms. We investigated whether government subsidies increase the technological innovation performance of IVD firms, whether this innovation leads to VC investment, and whether this VC investment improves the financial performance of firms (Figure 1).

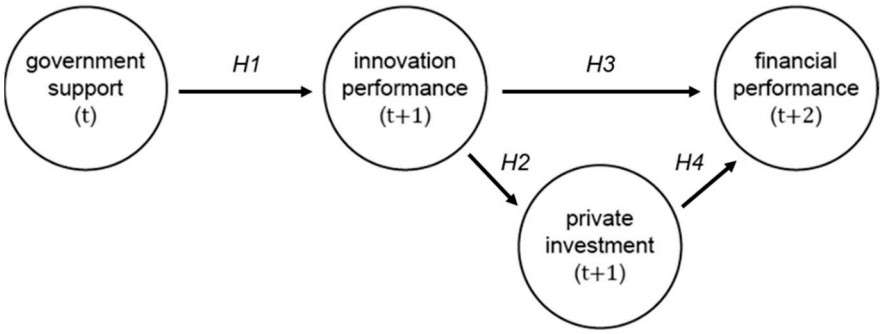

Figure 1. Research framework.

3. Methodology

3.1. Data

We analyzed IVD firms that obtained approval for the manufacture and sale of IVDs medical devices in Korea from 2012 to 2017. During this period, a total of 1157 IVDs were approved, and the total number of firms was 92. Among them, 43 firms (47%) manufactured products in Korea, 45 firms (49%) imported products from overseas countries, and 4 firms (4%) both manufactured and imported IVDs. In order to analyze the current status of the Korean IVDs industry, 47 manufacturers were analyzed (i.e., we excluded the importers).

In order to analyze the effect of R&D investment, the information of each firm, including financial data, government R&D subsidies, and VC investment, was collected through the electronic disclosure system of the Korean Financial Supervisory Service. The number of patents registered by the firms was used as a measure of innovation performance. Information on patents was collected from the Korea Intellectual Property Rights Information Service (KIPRIS).

The characteristics of the firms are shown in Table 1. The size of the firms was classified based on their number of employees. It was found that 24 firms had 50 or fewer employees. Nine firms had more than 51 employees and less than 100. Firms with 100 or fewer employees accounted for 70.2% of the total (n = 33), while 14 (29.8%) firms had more than 100 employees. A total of 35 firms (74.5%) had an age of 20 years or younger, and 12 had been around for more than 20 years, accounting for only 25.5% of the total. Firms in metropolitan areas accounted for 80.9% of the total (n = 38). The others were located in Chungbuk, Gangwon, and Gyeongnam. Firms that manufactured medical supplies and other related medicaments accounted for the largest proportion (n = 17; 36.2%).

Table 1. General characteristics of the sample firms.

Characteristics	Number of Firms	Ratio (%)
Size (number of employees)		
Small (≤50)	24	51.1
Medium (51–100)	9	19.1
Large (>100)	14	29.8
Age (year since formation)		
Young (≤20)	35	74.5
Established (>20)	12	25.5
Region		
Metropolitan area (Seoul, Gyeonggi, Daejeon)	38	80.9
Other	9	19.1
Main Business Area		
Medical supplies and other medicaments	17	36.2
Biological products	6	12.8
Medical/surgical equipment	5	10.6
Research on medical sciences and pharmacy	5	10.6
Medicinal chemicals and antibiotics	3	6.4
Others	11	23.4

3.2. Variables

Sales refers to the total income obtained through the firm's business activities. In general, it is measured by the number of sales of products produced by the firm. Income from the sale of securities and real estate were excluded. Profit means net income from sales except for the cost of the product. VC is total amount of R&D investment in firms originating from venture capital. Government support (gov_sup) is defined as the total amount of R&D expenses invested in the firm by the government. Patents reflects the number of domestic patent registrations of the firm. This was measured to verify whether innovation performance can induce VC investment. Size and age were applied as regulatory variables that can affect both independent and dependent variables. The size is the number of employees of the firm, and age was calculated as the number of years from the date of establishment to the present. The operational definitions of variables are summarized in Appendix A.

3.3. Analytic Method

This study conducted a qualitative in-depth interview after quantitatively performing a regression analysis on the effect of funding on company performance based on the data of companies in the Korean IVDs industry. Although this study attempted a quantitative analysis based on the total data of companies in the IVDs industry in Korea, it was judged that the number of companies was insufficient to strongly reveal statistical significance. Therefore, this study tried to confirm the robustness of the results through in-depth interviews.

Panel data from 47 IVDs manufacturing firms were analyzed. The analysis was conducted with a total of 319 observations. The research model according to each analytical method are as follows.

$$patent_{i,\,t+1} = \alpha_1 + \beta_1 gov\_supt_{i,\,t} + \gamma_1 Z_{i,\,t} + \varepsilon_{it} \quad (1)$$

$$vc_{i,\,t+1} = \alpha_2 + \beta_2 patent_{i,t+1} + \gamma_2 Z_{i,\,t+1} + \varepsilon_{it} \quad (2)$$

$$sales_{i,t+2}(profit_{i,\,t+2}) = \alpha_3 + \beta_3 vc_{i,t+1} + \gamma_3 Z_{i,\,t+1} + \varepsilon_{it} \quad (3)$$

The effect of government support on a firm's innovation performance was analyzed through a negative binomial regression (Equation (1)). Then, the effects of this innovation performance on attracting private investment (Equation (2)) and subsequently on financial performance (Equation (3)) were also analyzed through a regression method.

The subscript i indicates each firm and t indicates the year. Since there is a time difference between government support and a company's innovative performance, the number of patents after one year of government support was analyzed. In order to analyze the financial performance related to the innovation performance of companies generated by government support, sales and profits after two years of government support were analyzed. However, since the investment decisions of VC are made based on the latest information of the firms, the amount of VC investment after one year of government support, which is the time at which corporate innovation performance occurred, was analyzed. Finally, the financial performance in the year of and the year following VC investment was analyzed because VCs tend to improve corporate financial performance as quickly as possible. STATA 13.1 was used for the entire data analysis process.

Furthermore, in-depth interviews were conducted with twelve stakeholders to strengthen the reliability of the analysis results of this study. Interviewees included seven experts from government agencies related to diagnostic tests, three representatives of IVD companies and two university professors. The medical devices market, including IVDs, is a highly regulated market that is greatly affected by government regulations and policies [69]. Therefore, more interviews were conducted with government officials. Table 2 shows the representative characteristics of each expert who was interviewed.

Table 2. Features of each interviewee.

Case #	Category	Work Experience	Career/Expertise
1	Industry	32 years	IVD reagents and devices
2	Industry	24 years	IVD reagents and devices
3	Industry	19 years	Business development in medical device
4	University	13 years	Biomedical management of technology
5	Hospital	27 years	Diagnostic laboratory medicine
6	Government	9 years	Laboratory diagnosis
7	Government	12 years	Laboratory diagnosis
8	Government	18 years	National laboratory policy
9	Government	20 years	National laboratory policy
10	Government	33 years	National laboratory policy
11	Government	10 years	Medical device regulation
12	Government	15 years	Medical device regulation

4. Results and Discussion

4.1. Descriptive Statistics and Regression Analysis

The general characteristics and correlations of the research variables used in the analysis are shown in Table 3. Government support for IVD firms averaged KRW 241.9 million, and VC investment averaged KRW 705.4 million. The average number of patents for firms was 0.4. The average sales are KRW 7679 million, and the average profit was KRW 338.6 million. The size of the firms expressed by the number of employees was 57.5 on average. The average age calculated based on the date of establishment was 10.5 years. There was a significant correlation between sales and profit, VC investment and sales, patents and profit, patent and VC investment, and government support and patents. The number of employees was significantly correlated with the other variables, excluding VC investment. The age of firms was significantly correlated with sales, VC investment, and the number of employees.

Table 3. Descriptive statistics and correlations between variables.

Variable	Mean	SD	Profit	Sales	vc	Patent	gov_sup	Size	Age
profit	338.6	413.8	1						
sales	7,679	13,300	0.6345 ***	1					
vc	705.4	192.6	0.0899	0.2026 ***	1				
patent	0.4	1.2	−0.1138 *	0.0064	−0.1664 **	1			
gov_sup	241.9	392.5	−0.0237	0.0112	0.0433	0.2912 ***	1		
size	57.5	64.1	0.2290 ***	0.6081 ***	0.0295	0.2465 ***	0.2008 ***	1	
age	10.5	7.0	−0.0280	0.3625 ***	0.2028 ***	0.0674	−0.0122	0.4656 ***	1

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

Eight models were used to verify the impact of government support and VC investment on firms. The results of the analysis are shown in Table 4. As a result of the negative linear regression to verify the effect of government R&D subsidies on the innovation performance of firms (Model 1), we can conclude that government support had a significant positive effect on the innovation performance of firms ($p < 0.001$) (Hypothesis 1 is supported). This result indicates that government support in the IVDs industry led to patents being filed. This result supports those of previous studies that found that government support raises a firm's innovation performance [31,33,35,36,38]. In particular, this result is in line with that of a study by Shin, Choy, Lee, and Park [70]. According to the study, Korean biotechnology companies receiving government support had better innovation performance than companies that did not receive such subsidies. This result indicates that the IVDs industry can a improve firm's R&D performance with government support in the same way as other biotechnology firms.

Table 4. Results of regression analysis.

	Model 1 Patent (t + 1)	Model 2-1 vc (t + 1)	Model 2-2 Sales (t + 2)	Model 2-3 Profit (t + 2)	Model 3-1 Sales (t + 1)	Model 3-2 Profit (t + 1)	Model 3-3 Sales (t + 2)	Model 3-4 Profit (t + 2)
gov_sup(t)	0.1210 ***							
patent(t + 1)		−0.2961 ***	−5.8484 *	−2.5149 **				
vc(t + 1)					0.4672 *	0.2785 **	0.3310	0.2070 **
size(t)	0.2926							
age(t)	0.6460							
size(t + 1)		−0.0020	0.1386 ***	0.0345 ***	1.2608 ***	0.2792 ***	1.2082 ***	0.2854 ***
age(t + 1)		0.0799 ***	−0.0983	−0.1372 ***	−2.2260	−2.8662 ***	−2.5096	−2.4771 ***
N	314	315	304	314	304	314	314	314
Log-Likelihood/R^2	−236.0325	0.2845	0.2678	0.3222	0.3846	0.2975	0.2975	0.2922

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

In Model 2-1, it was found that the innovation performance of firms had a significant negative effect on VC investment ($p < 0.001$) (Hypothesis 2 is not supported). This result means that VC investment in the IVDs industry in Korea was not induced by patents. It was expected that the technological innovation performance of firms would induce VC investment, but our results show the opposite. This result may be due to the characteristics of the IVDs industry. The demand for IVDs is very low during non-outbreak periods. Furthermore, the IVDs industry is a typical small quantity batch production industry. IVD users prefer well-known products from big firms rather than the products of SMEs. This is consistent with trends in other high-tech markets, in which customers using high-tech products tend to prefer to use well-known products due to concerns about imperfections in the product [71]. With limited demand and high preference for existing well-known products, the barriers for the new products of SMEs to enter the market are relatively high. As a consequence, VC investment may not be easily attained due to the expected low profitability—even if a firm shows good innovation performance.

In addition, this result implies that the signal effect of government support is not induced by patents in the IVDs industry in Korea. However, this does not mean that government support is not effective at fostering the industry. Although the patents generated by government support did not induce VC investment in IVD firms, the signal effect of government support can induce VC investment and it can foster the industry. There are various studies that have found that government support induces VC investment. Receiving government R&D investment is regarded as the government's certification of a firm's quality, which acts as a signal for VCs to invest in the recipient firms [61,72,73]. Due to the signal effect, beneficiary firms receive more VC investment than non-beneficiary firms. Islam, Fremeth, and Marcus [74] confirmed that firms that received government support were more likely to receive VC investment than firms that did not receive government support in the clean energy industry. According to a study by Gullec and Potterie [75], both government subsidies and financial incentives increase private investment. Toole and Turvey [76] suggested that public investment resolves some uncertainties, and increases investment opportunities. A study by Colombo, Croce, and Guerini finds that government subsidies increased investment rates and decreased cash flow sensitivity [77]. In addition, since government subsidies serve as a signal to prove a firm's legitimacy, government financial support for SMEs brings more human resources and financial investment to the supported firms than the non-supported firms [78]. Kleinert, Volkmann, and Grünhagen [79] also found that prior financing, such as government subsidies, crowdfunding, and angel investment, has the effect of certifying the quality of a firm to investors and reducing information asymmetry in stock crowdfunding.

Models 2-2 and 2-3 found that the innovation performance of firms had a significant negative impact on sales ($p < 0.05$) and profit ($p < 0.01$) (Hypothesis 3 is not supported). This result means that firms' innovation performance did not lead to an increase in sales and profits in the short term. This result supports the findings of Park and Yang [59]. According to their study, the R&D cost has a negative impact on the profitability of SMEs

in the short term. As described above, most of the IVD firms in Korea are SMEs. Therefore, one of the reasons why the innovation performance of IVD firms has a negative effect on financial performance is that SMEs do not have enough capacity to lead technology commercialization. Small-scale firms usually have limitations when it comes to clinical trials and marketing. Therefore, this result suggests that the government has to offer a variety of support methods, such as clinical trial support, commercialization of products, and improvement of regulatory procedures, in order to ensure growth sustainability in the IVDs industry.

According to the results of Model 3, VC investment itself appears to have a significant positive impact on the first-year sales ($p < 0.05$) and first- and second-year profit ($p < 0.01$) (Hypothesis 4 supported). This result suggests that VC investment increases the financial performance of firms. As was suggested in Baum and Silverman's study, VC plays a coaching role in firms to recover investment by increasing commercialization [7]. Such coaching also includes cooperative commercialization strategies, such as strategic alliances and technology licensing, which facilitate the commercialization of technologies [80]. The IVDs industry has complicated commercialization procedures after technology development which involves clinical trials due to the nature of the industry (the fact that it deals with the diagnosis of human diseases). However, the Korean IVDs industry is a latecomer, and most of the companies are SMEs, so even if the technical capabilities are sufficient, the ability to commercialize them is often insufficient. Therefore, for the survival and development of IVD firms, it is necessary to actively attract VC investment.

4.2. In-Depth Interviews with Experts

In-depth interviews were conducted with experts in the IVDs industry and their opinions on the suggested research hypotheses and empirical results were summarized (Table 5). The contents of interviews for each hypothesis are summarized as follows.

Table 5. Experts' statements on hypotheses and empirical results.

Hypotheses		Statements	Source
H1	Role of government support	"Government support is a prerequisite for early-stage IVDs companies to receive angel investment or VC investment. With government support, companies can achieve innovation and receive additional investment."	Case 1
		"Private investment cannot be made in early IVDs companies that have proven nothing. One of the important roles of government support is to bridge these gaps."	Case 2
		"The goal of government support should focus not only on R&D but also expanding the market. It would be great if the government worked with various institutions to make political efforts to expand exports."	Case 3
		"The direction of government investment to foster the IVDs industry should be in parallel with (1) the development of technologies for diagnosing infectious diseases that have not existed before and (2) the investment to expand the market beyond a critical point."	Case 7
		"Since the ecosystem of the IVDs industry is not yet mature, it is desirable for companies to actively utilize various government support projects which provide life cycle management, guidelines, and specimens for clinical evaluation."	Case 12
H2	Attraction of private investment	"In order to expand private investment such as VC, it is important to secure technological competitiveness, which means not just patents, but breakthrough results that can affect investors' decision-making."	Case 9
H3	Role of technological innovation	"I think innovation performance has a positive effect on financial performance in the end. However, there might be large time gap before it happens."	Case 2
		"Considering the characteristics of the IVDs industry, I think innovation performance will have a positive effect on financial performance if you analyze a longer period of time."	Case 6

Table 5. *Cont.*

Hypotheses		Statements	Source
	Importance of technological commercialization	"Since the domestic IVDs market is still small, it is important to develop differentiated products along with reliable R&D results to stand out."	Case 11
		"IVDs companies and governments should focus on increasing the capacity of technology commercialization across the industry. The IVDs industry has a high level of difficulty in commercializing technology, so more investment is required to technology commercialization."	Case 4
		"I think it's a time for both companies and governments to put more resources into commercializing technologies that have already been developed rather than R&D of new technologies.	Case 6
		"Companies should target overseas markets from the R&D stage. Participating in underdeveloped country support projects of international organizations can be one way."	Case 8
		"Forming a consortium based on the business association to promote technology commercialization and market development is a good way to develop overseas markets."	Case 10
H4	Effect of VC investment	"Like private investment, innovation performance will have a positive impact on financial performance someday, but I think this impact will depend on the capabilities of the company."	Case 1
		"Even if a company succeeds in receiving investment, it does not generate profits immediately. Therefore, we need a system that can cooperate with other companies and research institutes, and a large company that can scale up the innovation performance of ventures."	Case 5

First, with regard to hypothesis 1, there are several roles of government support in the IVDs industry. In industries in their infancy, such as IVDs, government support usually precedes private investment (cases 1, 2, 3). Technological competitiveness through innovation achieved with government support leads to the attraction of private investment. In particular, biomedical technologies require support throughout the entire period of R&D (case 12). On the other hand, there were experts who emphasized overseas markets (case 6) or market formation (case 7) in the role of government support.

Regarding the role of innovation to attract VC investment (hypothesis 2), some experts concluded that the technological capabilities of firms are actually important in VC investment (case 9). Nevertheless, the opposite result of the empirical analysis suggests that the measure of technological competitiveness (e.g., the number of patents registered) is not appropriate. Breakthrough research that can influence investors' decision-making is important.

Concerning hypothesis 3, the effect of technological innovation on financial performance, the empirical results all showed a negative direction. The experts attribute this to the short time lag between technological innovation and firm's financial performance (cases 2, 6). If data with longer time lags can be constructed, the relationship between these two variables will be a positive. Meanwhile, some responses emphasized the expansion of investment in the commercialization stage instead of the R&D stage (cases 4, 6). In addition, there were also opinions that it is necessary to target the overseas market from the R&D stage (cases 8, 10).

Hypothesis 4 dealing with the effect of VC investment has been empirically proven, but the opinions of the experts were somewhat mixed. Firms that received a VC investment were proven to be relatively superior. However, there were also opinions that receiving VC investment does not guarantee financial performance by itself (case 1). In addition, in order for ventures in the IVDs industry to grow and generate profits through VC investment, large corporations interacting with them should exist in an ecosystem (case 5).

5. Conclusions

The government's R&D investment in companies has various effects. In the case of latecomer countries, the capital and the competitiveness of companies are insufficient, so government investment is particularly important. The IVDs industry is a technology-dependent industry with a high possibility of market failure. Therefore, government R&D subsidies are used as a major fostering strategy in many countries. Korea is a latecomer country in the IVDs market and is conducting large-scale government support to foster the IVDs industry. It is attempting to create a foundation to maintain the IVDs industry by developing companies through government support and inducing VC investment. VC investment is important because it leads to the development of companies through various avenues, such as through funding the company and moving towards technology commercialization.

Although many prior studies have studied the impact of government R&D and VC investment on the performance of companies, few of them have considered the relationship between two. Therefore, this study analyzed the effect of government support on firm innovation performance and the effect of this innovation performance on VC investment to provide an integrated view.

In this study, we demonstrated the following hypotheses: the effect of government support on corporate innovation performance, the effect of inducing VC investment on corporate innovation performance, the effect of innovative performance on financial performance, and the effect of VC investment on corporate financial performance. According to the results of this study, although government support does increase the technological innovation performance of IVD firms, these achievements do not induce VC investment. We expected innovation performance to induce VC investment, but a firm's number of patents had a negative impact on VC investment. In other words, innovation performance did not act as a signal to induce VC investment in the IVDs industry in Korea. In addition, the innovation performance of a company negatively affected the financial performance of the company. Considering that VC investment has a positive impact on firms' financial performance as described above, a more aggressive strategy to attract private investment beside a strategy that focuses on the development of technology is needed for the survival and growth of IVDs companies. Technical competence is an essential factor for a firm to survive in the IVDs market. Government officials also emphasized the importance of technological competitiveness. Companies should invest actively in R&D to produce superior products in order to stand out and survive. However, it is also very important to show actual financial performance to ensure the sustainable growth and survival of IVD firms.

Our results have the following policy implications. First, continuous early-stage investment from the government is an important factor in increasing a firm's innovation performance (e.g., number of patents). We confirmed that corporate innovation performance has a negative effect on corporate financial performance, and VC investment, which has a positive effect on financial performance, is not stimulated by corporate innovation performance. However, due to the nature of technology-dependent industries, such as the IVDs industry, innovation through continuous R&D is essential for the survival of companies. Therefore, the government's support policy should be set up in such a way that it allows early-stage companies to establish a stable profit structure and provides assistance for a relatively long time until they can survive on their own. Policies such as supporting the development of diagnostic technologies continuously, even when there are no demands due to specific infectious diseases should be implemented. Through policies of this kind, governments can prepare weapons for future infectious disease outbreaks. A government official noted that most of the diagnostic test technologies for most of the currently known infectious diseases are developed, and predicted that the future direction of technology development will focus on point-of-care tests or the modularization of them. She emphasized that these products are experimental and have high risks, so it is necessary

to create an environment in which the government can actively promote technological development by guaranteeing profits, such as purchasing.

Second, policymakers should consider policies that support the technology commercialization of SMEs. We found that R&D investment brings technological innovation but has a negative impact on sales and profits. The biotechnology industry, which includes the IVDs industry, is an industry that has a high risk of market failure due to the difficulty of technology development and commercialization [81–83]. Therefore, it is necessary to prepare policy support measures that boost the technology commercialization that results from innovation performance, for example, by providing education from or connections with organizations that specialize in technological industrialization. A government official mentioned that it is also necessary for the government to provide intangible assets, such as experience, to further promote technology development. She stressed that some IVD companies just have experience in developing theoretical technologies, so it is necessary to provide advice on situations or environments that may occur in medical fields, such as the diagnosis of infectious diseases.

In addition, strategies that involve expanding VC investment, such as fostering VC that specializes in the biotech industry, are also valid. VC investment actively serves as a coach to commercialize a company's technological performance [7]. It can further promote the growth of firms and increase the effectiveness of government support. Latecomer counties lack VC investment compared to developed countries, so an expansion strategy is particularly needed.

Third, domestic IVD firms need a strategy to invest in areas in which they can enter the global market in order to induce VC investment. In this study, it was confirmed that VC investment does not occur as a result of a firm's innovation performance. This suggests that IVD firms need to show more tangible outcomes to induce VC investment. In most cases, the domestic IVDs market is relatively small. Infectious diseases that break out within a single country are limited and it is difficult to predict when demand will occur, but various infectious diseases are spreading worldwide at this moment. Therefore, entering the global market can further increase the value of the company.

Finally, the government should promote the open innovation of companies in order to strengthen the efficiency of support for R&D and foster the industry. Open innovation is a management theory, but it is more often used to analyze government support and firms' innovation performance [84]. It originated from research culture in university and the practice of open science, contrary to the traditional entrepreneurial ecosystem [85]. Various studies have confirmed that companies can strengthen their innovation performance through open innovation [86–88]. Furthermore, companies in various industries can improve competitiveness and financial performance through open innovation [89,90]. In addition, it has been confirmed that open innovation can improve not only the delivery of technological innovation in companies but also the development of creative business models and entry into overseas markets [91,92]. Through open innovation, companies can overcome entry barriers, secure supply chains, and reduce uncertainty and sales costs through risk sharing [93]. Government officials and representatives of IVD companies also supported the idea. They noted that it would be possible for companies to secure overseas markets if they formed a consortium based on the association.

Despite the above findings, this study has some limitations. First of all, the number of firms involved in the statistical analysis is relatively small. This is due to the fact that the sample only includes manufacturers and excludes importers. For our analysis, it was proper to exclude firms that import without their own means of production, but this resulted in only 47 firms being analyzed. A more robust analysis will be possible if the number of firms entering the IVDs market increases in the future or if the scope of the analysis is expanded to related fields. Another limitation is that the innovation performance was only measured by the number of patents in this study. Innovations not measured by patents can also affect a firm's financial performance. Therefore, other variables, such as the number of commercialized products or technology transfer, should be considered in future studies.

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Appendix A

Table A1. Definition of variables.

Variable	Operational Definition
sales	Total income obtained through the company's business activities
profit	Net income from sales except for the cost of the product
vc	Total amount of R&D investment in firms from venture capital
gov_sup	Total amount of R&D subsidies by the government
patent	Number of registered domestic patents
size	Number of employees
age	Period from the year of establishment of the firm

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