Sustainability **2015**, *7*, 11998-12016; doi:10.3390/su70911998

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Effect of R&D Collaboration with Research Organizations on Innovation: The Mediation Effect of Environmental Performance

Gun Jea Yu and Seung-Yoon Rhee *

College of Business Administration, Hongik University, 94 Wausan-ro, Mapo-gu, Seoul 121-791, Korea; E-Mail: gy52@hongik.ac.kr

* Author to whom correspondence should be addressed; E-Mail: syrhee@hongik.ac.kr; Tel.: +82-2-320-1744; Fax: +82-2-322-2293.

Academic Editor: Marc A. Rosen

Received: 9 June 2015 / Accepted: 26 August 2015 / Published: 28 August 2015

Abstract: The purpose of this study was to advance our understanding of corporate environmental performance by linking its antecedents and consequences. This study examined how collaboration with research organizations, as a proactive strategic decision, influences the environmental performance of firms, which in turn leads to innovation performance. Using the data collected from 597 Korean firms representing a cross-section of industries, we found that a firm's collaboration with research organizations positively affected the firm's environmental performance, which positively influenced its innovation performance. Furthermore, the results indicated a full mediation effect of environmental performance on the relationship between collaboration with research organizations and innovation performance. This study offers a more comprehensive understanding of corporate environmental performance and discusses implications for innovation performance. Limitations and future research directions are also discussed.

Keywords: collaboration; research organization; environmental performance; innovation

1. Introduction

In recent years, there has been a growing interest in improving firms' environmental performance by meeting or exceeding environmental regulations [1–3]. The notion of environmental performance refers to the extent to which corporate strategies, policies, and operations are geared toward protecting the natural environment and promoting sustainable development [4]. Facing tight government regulations

along with increasing societal and media attention, firms seek to respond to these external pressures by formulating and implementing environmental strategies. Moreover, environmental performance has been found to be an important predictor of firm market value and operational performance [5–7]. Therefore, effective strategies to manage environmental performance become crucial for establishing legitimacy and building a sustainable competitive advantage.

To this end, this study examined how a firm's collaboration with external organizations, as a proactive environmental strategy, influences the firm's environmental performance and eventually its innovation performance. Despite the growing interest in enhancing environmental performance, only a few recent studies have considered the effects of collaboration decisions on the achievement of firm's environmental objectives [3]. For example, technology and research alliances with other companies have been suggested to reduce environmental influences and to build organizational capabilities [8]. Shared environmental planning between organizations in the supply chain has been found to increase manufacturing performance [9]. We attempt to contribute to the ongoing discussion by empirically testing the effects of strategic collaboration with external research organizations on the firm's level of environmental performance. Since proactive environmental management requires firms to develop leading low-impact technologies and innovative green products, R&D collaboration with research organizations becomes essential.

We further extended our argument by theorizing and empirically testing the effect of environmental performance on the firm's innovation performance. Prior studies have suggested that strong environmental performance of a firm is indicative of innovative culture, deep tacit knowledge and skills required for green technologies, and organization-wide commitment to environmental management [4,10]. However, relatively little is known about how environmental performance relates to the firm's innovative performance. Drawing on the resource-based view of a firm's competitive advantage [11,12], we proposed that environmental performance achieved through rare and valuable technological, organizational, and human resources is likely to predict the innovative performance of the firm.

This paper contributes to the environmental management literature by linking the antecedents and consequences of firm's environmental performance. More specifically, this study examined how collaboration with external research organizations, which is considered a proactive strategic decision, improves environmental performance, which in turn results in successful innovation performance. In doing so, this study attempted to enhance the understanding of the environmental performance by providing a more comprehensive picture rather than by focusing on either the antecedents or the outcomes [3]. In addition, by examining the effect of collaboration with external research organizations, we investigated how collaborative relationships can create opportunities for environmental advancement. Lastly, we aimed to show how effective environmental management leads to a firm's innovation performance, thus suggesting a spillover effect of green innovation on diverse domains of innovation.

2. Literature Review and Hypotheses Development

2.1. The Drivers of Environmental Performance

The notion of environmental performance is drawn from the research on the strategic importance of managing the natural environment and environmental accountability [13–15]. The growing managerial

interest in environmental performance is rooted in mounting evidence that strong environmental performance is positively related to corporate financial performance [16–18]. Additionally, societal interest and media scrutiny in corporate environmental performance are reflected partly in the recent introduction of ISO 14001, as a standard for environmental management systems. Firms are required to conform to a growing number of newly developed regulations, such as the End of Life Vehicle (ELV), Waste Electrical and Electronic Equipment (WEEE), and Restriction of Hazardous Substances (RoHS) Directives.

Previous studies have identified several drivers that motivate firms to meet or exceed compliance requirements in their environmental performance, which includes both internal capabilities and external opportunities and constraints [2,4,10]. The resource-based view suggests that internal resources classified as tangible, intangible, and personnel-based enable firms to implement environmental strategies and policies [10,19]. These three types of resources are discussed below.

First, tangible resources include physical and financial assets, such as plant, equipment, and raw materials [12]. Installation of pollution-removing or filtering devices can certainly help firms meet the environmental requirements in a short-run [20]. Changes that are more fundamental are possible through the application of new technologies throughout the production process. The new pro-environmental technologies can improve firms' waste reduction procedures and help achieve operational and fuel efficiency [21,22]. The level of discretionary resources or slack in the organization is known to influence the environmental performance of the firm as well [23]. Having slack resources is likely to allow firms to engage more actively in addressing environmental issues in their strategy and operation [24].

Second, intangible resources involve technologies and the skills required to use them as well as a firm's reputation [12]. Cross-functional coordination and integration, which are essential in applying green technologies throughout the firm, can foster the technological and communicative skills of workers at all levels [25]. As internal routines are established using accumulated tacit knowledge regarding environmental management, firm's environmental performance is likely to improve. In the case of multinational firms, the need to comply with varying environmental regulations worldwide often results in the establishment of environmental management systems [2]. Through such systems, multinational firms standardize their compliance procedures and seek to exceed the minimum environmental regulation standards of the countries that have the most stringent ones. Hence, instead of maintaining multiple local systems of environmental management, a growing number of multinational firms are adopting proactive systems that routinely exceed compliance [2,5]. Several studies have found evidence that environmental management systems result in better environmental performance [26] and more positive reputation [5].

Finally, personnel-based resources refer to the psychological aspects of the firm, including organizational culture and the commitment and loyalty of employees [12]. Addressing environmental issues through organization-wide technological innovation is a comprehensive and complex procedure. Hence, employee involvement and commitment become critical in achieving and maintaining the firm's environmental goals [27]. With a focus on managerial attitude and action, past research has shown that top management commitment to environmental policies, strategic planning processes, proactive culture, and managerial action taking are significant predictors of the firm's environmental performance [28,29]. Because effective implementation of an environmental strategy involves significant commitment and changes in diverse aspects, such as corporate culture, employee attitudes, marketing and human resource

strategies, top management commitment and drive is crucial [30,31]. Hunt and Auster [32] also showed that both prioritization of environmental management issues and active involvement of top management were important factors of successful environmental performance.

In addition to the firm's internal resources, external stakeholders have been found to influence firm's environmental performance [33,34]. Extending the resource-based view of a firm's environmental performance, Hart [4] proposed that external stakeholders impose pressure and constraints but also offer opportunities for improving environmental performance. For instance, governments create incentive for firms to minimize environmental costs by imposing disposal and toxic emission penalties and by sponsoring programs to certify environmentally responsible products [35]. Local communities and external stakeholders demand openness and transparency, which has led firms to publish annual sustainability or environmental reports [4]. Firms seek to incorporate inputs from customers, environmentalists, the media and regulators in their product design and development [35]. While external stakeholders tend to impose tremendous pressure on firms to alter their operations to address negative environmental effects, they also create opportunities for firms to fundamentally rethink their approach toward environmental management.

Together, a firm's internal resources and capabilities, along with the constraints imposed and opportunities offered by external stakeholders, are likely to shape the direction and the strength of the firm's environmental strategies. Two general types of environmental strategies have been identified in the literature. The first approach is the reactive or compliance strategy that involves short-term, "end-of-pipe" efforts aimed at meeting minimal compliance levels [10,24]. Because implementing green strategies entails risks of failure and unforeseen costs, managers may be tempted to act conservatively by meeting the easiest compliance regulations and thus managing the corporate image [13].

The second approach is the proactive strategy that goes beyond mere compliance by focusing on pollution prevention through product and process innovation with a long-term perspective [4]. It involves structural investments in green technologies together with production redesign and innovative equipment. Because the proactive environmental strategy requires comprehensive and fundamental changes in operation and employee skills and attitudes, it is difficult to put into practice. Nonetheless, when implemented successfully, it is likely to become an inimitable, distinct source of competitive advantage [1,10].

In this study, we suggest that collaboration with research organizations is a proactive strategic decision that fosters the firm's environmental performance, which in turn influences innovation performance. Drawing on the strategy typology of Miles and Snow [36], we propose that a firm's decision to develop and maintain collaborative relationships with research organizations indicate the firm's proactive or prospector strategy that focuses on pollution prevention rather than on end-of-pipe solutions. Because pollution prevention strategies involve technologically complex innovations [4], firms may resort to such collaborative relationships to maximize the speed and efficiency of their proactive strategies. In the following sections, we discuss the general outcomes of environmental performance and then present our research hypotheses.

2.2. The Outcomes of Environmental Performance

Regarding the consequences of environmental performance, past research has revealed predominantly positive outcomes of strong environmental performance, such as increased stock market returns [7], firm

market values [5,37], efficiency and profitability [6,10]. Environmental performance can enhance firm market value and firm performance in several ways. The first of these involves market opportunities created by customer preferences for environmentally friendly products and services [13]. Next, strong environmental performance can be cost-saving by reducing energy and resource costs as well as the risk of facing legal sanctions, higher insurance, and remedial costs [6,13]. Additionally, reputational effects through strong environmental performance contribute to revenue increase as well [38].

For example, receiving environmental rewards has been positively associated with market returns [7]. Environmental performance that exceeds local environmental regulation standards is linked to enhanced market value [5]. In terms of operational performance outcomes, effective environmental performance has been associated with increased efficiency and profitability [6,8,10]. Reducing toxic emissions has been associated with an increased return on sales, return on assets, and return on equity in the following year [6].

Past research has focused mainly on the market and operational outcomes of a firm's environmental performance [5–7], whereas relatively little is known regarding a longer-term innovative performance outcomes. Moreover, researchers have paid little attention to the spillover effect of accumulated skills and knowledge through green innovation process on diverse domains of innovation, such as new product introductions and technology patents.

In the following sections, we first link collaboration with external research organizations, as a proactive strategic decision, to firm environmental performance. We then explore how strong environmental performance enhances the firm's innovation performance.

2.3. The Effect of Collaboration with Research Organizations on Environmental Performance

Firms need to cooperate with external collaborators, including suppliers, customers, competitors, and research organizations to gain new knowledge and skills in response to rapid changes in technology and regulations. Particularly the domain of firm environmental performance tends to encourage the firms to develop collaborative relationships with external stakeholders. More specifically, for the firms to comply with the growing number of environmental regulations, it becomes important to adopt and advance the current state of green technology through collaboration with external organizations [4].

Investments in low-impact technologies and green innovation through collaboration with external organizations indicate the firms' proactive environmental strategy that seeks to exceed minimal compliance levels and lead the industry standards. According to the Miles and Snow's [36] strategy typology, the proactive environmental strategy reflects the prospector strategy that takes a more aggressive approach by redefining its market and introducing new technologies and systems [39,40]. There is a consensus in the literature that environmental performance can be enhanced by taking a proactive prospector strategy [4,13]. Prospectors are in charge of leading the change in their industries by introducing new products and finding new opportunities [40].

To take a proactive stance and to stay a step ahead of competitors regarding environmental performance, fundamental changes in technologies, systems, processes, and products are essential [1]. Collaboration with external organizations, which is considered a type of alliance, has been recognized as an effective way of generating new technology and products [41–44]. From the perspective of resource-based view, firms can develop valuable and inimitable resources and capabilities that are environmentally oriented [4] through the collaborative relationships. For instance, firms can share the

costs and risks of R&D with collaborators [45,46], which certainly helps the firms attain tangible physical assets by active investing in pro-environmental plants and equipment [12]. Collaboration with external organizations can also enhance the likelihood of building intangible resources, such as low-impact technologies, and the skills to use them. New knowledge and skills acquired through the collaboration may result in innovative technology and product development [47,48]. Internal coordination and integration skills nurtured through inter-organizational coordination and communication activities [42] are the key capabilities of the firm in pursuing pro-environmental changes [25]. Regarding personnel-based resources, top management's decision to collaborate with external organizations may reflect the firm's commitment to proactive environmental strategy. Searching for potential collaborators and building and maintaining the relationships require substantial investment and commitment [49]. Such managerial action taking and the resulting culture of environmental responsiveness become unique and valuable capabilities [30,32]. These tangible, intangible, and personnel-based resources acquired and developed through collaboration with external organizations represent a distinct source of sustainable competitive advantage.

Among the various types of collaborators, research organizations, such as universities and research labs, are critical resources necessary to enhance firms' innovative competence [41–44,50]. The positive effect of collaboration with research organizations on innovation performance has been empirically supported [49,51,52]. In addition to the direct evidence, indirect evidence also exists; for example, collaboration with research organizations aids firms in curtailing new product development cycles [53] and encourages industrial R&D spending [54].

The collaboration with research organizations provides several advantages to firms. First, firms can obtain new knowledge and complementary assets that would otherwise be difficult to initiate [42]. Specifically, firms can acquire scientific and specialized knowledge developed and transferred to them by research organizations [55]. The mutual focus on strengthening environmental performance can motivate research organizations to develop pro-environmental technologies by cooperatively setting environmental goals and sharing plans [8,9]. For example, the Research Institute of Innovative Technology for the Earth (RITE) in Japan has been established with joint funding from the government and corporations with the purpose of developing green power technology [4].

Second, the costs and risks of R&D to the firm can be decreased by sharing them with collaborators [45,46]. Implementing environmental strategies entails extensive R&D investment, including failure risks and unforeseen costs [56]. For example, the capital required for the technological development and operation of pollution control devices has increased consistently [57–60]. Through collaboration with research organizations, firms may share such risks and costs and thus commit more strongly to environmental excellence [21].

Collaboration with research organizations, in particular, has been associated with more incoming spillover of R&D knowledge into the firm and less outgoing spillovers [61–63]. When firms collaborate with suppliers or competitors, they make an effort to maximize the gain of incoming spillovers as well as to minimize the loss of outgoing spillovers [64]. In comparison, research organizations, such as universities and research institutes, are important sources of knowledge spillovers due to their explicit focus on knowledge generation and diffusion [65]. Hence, firms with collaborative relationships with research organizations can share the costs and risks associated with green technological innovation and operation and can benefit from the incoming spillover of new knowledge. Therefore, we propose the following hypothesis.

Hypothesis 1: Collaboration with research organizations will be positively associated with a firm's environmental performance.

2.4. The Effect of Environmental Performance on Innovation Performance

Strong environmental performance requires comprehensive technological, system, and human resources innovation, including process innovation, fundamental changes in product design, and cross-functional integration as well as coordination with external stakeholders [1,4,10]. Such organization-wide commitment and involvement in environmental management tend to facilitate the acquisition and accumulation of intangible resources within the firm, including the skills, routines, and tacit knowledge required to implement environmental strategies and policies. These human, organizational, and social capitals are likely to enhance the firm's innovative capabilities [66,67].

Indeed, past research has shown that pollution prevention efforts result in innovative manufacturing performance [68]. For firms to exhibit strong environmental performance, a fundamental rethinking of production and operation processes is required, which thus creates opportunities for technological advancement [10] and for the building of innovative capabilities [21,22]. Such innovative capabilities, reflected through human capital (*i.e.*, employee knowledge and skills) and organizational capital (*i.e.*, patents, manuals, systems and processes) [67], can spill over into diverse domains of innovation, such as biotechnology or information technology.

Furthermore, in an attempt to achieve strong environmental performance, firms seek to facilitate coordination across functions and with external stakeholders [10]. The coordination capabilities and knowledge that flow through the networks of interrelationships have been found to constitute social capital, which plays a critical role in improving innovation performance within the firm [25,69]. Hence, firms' innovative capabilities, developed through environmentally sustainable activities, will increase the firms' innovative performance. Thus, we hypothesize as follows:

Hypothesis 2: Environmental performance will be positively associated with innovation performance.

2.5. The Mediating Effect of Environmental Performance

Firms facing growing demands for environmental performance need to take a proactive stance and build technological, organizational, and human resources required for environmentally sustainable economic activities [4]. R&D collaboration with external organizations can serve a firm's proactive environmental aims through the development of low-impact technologies and product innovation. In particular, collaborative relationships with research organizations facilitate sharing and transfer of specialized new knowledge, technologies, and skills with a pro-environment focus [8]. In addition to the intangible resources, such collaboration encourages investment in tangible assets, including pro-environmental plants and equipment through sharing of R&D costs and risks involved in new technology development [45,46]. Additionally, the proactive strategic decision to collaborate with research organizations represents top management's commitment to environmentally responsible business, thus promoting firms' environmental performance.

Firms' environmental performance achieved through the tangible, intangible, and personnel-based resources that are rare and valuable may further extend to the firms' innovation performance. For firms

to exhibit strong environmental performance that goes beyond compliance, innovative technological and organization-wide process solutions are imperative [10]. The human, organizational, and social capitals accumulated through environmental management builds the innovative capabilities of firms [67], which enable the firms to become more entrepreneurial and more equipped to produce innovative outcomes. Hence, we hypothesize as follows. Figure 1 depicts our conceptual model.

Hypothesis 3: Environmental performance will mediate the relationship between collaboration with research organizations and innovation performance.

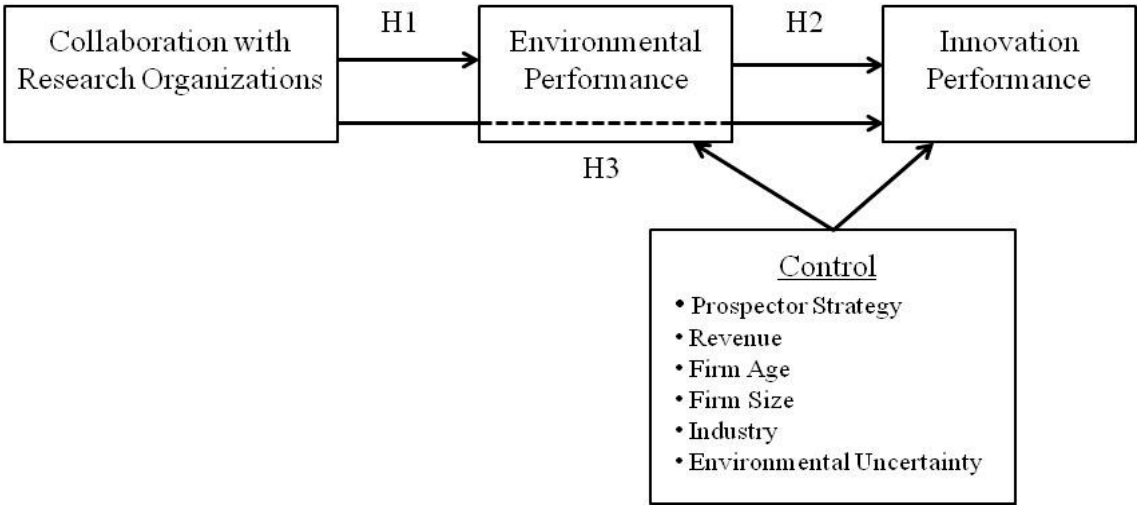

Figure 1. Research model.

3. Methodology and Measurement

3.1. Data Collection

To test our hypotheses, we used the data collected through the Korean manufacturing panel survey conducted in 2013. Of the 2000 firms contacted initially, 601 firms responded (for an effective response rate of 27.1%). Four firms were excluded due to missing data, resulting in a final sample of 597 firms. Among the 597 firms, 93 percent of the firms were small or medium-sized while large firms accounted for 7 percent. The sample included Korean manufacturing firms operating in four industrial sectors: automobile (28%), machine (34%), shipbuilding (19%), and telecommunication (19%). The average sales of each industry are as follows: automobile (88.7 million dollar), machine (41.9 million dollar), shipbuilding (43.6 million dollar), and telecommunication (93.9 million dollar). These firms are all subject to the environmental regulatory framework, including the Kyoto Protocol and End of Life Vehicle (ELV), Waste Electric and Electronic Equipment (WEEE), and Restriction of Hazardous Substances (RoHS) Directives. Facing these external pressures, the Korean manufacturing firms seek to respond to the regulations and media attention by implementing pro-environmental strategies and developing new technology. The context of our sample fits the research purpose of the current study.

Common method bias could be one potential weakness of the data in that the respondents from the same department (regulatory and compliance department) were assessed on the independent (collaboration with research organizations) and the mediator (environmental performance) variables. We conducted Harman's one factor test to investigate the extent of common method bias in our sample [70].

We conducted principal component analysis on all items consisting of one dependent variable and three independent variables. Four factors were shown to have eigenvalues greater than 1. In total, these variables explained 71% of the variance, and the first factor accounted for only 28% of the total variance. This procedure provided the evidence that a single method-driven factor does not represent our data well. Therefore, we concluded that common method bias did not compromise our results.

3.2. Measures

Innovation performance. Our dependent variable, innovation performance, was measured by patent counts over a two-year period, from 2012 to 2013, reported by the participating firms. Patent-based measures for innovation performance are among the most widely used indicators that researchers can use to compare innovative performance of firms in terms of new technologies and new products [71–75].

Environmental performance. The mediating variable, environmental performance, was measured by an index that evaluates the reduction of firms' environmental effects on four categories: non-renewable resources, energy, inputs, and emissions to air and water [76]. The respondents were asked to complete a questionnaire and evaluate the extent to which the firm reduced its environmental effect on the four categories on a scale of 1 (no reduction) to 7 (extensive reduction).

Collaboration with research organizations. The independent variable, collaboration with research organizations, was measured using two items adopted from the previous studies [51,55]: "To what extent does your firm collaborate with universities?" and "To what extent does your firm collaborate with public or private research institutions?" We used a 7-point Likert scale of 1 (very low) to 7 (very high). Cronbach's alpha was 0.86, indicating high reliability.

Control variables. We controlled for prospector strategy of firms because it has been found to be a significant predictor of environmental performance [8,56]. While collaboration with research organizations reflects the firm's prospector strategy for environmental performance, we controlled for other aspects of the prospector strategy additionally such as production redesign and new equipment for environmental protection [13], given the comprehensive nature of the concept. Personnel in regulatory and compliance department evaluated the extent to which the firm made investment in plants and equipment in advance on a scale of 1 (very low) to 7 (very high) [77–79].

In addition, we created several control variables at the firm and industry levels. At the firm level, we created a revenue variable logged to reduce skewness. Firm age was measured by the number of years a firm has operated. The number of employees and the scale of operations measured firm size. We created a dummy variable for industry classification to reflect the variance among the diverse industries. Furthermore, we controlled for R&D expenditure and the environmental uncertainty, which influences a firm's strategy, using eight items: (1) two items for market activities; (2) two items for production and information technology; (3) two items for government regulations/policies; and (4) two for industrial relations. These items were developed from the previous studies [80–84].

3.3. Estimation

The dependent variable was the number of patents, which is a count variable. Thus, ordinary least square regression (OLS) was not appropriate due to the violation of OLS assumption of homoscedastic normally distributed error terms. In this situation, Poisson regression is often recommended as the

estimation technique [85,86]. However, we found that the dependent variable was skewed, and it needed to be transformed. We logged this variable to fix the skewness of the data distribution, and, as a result, we adopted the OLS model.

4. Results

Table 1 displays descriptive statistics and correlations for the study variables. We found some significant correlations among the variables. For example, collaboration with research organizations and prospector strategy were positively associated with innovation performance and environmental performance. In addition, environmental performance was positively related to innovation performance. We calculated variance inflation factors (VIF) to detect any problems with multicollinearity. The VIF ranged between 1.25 and 1.27, which is well below the suggested cut-off point of 10, indicating that multicollinearity did not affect the results of our analyses.

Table 1. Means, standard deviations, and correlation coefficients.

	Variables	Mean	S.D.	1	2	3	4	5	6	7	8
1	Innovation performance	0.89	1.16								
2	Environmental performance	4.20	1.14	0.25 *							
3	Collaboration with research organizations	0.01	0.93	0.3 *	0.38 *						
4	Revenue	3.86	0.98	−0.03	−0.07	−0.06					
5	R&D expenditure	1.01	0.98	0.06	0.03	−0.02	−0.05				
6	Firm age	18.59	11.18	0.2 *	0.10	0.08	−0.05	0.11			
7	Firm size	4.65	0.88	0.29 *	0.12	0.12	−0.07	0.05	0.34 *		
8	Prospector strategy	3.31	1.80	0.20 *	0.27 *	0.31 *	−0.06	0.01	0.05	0.04	
9	Environmental uncertainty	4.57	0.68	0.09	0.25 *	0.11	−0.08	0.04	0.01	0.09	0.21 *

* $p < 0.05$; $n = 597$.

Table 2 presents the results of the OLS regression analyses. The baseline model (Model 1) contains control variables. Model 3 shows that the effect of collaboration with research organizations on environmental performance is positive and significant ($\beta = 0.357$, $p < 0.001$); thus, Hypothesis 1 is supported. Further, inclusion of collaboration with research organization variable resulted in a significant improvement in R^2 compared to the model that included only the control variables ($\Delta R^2 = 0.03$, $F_{1535} = 32.02$, $p < 0.001$). As shown in Model 4, the environmental performance of firms significantly predicted innovation performance ($\beta = 0.197$, $p < 0.001$), thereby supporting Hypothesis 2. In addition, inclusion of environmental performance variable significantly improved R^2 ($\Delta R^2 = 0.033$, $F_{1535} = 73.68$, $p < 0.001$).

Table 2. Results of OLS regression analyses.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Variables	Innovation performance		Environmental performance	Innovation performance	
Revenue	0.025	0.028	−0.024	0.031	0.031
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
R&D expenditure	0.275 ***	0.233 ***	−0.005	0.264 ***	0.234 ***
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Firm age	0.007 †	0.007 †	0.003	0.007	0.007
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Firm size	0.334 ***	0.304 ***	0.046	0.317 ***	0.297 ***
	(0.06)	(0.05)	(0.05)	(0.05)	(0.05)
Prospector strategy	0.1 ***	0.062 *	0.088 **	0.072 **	0.049 †
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Environmental uncertainty	0.04	0.023	0.310 ***	−0.024	−0.024
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
Collaboration with research organizations		0.255 ***	0.357 ***		0.201 ***
		(0.05)	(0.05)		(0.05)
Environmental performance				0.197 ***	0.151 ***
				(0.04)	(0.04)
constant	−1.724 ***	−1.332 **	2.479 ***	−2.105 ***	−1.707 ***
	(0.45)	(0.45)	(0.45)	(0.45)	(0.46)
F-value	17.91	19.359	17.134	19.101	18.953
R^2	0.19	0.225	0.205	0.223	0.243
ΔR^2		0.03 ***	0.07 ***	0.033 ***	0.053 ***

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; $n = 597$; Standard errors are in parentheses. Industry fixed effects are included in the models but not displayed here.

We used two tests to investigate the mediation effect of environmental performance on the relationship between the collaboration with research organizations and innovation performance. First, we conducted Baron and Kenny's three-step analysis [87]. In the first step, we found that collaboration with research organizations was positively and significantly associated with innovation performance (Model 2; $\beta = 0.255$, $p < 0.001$). In the second step, the mediator (environmental performance) was found to be positively and significantly associated with innovation performance (Model 4; $\beta = 0.197$, $p < 0.001$), as proposed in the analysis of Hypothesis 2. In the third step, the results showed that the mediator (environmental performance) had a significant effect on the dependent variable (innovation performance), even after controlling for the effect of collaboration with research organizations (Model 5; $\beta = 0.151$, $p < 0.001$). The coefficients of collaboration with research organizations predicting innovation performance were significant (Model 5; $\beta = 0.201$, $p < 0.001$). These results indicate a partial mediation effect of environmental performance on the relationship between collaboration with research organizations and innovation performance, thus supporting Hypothesis 3.

In addition, we conducted a Sobel test to confirm the mediation effect [88]. Among the multiple ways to test for a mediation effect (e.g., production of coefficients, difference in the coefficients, *etc.*), we selected the production of coefficients due to this method's higher statistical power and lower Type I error rate [89]. Table 3 reports a significant mediating effect of environmental performance on the relationship between collaboration with research organizations and innovation performance ($Z = 3.58$, $p < 0.001$), confirming Hypothesis 3. Environmental performance had an effect ratio of 0.2, indicating a full mediation effect [90].

Table 3. Sobel (1982) test of the mediation effect of environmental performance.

Mediator	c	a	σ_a	b	σ_b	Z	Effect Ratio
Environmental performance	0.37	0.47	0.05	0.16	0.04	3.58 ***	0.2

Note: $Z = a \times b/\sqrt{a^2\sigma_b^2 + b^2\sigma_a^2}$ effect ratio = a × b/c; where a is the effect of independent variable on a mediator; b is the effect of mediator on dependent variable; and c is the effect of independent variable on dependent variable. *** $p < 0.001$ (two-tailed).

5. Conclusions

The purpose of the present study was to explore the effect of R&D collaboration with research organizations on innovation performance through corporate environmental performance. Unlike previous studies that have focused on either some antecedents or the consequences of environmental performance [3], this approach can extend our understanding of environmental performance, as it captures the full spectrum of environmental performance by linking both its antecedent and consequence.

We found that firms with collaborative relationships with research organizations exhibited strong environmental performance (H1). The results also showed that the environmental performance of firms was positively associated with innovation performance (H2). Furthermore, firms' environmental performance fully mediated the relationship between collaboration with research organizations and innovation performance (H3).

The findings from the present study add to the body of environmental research by recognizing the importance of collaboration with research organizations in serving the environmental aims of firms. Previous studies have focused on internal and external resources, such as physical assets, slack resources, and psychological resources, which enable firms to strengthen their environmental performance [12,20,24]. However, our findings suggest the importance of firms' collaborative relationships with research organizations in building tangible, intangible, and personnel-based resources that are rare, valuable, and essential in serving the firm's environmental aims.

Through R&D collaboration, firms can implement innovative technologies in their operations and thus provide swifter and more profound green solutions while reducing the costs and risks they entail. Collaborative relationships with research organizations, in particular, can be even more beneficial compared to those with other kinds of external organizations due to a larger incoming spillover of new and specialized knowledge [61–63]. Our finding corroborates prior studies, which have suggested the importance of broader collaboration for system redesign and technological innovation for sustainable management [4]. The research on innovative capabilities of firms also emphasizes knowledge evolution through the firms' social capital, which involves networks of external organizations [67]. We encourage researchers to further investigate the nature of these collaborative relationships in terms of the strength

(*i.e.*, weak *vs.* strong ties) and the structure of networks (*i.e.*, degree of centralization) [91] as well as contingencies that determine the effectiveness of the collaborative relationships, given the changing environmental pressures.

In addition, we sought to capture the full spectrum of environmental performance by linking its antecedents and consequences, thus addressing the call for a more comprehensive understanding of the phenomenon [3]. More specifically, this study extends our understanding of environmental performance by uncovering its mediating process that links collaboration with research organizations to innovation performance. Firms' innovative capabilities, such as skills, routines and tacit knowledge developed and accumulated through environmentally sustainable activities, can promote the firms' innovative performance, thus suggesting a spillover effect to other domains of innovation. This possibility of the synergistic effect of environmental and innovation performance opens up an interesting avenue for future research.

The current research has practical implications for improving corporate environmental performance and subsequently innovation performance. Firms that seek to gain a competitive advantage through better environmental performance need to build collaborative relationships with research organizations to take a proactive stance and go beyond compliance. The basis for gaining a competitive advantage is increasingly rooted in the firm's capabilities to reduce pollution and achieve green technological innovation in product design and production [4]. More proactive environmental strategies are crucial for building the required capabilities and responding effectively to the increasing public awareness. Firms may establish long-term pay systems, such as stock options, to reinforce consistent commitment to risky environmental strategies [13]. Frequent, continuous communication with and learning from multiple stakeholders regarding growing regulations and heterogeneous demands will certainly be helpful in forming and implementing environmental strategies [1,15]. Additionally, creating a subgroup of board of directors to monitor the firm's environmental performance and provide advice can be beneficial [13,92].

Our research findings need to be interpreted in light of the following limitations. First, we used a sample of Korean manufacturing firms. Given the growing pressures and legal reinforcements for better environmental performance in Korea, the context of our sample fits the research purpose. However, subsequent studies should test the antecedents and consequences of environmental performance in other contexts and countries with diverse regulatory demands to ensure the external validity of the current findings.

Second, while we underscored the benefits of collaboration with research organizations, diverse stakeholders, such as customers, professional associations, and competitors, can also influence a firm's environmental performance [41,42,45]. Future research may extend our findings by incorporating the effects of multiple stakeholders and investigating how the varied demands and pressures may influence firm's environmental performance.

Third, although researchers have extensively used patent data to capture innovation performance, these data have limitations [93–95]. The operationalization of innovation performance using patent data may capture only technological dimension among diverse dimensions in innovation, such as organizational innovation and business model innovation. Moreover, firms have multiple ways to protect their knowledge and technology without patenting their knowledge [96]. Further studies need to evaluate the generalizability of our studies using other types of measures of innovation performance, such as the number of new products [97].

Finally, while our study provides new insights into the organizational antecedents and consequences of corporate environmental performance, it does not empirically test the detailed mechanism of how strong environmental performance leads to innovation performance. Thus, it would be useful to conduct further in-depth studies to improve our understanding of the potential spillover effects from green innovation to other domains of innovation, such as information technology and service technology.

Acknowledgments

This work was supported by the Hongik University new faculty research support fund.

Author Contributions

The authors have contributed equally in the research design and development, the data analysis and the writing of the paper. The authors have read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Aragon-Correa, J.A.; Sharma, S. A contingent resource-based view of proactive corporate environmental strategy. *Acad. Manag. Rev.* **2003**, *28*, 71–88.
2. Sharfman, M.P.; Shaft, T.M.; Tihanyi, L. A model of the global and institutional antecedents of high-level corporate environmental performance. *Bus. Soc.* **2004**, *43*, 6–36.
3. Wisner, P.S.; Epstein, M.J.; Bagozzi, R.P. Organizational antecedents and consequences of environmental performance. *Adv. Environ. Account. Manag.* **2006**, *3*, 143–167.
4. Hart, S.L. A natural-resource-based view of the firm. *Acad. Manag. Rev.* **1995**, *20*, 986–1014.
5. Dowell, G.; Hart, S.; Yeung, B. Do corporate global environmental standards create or destroy market value? *Manag. Sci.* **2000**, *46*, 1059–1074.
6. Hart, S.L.; Ahuja, G. Does it pay to be green? An empirical examination of the relationship between emission reduction and firm performance. *Bus. Strat. Environ.* **1996**, *5*, 30–37.
7. Klassen, R.D.; McLaughlin, C.P. The impact of environmental management on firm performance. *Manag. Sci.* **1996**, *42*, 1199–1214.
8. Sharma, S.; Vredenburg, H. Proactive corporate environmental strategy and the development of competitively valuable organizational capabilities. *Strat. Manag. J.* **1998**, *19*, 729–753.
9. Vachon, S.; Klassen, R.D. Environmental management and manufacturing performance: The role of collaboration in the supply chain. *Int. J. Prod. Econ.* **2008**, *111*, 299–315.
10. Russo, M.V.; Fouts, P.A. A resource-based perspective on corporate environmental performance and profitability. *Acad. Manag. J.* **1997**, *40*, 534–559.
11. Barney, J. Firm resources and sustained competitive advantage. *J. Manag.* **1991**, *17*, 99–120.
12. Grant, R.M. The resource-based theory of competitive advantage. *Calif. Manag. Rev.* **1991**, *33*, 114–135.

13. Berrone, P.; Gomez-Mejia, L.R. Environmental performance and executive compensation: An integrated agency-institutional perspective. *Acad. Manag. J.* **2009**, *52*, 103–126.
14. Buysse, K.; Verbeke, A. Proactive environmental strategies: A stakeholder management perspective. *Strateg. Manag. J.* **2003**, *24*, 453–470.
15. Kassinis, G.; Vafeas, N. Stakeholder pressures and environmental performance. *Acad. Manag. J.* **2006**, *49*, 145–159.
16. Bansal, P.; Clelland, I. Talking trash: Legitimacy, impression management, and unsystematic risk in the context of the natural environment. *Acad. Manag. J.* **2004**, *47*, 93–103.
17. Gilley, K.M.; Worrell, D.L.; Davidson, W.N.; El-Jelly, A. Corporate environmental initiatives and anticipated firm performances: The differential effects of process-driven *versus* product-driven greening initiatives. *J. Manag.* **2000**, *26*, 1199–1216.
18. Sharfman, M.P.; Fernando, C.S. Environmental risk management and the cost of capital. *Strat. Manag. J.* **2008**, *29*, 569–592.
19. Clarkson, P.M.; Li, Y.; Richardson, G.D.; Vasvari, F.P. Revisiting the relation between environmental performance and environmental disclosure: An empirical analysis. *Account. Organ. Soc.* **2008**, *33*, 303–327.
20. Kemp, R. An economic analysis of cleaner technology: Theory and evidence. In *Environmental Strategies for Industry*; Fischer, K., Schot, J., Eds.; Island Press: Washington, DC, USA, 1993; pp. 79–113.
21. Dean, T.J.; Brown, R.L. Pollution regulation as a barrier to new firm entry: Initial evidence and implications for future-research. *Acad. Manag. J.* **1995**, *38*, 288–303.
22. Shrivastava, P. Environmental technologies and competitive advantage. *Strat. Manag. J.* **1995**, *16*, 183–200.
23. Sharma, S. Managerial interpretations and organizational context as predictors of corporate choice of environmental strategy. *Acad. Manag. J.* **2000**, *43*, 681–697.
24. Christmann, P. Effects of "best practices" of environmental management on cost advantage: The role of complementary assets. *Acad. Manag. J.* **2000**, *43*, 663–680.
25. Groenewegen, P.; Vergragt, P. Environmental issues as threats and opportunities for technological innovation. *Technol. Anal. Strateg. Manag.* **1991**, *3*, 43–55.
26. Florida, R.; Davison, D. Gaining from green management: Environmental management systems inside and outside the factory. *Calif. Manag. Rev.* **2001**, *43*, 63–84.
27. Shrivastava, P. Ecocentric management for a risk society. *Acad. Manag. Rev.* **1995**, *20*, 118–137.
28. Epstein, M.J.; Roy, M.J. Managing corporate environmental performance: A multinational perspective. *Eur. Manag. J.* **1998**, *16*, 284–296.
29. Winn, M.I.; Angell, L.C. Towards a process model of corporate greening. *Org. Stud.* **2000**, *21*, 1119–1147.
30. Keogh, P.D.; Polonsky, M.J. Environmental commitment: A basis for environmental entrepreneurship? *J. Org. Change Manag.* **1998**, *11*, 38–49.
31. Menon, A. Enviropreneurial marketing strategy: The emergence of corporate environmentalism as market strategy. *J. Mark.* **1997**, *61*, 51–67.
32. Hunt, C.B.; Auster, E.R. Proactive environmental management: Avoiding the toxic trap. *Sloan Manag. Rev.* **1990**, *31*, 7–18.

33. Ambec, S.; Lanoie, P. Does it pay to be green? A systematic overview. *Acad. Manag. Perspect.* **2008**, *22*, 45–62.
34. Banerjee, S.B.; Iyer, E.S.; Kashyap, R.K. Corporate environmentalism: Antecedents and influence of industry type. *J. Mark.* **2003**, *67*, 106–122.
35. Fiksel, J. Design for environment: The new quality imperative. *Corp. Environ. Strat.* **1993**, *1*, 49–55.
36. Miles, R.E.; Snow, C.C. *Organizational Strategy, Structure, and Process*; McGraw-Hill: New York, NY, USA, 1978.
37. Konar, S.; Cohen, R.A. Does the market value environmental performance? *Rev. Econ. Stat.* **2001**, *83*, 281–289.
38. Epstein, M.J. *Measuring Corporate Environmental Performance*; Irwin Professional Publishing: Chicago, IL, USA, 1996.
39. Moore, M. Towards a confirmatory model of retail strategy types: An empirical test of miles and snow. *J. Bus. Res.* **2005**, *58*, 696–704.
40. Desarbo, W.S.; di Benedetto, C.A.; Song, M.; Sinha, I. Revisiting the miles and snow strategic framework: Uncovering interrelationships between strategic types, capabilities, environmental uncertainty, and firm performance. *Strat. Manag. J.* **2005**, *26*, 47–74.
41. Ahuja, G. Collaboration networks, structural holes, and innovation: A longitudinal study. *Adm. Sci. Q.* **2000**, *45*, 425–455.
42. Das, T.K.; Teng, B.S. A resource-based theory of strategic alliances. *J. Manag.* **2000**, *26*, 31–61.
43. Doz, Y.L.; Hamel, G. *Alliance Advantage: The Art of Creating Value through Partnering*; Harvard Business School Press: Boston, MA, USA, 1998.
44. Eisenhardt, K.M.; Schoonhoven, C.B. Resource-based view of strategic alliance formation: Strategic and social effects in entrepreneurial firms. *Organ. Sci.* **1996**, *7*, 136–150.
45. Hagedoorn, J. Inter-firm R&D partnerships: An overview of major trends and patterns since 1960. *Res. Policy* **2002**, *31*, 477–492.
46. Veugelers, R. Internal R&D expenditures and external technology sourcing. *Res. Policy* **1997**, *26*, 303–315.
47. Baum, J.A.C.; Calabrese, T.; Silverman, B.S. Don't go it alone: Alliance network composition and startups' performance in Canadian biotechnology. *Strat. Manag. J.* **2000**, *21*, 267–294.
48. Stuart, T.E. Interorganizational alliances and the performance of firms: A study of growth and innovation rates in a high-technology industry. *Strat. Manag. J.* **2000**, *21*, 791–811.
49. Faems, D.; van Looy, B.; Debackere, K. Interorganizational collaboration and innovation: Toward a portfolio approach. *J. Prod. Innovat. Manag.* **2005**, *22*, 238–250.
50. Schoenmakers, W.; Duysters, G. Learning in strategic technology alliances. *Technol. Anal. Strat. Manag.* **2006**, *18*, 245–264.
51. Belderbos, R.; Carree, M.; Lokshin, B. Cooperative R&D and firm performance. *Res. Policy* **2004**, *33*, 1477–1492.
52. Nieto, M.J.; Santamaria, L. The importance of diverse collaborative networks for the novelty of product innovation. *Technovation* **2007**, *27*, 367–377.
53. Mansfield, E. Academic research and industrial innovation. *Res. Policy* **1991**, *20*, 1–12.
54. Jaffe, A.B. Characterizing the technological position of firms with application to quantifying technological opportunity and research spillovers. *Res. Policy* **1989**, *18*, 87–97.

55. Klevorick, A.K.; Levin, R.C.; Nelson, R.R.; Winter, S.G. On the sources and significance of interindustry differences in technological opportunities. *Res. Policy* **1995**, *24*, 185–205.
56. Aragón-Correa, J.A. Strategic proactivity and firm approach to the natural environment. *Acad. Manag. J.* **1998**, *41*, 556–567.
57. Brock, W.A.; Evans, D.S. Small business economics. *Small Bus. Econ.* **1989**, *1*, 7–20.
58. Pashigian, B.P. The effect of environmental regulation on optimal plant size and factor shares. *J. Law Econ.* **1984**, *27*, 1–28.
59. Porter, M.E. *Competitive Strategy: Techniques for Analyzing Industries and Competition*; Free Press: New York, NY, USA, 1980.
60. Scherer, F.M.; Ross, D. *Industrial Market Structure and Economic Performance*, 3rd ed.; Houghton Mifflin: Boston, MA, USA, 1990.
61. De Bondt, R.; Slaets, P.; Cassiman, B. The degree of spillovers and the number of rivals for maximum effective R&D. *Int. J. Ind. Organ.* **1992**, *10*, 35–54.
62. Röller, L.; Siebert, R.; Tombak, M. *Why Firms form Research Joint Ventures: Theory and Evidence*; WZB Discussion Paper 97-06; Centre for Economic Policy Research: London, UK, 1997.
63. Amir, R.; Evstigneev, I.; Wooders, J. Noncooperative *versus* cooperative R&D with endogenous spillover rates. *Games Econ. Behav.* **2003**, *42*, 183–207.
64. Martin, S. Spillovers, appropriability, and R&D. *J. Econ.* **2002**, *75*, 1–32.
65. Cassiman, B.; Veugelers, R. R&D cooperation and spillovers: Some empirical evidence from Belgium. *Am. Econ. Rev.* **2002**, *92*, 1169–1184.
66. Davenport, T.H.; Prusak, L. *Working Knowledge: How Organizations Manage What They Know*; Harvard Business Press: Boston, MA, USA, 1998.
67. Nahapiet, J.; Ghoshal, S. Social capital, intellectual capital, and the organizational advantage. *Acad. Manag. Rev.* **1998**, *23*, 242–266.
68. Klassen, R.D.; Whybark, D.C. The impact of environmental technologies on manufacturing performance. *Acad. Manag. J.* **1999**, *42*, 599–615.
69. Subramaniam, M.; Youndt, M.A. The influence of intellectual capital on the types of innovative capabilities. *Acad. Manag. J.* **2005**, *48*, 450–463.
70. Podsakoff, P.M.; Organ, D. Self-reports in organizational research: Problems and prospects. *J. Manag*. **1986**, *12*, 531–544.
71. Bresman, H.; Birkinshaw, J.; Nobel, R. Knowledge transfer in international acquisitions. *J. Int. Bus. Stud.* **1999**, *30*, 439–462.
72. Freeman, C. *The Economics of Industrial Innovation*, 2nd ed.; MIT Press: Cambridge, MA, USA, 1982.
73. Griliches, Z. *Introduction to R&D and Productivity: The Econometric Evidence*; University of Chicago Press: Chicago, IL, USA, 1998.
74. Patel, P.; Pavitt, K. The localized creation of global technological advantage. In *Technological Innovation, Multinational Corporations and New International Competitiveness: The Case of Intermediate Countries*; Molero, J., Ed.; Harwood Academic Publishers: New York, NY, USA, 1995.
75. Pavitt, K. Uses and abuses of patent statistics. In *Handbook of Quantitative Studies of Science Policy*; van Raan, A., Ed.; Elsevier: Amsterdam, The Netherland, 1988.

76. Wagner, M.; Schaltegger, S. The effect of corporate environmental strategy choice and environmental performance on competitiveness and economic performance: An empirical study of EU manufacturing. *Eur. Manag. J.* **2004**, *22*, 557–572.
77. Abernethy, M.A.; Guthrie, C.H. An empirical assessment of the "fit" between strategy and management information system design. *Account. Finance* **1994**, *34*, 49–66.
78. Chong, V.K.; Chong, K.M. Strategic choices, environmental uncertainty and SBU performance: A note on the intervening role of management accounting systems. *Account. Bus. Res.* **1997**, *27*, 268–276.
79. Ittner, C.D.; Larcker, D.F.; Rajan, M.V. The choice of performance measures in annual bonus contract. *Account. Rev.* **1997**, *2*, 231–256.
80. Cooper, R. *When Lean Enterprises Collide*; Harvard Business School Press: Boston, MA, USA, 1995.
81. D'Aveni, R.A.; Gunther, R.E. *Hypercompetitive Rivalries*; The Free Press: New York, NY, USA, 1995.
82. Goldman, S.L.; Nagel, R.N.; Preiss, K. *Agile Competitors and Virtual Organizations*; Van Nostrand Reinhold: New York, NY, USA, 1995.
83. Hamel, G.; Prahalad, C.K. *Competing for the Future*; Harvard Business School Press: Boston, MA, USA, 1994.
84. Hoque, Z.; Hopper, T. Political and industrial relations turbulence, competition and budgeting in the nationalized jute mills of Bangladesh. *Account. Bus. Res*. **1997**, *27*, 125–143.
85. Hausman, J.; Hall, B.; Griliches, Z. Econometric models for count data with an application to the patents-R&D relationship. *Econometrica* **1984**, *52*, 909–938.
86. Henderson, R.; Cockbum, I. Scale, scope, and spillovers: The determinants of research productivity in drug discovery. *RAND J. Econ.* **1996**, *27*, 32–59.
87. Baron, R.M.; Kenny, D.A. The moderator-mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *J. Pers. Soc. Psychol.* **1986**, *51*, 1173–1182.
88. Sobel, M.E. Some new results on indirect effects and their standard errors in covariance structure models. In *Sociological Methodology*; Tuma, N., Ed.; American Sociological Association: Washington, DC, USA, 1986.
89. Preacher, K.J.; Hayes, A.F. SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behav. Res. Methods Instrum. Comput.* **2004**, *36*, 717–731.
90. Jose, P. Workshop on statistical mediation and moderation: Statistical mediation. In Proceedings of the SASP Conference, Wellington, New Zealand, 8–9 June 2008.
91. Adler, P.S.; Kwon, S.W. Social capital: Prospects for a new concept. *Acad. Manag. Rev.* **2002**, *17*, 17–40.
92. De Villiers, C.; Naiker, V.; van Staden, C.J. The effect of board characteristics on firm environmental performance. *J. Manag.* **2011**, *37*, 1636–1663.
93. Rosenkopf, L.; Nerkar, A. Beyond local search: Boundary-spanning, exploration, and impact in the optical disk industry. *Strat. Manag. J.* **2001**, *22*, 287–306.
94. Quintana-Garcia, C.; Benavides-Velasco, C.A. Innovative competence, exploration and exploitation: The influence of technological diversification. *Res. Policy* **2008**, *37*, 492–507.
95. Katila, R.; Ahuja, G. Something old, something new: A longitudinal study of search behavior and new product introduction. *Acad. Manag. J.* **2002**, *45*, 1183–1194.

96. Gittelman, M. A note on the value of patents as indicators of innovation: Implications for management research. *Acad. Manag. Perspect.* **2008**, *22*, 21–27.
97. Kochhar, R.; David, P. Institutional investors and firm innovation: A test of competing hypotheses. *Strat. Manag. J.* **1996**, *17*, 73–84.