R&D Cooperation and unintended innovation performance: Role of appropriability regimes and sectoral characteristics

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Abstract

This research empirically examines the relation between R&D cooperation and unintended innovation performance. The effects of appropriability and sectoral conditions on the unintended innovation performance in the context of R&D cooperation were also tested. Binary logistic regression was used to analyze the manufacturing firms sampled from the Korea Innovation Survey (KIS) 2012. Our estimation results show that for the high-tech focal firms under strong appropriability regime, cooperation with competitors increases the likelihood of their unintended innovation performance. For the high-tech focal firms under weak appropriability regime, cooperation with customer and user firms and universities increases the likelihood of their unintended innovation performance. For the low-tech firms under strong appropriability regime, cooperation with the customer and user firms and advisory organizations increases the likelihood of unintended innovation performance. For the low-tech firms under weak appropriability regime, cooperation with competitors and government research institutes increases the likelihood of unintended innovation performance. As a whole, the significance of this paper lies in shedding a new light on approaching the innovation performance with the notion of unintended innovation performance, which is shaped by different partner types and environmental conditions.

Keywords: Unintended innovation performance, R&D cooperation, High technology industry, Low technology industry, Appropriability regime

1. Introduction

R&D cooperation is characterized by intensive knowledge exchange and organizational learning processes which requires lower transaction costs than in pure market-based transactions (Becker and Dietz, 2004; Dachs et al., 2008). Among the various motives of R&D cooperation, firms gain access to complementary technologies (Mohnen and Hoareau, 2003; Miotti and Sachwald, 2003), thereby improving the probability of success in their innovation projects (Becker and Dietz, 2004; Sampson, 2007; Abramovsky et al., 2008; Freel and Harrison, 2006). In fact, a large number of cross-sectional studies found that R&D cooperation helps boosting focal firms' innovation performance (Cincera et al., 2003; Belderbos et al., 2006). However, some scholars emphasize the inherently unstable nature of R&D cooperation which generates disappointing outcomes (Harrigan, 1988; Kogut, 1988; Kesteloot and Veugeler, 1995; Barkema et al., 1997; Mora-Valentin et al, 2004; Reuer and Zollo, 2005; Lhuillery and Pfister, 2009). Despite the unstable nature and unexpected risks inherent in R&D cooperation that may result in failure, such features may bring about unintended success in R&D cooperation.

As a whole, previous literature has left two important research gaps unfilled. First of all, existing studies failed to integrate the notion of unintended success, which exceeds the initial expectations based on established goals in R&D cooperation. Such unintended success needs more attentions from scholars, as the idea that unintended success or unpredictable outcomes create values within innovation processes has become well accepted (Diaz de Chumaceiro, 1995; Shane, 2000; Thomke, 2003; Dew, 2009; Austin et al., 2012). A list of unintended success would include anesthesia, aspartame, cellophane, corn flakes, dynamite, lithium, nylon, PVC, photography, rayon, smallpox vaccine, stainless steel, Teflon, Viagra, vulcanized rubber, x-rays, and many more (Simonton, 2004; Austin et al., 2012). In the context of R&D cooperation, the collaboration between International Business Machines ("IBM") and Asea Brown Boveri ("ABB") in 1987 was originally aimed at developing an expert system for monitoring and guiding the maintenance of asynchronous electric motors. However, the cooperation not only increased IBM's reputation in the expert systems market as expected, but also produced some unintended technological success to be accrued to IBM's R&D project on the development of a broader 'shell' for personal computers (Tunisini and Zanfei, 1998). Accordingly, this study fills the gap of the unintended dimension of the innovation performance by empirically testing the unintended innovation performance as the innovation outcome which exceeds the preset goals in R&D cooperation. Accordingly, the first objective of this study is to investigate the relation between R&D cooperation and unintended innovation performance.

Secondly, previous research has not paid adequate attention to the external environments that shape the relationship between R&D cooperation and unintended innovation performance (Bayona et al., 2001; Arranz and de Arroyabe, 2008; Wu, 2012). Scholars have argued that sectoral technological characteristics and appropriability conditions are two important environmental factors that influence a firm's resource-seeking behaviors (e.g. searching for similar or complementary resources). Likewise, both sectoral technological characteristics and appropriability conditions have been considered as key factors, as they brought important implications to organizational learning literature (Harrigan, 1988; Doz, 1996). In particular, investigating the R&D cooperation by low-tech firms has been limited to certain industries such as food processing, agribusiness, etc. which may not represent the general population of the firms engaged in low-tech industry (Van de Vrande et al., 2009; Maietta, 2015). However, it is important to note that even low-tech firms actively pursue and engage in R&D cooperation, as innovation is not a unique concern for high-tech firms, but also for the firms in low-tech industries (Zhao 2009; Martinez et al., 2017). Hence, the second objective of this study is to examine the environmental factors that shape the unintended innovation performance in both high-tech and low-tech firms' R&D cooperation activities.

With the research objectives in mind, this study intends to contribute to the literature in three important aspects. First, research on R&D cooperation has mainly focused on identifying mechanisms through which strategic cooperation helps firms to enhance their innovation performance (Powell et al., 1996; Stuart, 2000; Bell, 2005; Ahuja, 2000). Despite the extensive literature in this area, the effect of R&D cooperation on unintended innovation performance has not been examined yet. In fact, the gap for unintended innovation performance in R&D cooperation have not featured in the empirical modeling or testing, despite its prevalent presence in conceptual and theoretical papers (Austin et al., 2012). Also, compared with general innovation performance, unintended innovation performance should require more attentions, as general innovation performance with its basis on a rational approach is only focused on reducing uncertainty and thereby precipitously killing a project that could result in unintended and valuable breakthroughs (Austin et al., 2012). Second, studies on inter-organizational R&D cooperation have addressed various types of partner relationships (e.g. firm-firm, firm-government research institute, firm-university, etc.). However, it is important to consider how different partner types may shape the outcome of R&D cooperation. Whereas, some collaboration focuses on process innovation by incrementally improving the existing internal knowledge-base with an external partner's specific capabilities, others are aimed at product innovation by tapping external knowledge to investigate technologies that are new to the firm (Ahuja, 2000; Bercovitz and Feldman, 2007). Thus, this study investigates the impact of partner types on unintended innovation performance in process and product-oriented innovation activities. Lastly, research on R&D cooperation has mainly focused on addressing the cooperation initiated by high-tech firms. However, many low-tech firms are also pursuing innovation activities by forming R&D cooperation (Hirsch-Kreinsen, 2008; Zhao, 2009; Heidenreich, 2009). This study fills in the gap by making a comparison between high-tech and low-tech R&D cooperation.

Next section begins with the theoretical background by reviewing the streams of literature in R&D cooperation. Section 3 entails methodological approach and process along with descriptive statistics of our samples. Section 4 presents the results of the empirical analysis, which used binary logistic model and propensity score matching (PSM) approach. The last section provides the implications drawn from the findings and future directions of the research.

2. Literature review

2.1. Sources of unintended innovation performance in R&D cooperation

Unintended innovation performance in our study is defined as performing better than firms' initial performance goal. In fact, firms may gain unintended above-normal returns when they have superior information, when they are lucky, or both (Barney, 1986). It is argued that all other apparent sources of either quasi-rents or market power ultimately lead to the importance of either superior information or luck. Obviously, these arguments imply that even firms' endeavor for resource heterogeneity and imperfect mobility is present; it is still difficult for the firms to achieve above normal returns, which exceed the initial expectations or target goals. Likewise, utilization of in-house capabilities and resources is not sufficient to achieve above normal returns. This is why the competitive advantage of a firm is derived from recombination of its internal resources with external resources (Amit and Schoemaker, 1993; Sarasvathy, 2001). In this sense, R&D cooperation improves focal firm's internal technological capability by acquiring new technological resources from external partners. As a result, R&D cooperation provides opportunities for focal firms to achieve above normal returns, which go beyond their initial expectations and target goals.

According to the extended resources-based view, the sources of unintended innovation performance lie in a subset of shared resources and non-shared resources owned by each actor in R&D cooperation (Lavie, 2006) that are based on the willingness of participating firms to share or not to share their resources. On the one hand, when the intersection of shared resource sets between a focal firm and its partner in R&D cooperation is similar and substantial; both the actors pool their resources to achieve a greater scale and competitive position in their industry. The similarity in shared resources is increased when the R&D cooperation is formed with competitors. R&D cooperation between the firms with similar resources improve focal firms' efficiency-based performance (e.g. cost saving) which has its focus on "economies of sameness" (Larsson and Finkelstein, 1999; Bauer and Matzler, 2014). In fact, R&D cooperation with its emphasis on sharing of similar resources may offer both "appropriated relational rents" and "inbound spillover rents" for focal firms (Lavie, 2006; Gnyawali and Park, 2011). The former rents are intentionally and mutually transmitted between partners, since their related resources are shared via R&D cooperation. The latter rents are unilateral in nature, as they are acquired by focal firms' opportunistic behavior. Despite the fact that inbound spillover rents are derived from partners' both shared and non-shared resources, the rents are primarily derived from the acquisition of counterparts' resources that have not been intended for sharing. This is the reason why inbound spillover rents are usually associated with the competitors that collaborate strategically. Since both of the participating actors are likely to be confronted with similar set of problems in their end-product markets, R&D cooperation with the competitors results in lower levels of causal ambiguity and higher potentials of adoption that are derived from the utilization of similar resources (Ritala and Hurmelinna-Laukkanen, 2009). Furthermore, when the participating actors possess adequate industry-specific common knowledge, the focal firm not only improves their knowledge sharing activities for common benefit resulting in appropriated relational rents (Grant and Baden-Fuller, 2004; Cohen and Levinthal, 1990), but also absorbs counterpart's core capability through the windows of intended opportunities or unintended opportunities. Likewise, since cooperation grants focal firms to gain access to the shared resources of its partners, the leakage of knowledge associated with such resources from counterparts is inevitable. When a focal firm holds latent objectives to target the core assets of its partner, the focal firm exploits the cooperation for its private benefits with its opportunistic strategic action called "Trojan Horses" (Hennart et al., 1999; Kale et al., 2000). Thus, when similar resources are sought by the focal firms in R&D cooperation, common benefits and inbound spillover are the sources of focal firms' unintended innovation performance in R&D cooperation.

On the other hand, when the cooperation with complementary partners (e.g. customer and user firms, suppliers, affiliation, university, government research institute, and private service firms) is formed, the intersection of shared resources is diminutive. In this case, the focal firm seeks to achieve synergies by employing distinct resources that are difficult to be acquired or accumulated by collaborating with any given firm. When cooperation is formed, each participating actor endows its resources with the expectation of generating common benefits from the shared resources between the actors. Also, the actors expect appropriated relational rent to be extracted through combination, exchange, and co-development of their idiosyncratic resources (Dyer and Singh, 1998; Lavie, 2006). Complementary-based R&D cooperation with their basis on resource deployment and exploitation provide focal firms with opportunities to pursue "economies of fitness" and grow their turnover and market share (Helfat, 1997; Bauer and Matzler, 2014). However, R&D cooperation accompanies uncertainties by its nature (Eriksson and Sharma, 2003; Cook et al., 1983). In particular, owing to the resource uncertainty, focal firms lack knowledge on the resources controlled by the counterpart, as well as their importance and usefulness. Likewise, resource uncertainty exists, as the focal firms do not fully understand the expected outcome of the R&D cooperation with the biases created by their existing organizational rules and management systems (Eriksson and Sharma, 2003). These uncertainties in R&D cooperation could only be resolved over time rather than right at the time of forming partnerships (Doz, 1996). In this sense, the participating actors in R&D cooperation need to take time to figure out counterparts' competence, skillset, and work process to make a compromise with one another. Interactive cycles of learning, evaluation, and adjustment allow focal firms to see unexpected benefits or risks inherent in collaboration schemes (Doz, 1996). Thus, R&D cooperation provide focal firms to gain access to external complementary resources for their unintended innovation performance, which is derived from learning opportunities provided by partnering actors' complementary resources.

2.2. External environmental conditions and R&D cooperation

It is critical to note the two important environmental conditions that have significant impact on the sources of the unintended innovation performance in R&D cooperation. First, sectorial characteristics shaped by technological traits (high-tech or low-tech) in which a focal firm is affect its cooperative strategy (Harrigan, 1988). In fact, firms seek to gain access to new technologies in a timely manner to enhance their organizational learning and performance, in order to survive in a highly competitive market. This is the reason why technological traits determine the opportunities of a focal firm to acquire, assimilate, and commercialize new technologies from their partners (Pavitt, 1984; Malerba, 2002; Lee and Yoon, 2015). Second, sectorial characteristics shaped by appropriability conditions ensure focal firms to appropriate their own outcomes and have a higher probability of cooperating in R&D (Cassiman and Veugelers, 2002; Henttonen et al., 2016; Zobel et al., 2017). The importance of appropriability conditions is derived from the competitive view of strategic cooperation, in which the learning race of competing firms becomes intense under high levels of competition (Hamel, 1991). Thus, this study takes into account both technological traits and appropriability conditions that deserve more attentions in competitive environment, as they are the critical determinants of the sources of the unintended innovation performance in R&D cooperation.

High-tech industries by nature have many unknown and underdeveloped technologies with great potentials that may have a significant and positive impact on the unintended innovation performance in R&D cooperation. Such high-tech firms have challenges predicting future market needs to develop their technology strategies. Wrong decisions under a certain technological change can unexpectedly render a firm's competencies obsolete or hamper its strategic decision to invest in radical innovation projects that have significant potentials to cannibalize current products and services in the market (Mezias and Glynn, 1993). This is the reason why R&D cooperation with competitors helps focal firms cope with unexpected technological uncertainty by pooling of resources and the sharing of risks. At the same time, such R&D cooperation with competitors provides focal firms with some unexpected opportunities derived from the acquisition of supplementary knowledge and cushioning the risks (Bouncken and Kraus, 2013). Accordingly, previous studies argued that R&D cooperation with competitors is the best choice under a strong appropriability condition (Ganguli, 2007; Gnyawali and Madhavan, 2001). Such appropriability condition promotes an active flow of appropriated relational rents and knowledge spillover rents between a focal firm and its partner. Likewise, low level of causal ambiguity, (occurred from overlapping of experiences, technological knowledge, and background) is beneficial for the effectiveness of R&D cooperation between the competing firms that promote the integration of knowledge and resources to create innovation and achieve technological breakthroughs (Strang and Still, 2006; Cohen and Levinthal, 1990). Likewise, absorptive capacity is relatively higher when the R&D cooperation is made between the competitors than non-competitors, as the lack of absorptive capacity may be hampered in the context of R&D cooperation between non-competitors owing to diverging knowledge bases of each participating actor (Jiang et al., 2010). Thus, R&D cooperation with competitors possessing similar resources is more likely to result in unintended innovation for the high-tech firms under strong appropriability conditions.

In contrast, weak appropriability conditions in high-tech industry provide followers with the windows of opportunities to easily imitate incumbent innovator’s knowledge and product. However, a focal firm in such condition may not be fully ensured with the profits from their R&D cooperation outcomes, as the competitor’s opportunistic behavior resulting in undesirable and unintended inbound spillover for competitors, may become substantial burden for the focal firm (Ritala and Hurmelinna-Laukkanen, 2013). In fact, the outcomes of R&D cooperation in such weak appropriability conditions may not be protected with intellectual property rights (i.e. patent strategy). The firm needs to change their appropriability conditions through combining with complementary assets from outside and integrating these resources into their product and services (Dahlander and Wallin, 2006; Dyer and Singh, 1998). As such, rather than forming R&D cooperation with competitors, focal firms have tendency to pursue forming tight networks or community-based partnerships with non-competing entities to gain access to complementary assets and combine different types of knowledge throughout the supply chain (Dahlander and Wallin, 2006). In fact, focal firms adopting the supply chain strategy may unexpectedly capture new market opportunities by collaborating with such non-competing partners, thereby developing and introducing a new disruptive technology to the market (Porter, 1979). Partnering with suppliers allows focal firms to accelerate product development cycles, lower input costs and enhance end-product quality. With the Customer and user firms, the focal firms could gain sustainable relationship with clients and customers, capability responding to understand market needs, capture potential product segments. Cooperation with Customer and user firms can be used as a major source of innovation, as it could serve as an important to acquire information about customer preferences (Gruner & Homburg, 2000). Sometimes, customers and clients can unexpectedly suggest new innovative ideas, as users often desired added capabilities in future versions of the product after being familiarized with the new product (Enkel et al., 2005). Also, focal firms often enter into R&D cooperation with government research institutions (hereafter, GRI) and universities to focus on basic science research to discover something new and acquire tacit knowledge (Sakakibara, 2002). With the rich stock of knowledge and expertise, the research institutes offer focal firms with problem-solving consultancy services that add both technological and commercial value by helping them overcome the innovation obstacles (Tijssen, 2006; Etzkowitz et al., 2000; Yoon and Lee, 2013). Furthermore, focal firms focus not only on the acquisition of technological capabilities from the partners (e.g. research institutes, universities, etc.), but also market-oriented capabilities of their partnering suppliers and Customer and user firms (customers) that include marketing, efficient manufacturing, and after-sales support (Gans and Stern, 2003). Thus, R&D cooperation with non-competing partners possessing complementary resources is more likely to result in unintended innovation for the high-tech firms under weak appropriability conditions.

Generally, low-tech industries are mature, as technologies and market conditions change slowly. Hence, low-tech firms are less likely to be able to face the challenges of technological change than R&D-intensive high-tech firms (Pavitt, 1984). The firms in low-tech industries pursue innovation activities that are not usually based on the latest scientific or systematic research, but often involve practice-based approach, implicit knowledge and learning that are primarily based on incremental development (Heidenreich, 2009). However, this low-tech industry which is classified as being traditional actually is engaged in many activities and utilizes advanced technological resources (Santamaría et al., 2009). With the increasing dynamics of scientific technology and competitive pressure in global sales market, low-tech industry is moving away from its old characteristic of being 'supplier-dominated' (Pavitt, 1984) to the new suppliers for innovative application, smart materials (e.g. for packaging), advanced instrumentation, etc. along with the machinery supplied by mechanical engineering firms (Santamaría et al., 2009). In other words, these supply-driven categories and market opportunity-orientations need to be supplemented by reflecting demand characteristics and technological opportunity-orientations to provide a more adequate account (Hansen and Serin, 1997). As a whole, these diversified resources and activities especially in terms of advanced technologies constitute a high potential through which network relationships and cooperation can be better utilized, which in turn can be translated into innovation for low-tech firms (Robertson and Patel, 2007).

The low-tech firms under strong appropriability regime often take advantage of their own established brand-names and reputations for a competitive market position. In fact, low tech industries inherently have risk for easy imitations. However, the reputation as informal appropriability instruments has a role of barrier to imitation (Gemser, 2001). This is why the reputation and brand name has often been the driving force and main source of leverage for large firms’ expansion into new markets. The companies with strong reputation and brand power have been taking up a majority of market share even in such brand-dominated segments (i.e. Coca-Cola). This leads to brand-oriented low-tech firms to further acquire complementary resources from cooperation and enhance their overall capabilities from product development to marketing functions (Wognum et al., 2011). In particular, many low-tech firms take part in the purposeful use of network for seeking market opportunities and enhancing value chain, and that may compensate for possible disadvantages of their relatively small internal R&D expenditure (Heidenreich, 2009). Collaborating with external actors helps focal firms overcome the limitations derived from their own resources and know-how in developing new production and increasing potentials for innovation (Hirsch-Kreinsen et al., 2005, p. 23). Since both brand and labelling of the products emphasize the importance of transparency and sustainability in business systems, the low-tech firms should cooperate with external parties by considering the match between their supply chain and future reputation. This type of collaboration brings together actors utilizing shared resources for the purpose of consolidated procurement or for making a purchase through one entity wishing to achieve economies of scale. From the perspective of incremental improvement, the focal firm can develop new distribution channels for finished goods, increase the production capacity, and optimize the produced goods that will eventually improve effectiveness of advertisements and the distribution. In other words, complementary resources allow low-tech firms to have their basis for resource redeployment and exploitation (Helfat, 1997; Bauer and Matzler, 2014). Thus, R&D partner possessing complementary resources is more likely to result in unintended innovation for the low-tech firms under strong appropriability conditions.

The low-tech firms under weak appropriability regime are mainly manufacturers of mature resources which could be affected by radical technological shift in the industry (Malerba and Orsenigo, 1997; Laestadius, 2000). Likewise, technological change and technology diffusion in other sector directly or indirectly lead to substantial changes in the structure of traditional industries (Robertson, 2007). In fact, the improvements in Information and Communications Technologies (ICT) not only contributed to the increase in process efficiency, but also to the introduction of innovative marketing tools. To be more specific, new technologies may be applied more or less in modifying the production input, thereby having both direct and indirectly impact on the mature resources manufacturing industry. They bring about incremental or revolutionary transformation to existing process and products through the introduction of radically new technologies that are not in the scope of the present industry (Laestadius, 2000). The application on technological knowledge has potential of breakthroughs for product and process related innovation. Also, niche market will emerge for ventures which specialize in new business processes and products. In this sense, the incorporation of new technologies by low-tech firms may offer them with competitive advantages, as potential customers may find the usefulness of substantially-enhanced product in the traditional sector (Robertson, 2007). Despite the enhanced opportunities for knowledge creation, low-tech firms may not have enough capabilities identify technologies that match their internal needs (Hirsch-Kreinsen, 2008). This is the reason why the low tech firms are enhancing their absorptive capability for adaptation of new technologies for their potential benefits by collaborating with local universities and GRIs through their education and research activities (Maietta, 2015). By collaborating local universities and GRIs, low-tech firms are able to explore new and emerging technologies through mutual learning activities without having to concern about the counterparts' non-disclosure motives. In fact, not only such collaboration results in transfer of new technologies, but also facilitates traditional teaching role of local universities and GRIs to assist the modernization of low tech firms (Etzkowitz et al., 2000). Thus, R&D cooperation with non-competing partners possessing complementary resources is more likely to result in unintended innovation for the low-tech firms under weak appropriability conditions.

Figure 1. Research framework: Sources of unintended innovation performance

		Level of technological intensity	
		High technology industry	**Low technology industry**
Strength of Appropriability Regime	**Strong**	**Partner with similar resources**	**Partner with complementary resources**
		• Cushioning risks • Low causal ambiguity and common language	• Network for competitive market position • Market opportunity orientation
	Weak	**Partner with complementary resources**	**Partner with complementary resources**
		• Complementary assets from outside • Access and combine research and market oriented capability	• Application for advance technological resources • Technological opportunity orientation

3. Research design

3.1. Methodology

Our research objectives are: (1) to examine the impact of R&D cooperation on unintended innovation performance; and (2) to test the relation between partner types and on unintended innovation performance, after considering environmental characteristics including the technological traits and appropriability conditions of the sectors.

For the first objective, the impact of R&D cooperation on the unintended innovation performance has been examined by using the whole sample. Subsequently, in order to test the different effect of partners, the sample firms have been split into four mutually exclusive groups. For the categorization of the sample firms based on technological traits, this study followed the technological intensity classification in manufacturing industries (High technology level, Medium high technology level, Medium low technology level, and Low technology level) provided by OECD (2013). As a result, the sample firms have been split into two groups: HT group (includes high technology industry, and medium high technology industry) and LT group (includes low technology industry and medium low technology industry). For further categorization of the sample firms with the appropriability conditions, this study computed an industry average of legal and strategic appropriability conditions (Veugelers and Cassiman, 2005; Bonte and Keibach, 2005; Lhuillery and Pfister, 2009). We have drawn the data from KIS (Korean Innovation Survey) 2012 to measure the appropriability conditions. In the KIS 2012, the respondent firms were asked to rate the importance of seven different methods for protecting product and process innovation outcomes in 4-Likert scale (0: not utilized, 1: low, 2: medium, 3: high importance). We used seven items that are related to legal protections (patents, utility model, design right, and trademark right) and strategic protections (secrecy, complexity of product design, and lead time). The scores on the seven items were averaged at two digit level of industry. If the average value of each industry was above the median value, we designated the industry as strong appropriability condition; otherwise we designated the industry as weak appropriability condition.

Our categorization process is as follows: (1) strong and weak appropriability condition within high-tech industry; and (2) strong and weak appropriability conditions within low-tech industry. As a result of taking into account the two criteria (technological traits and approproability conditions) and the categorization process of the sample firms, four groups of the sample firms have been generated: group 1 (strong appropriabilty regime in high technology industry), group 2 (weak appropriability regime in high technology industry), group 3 (strong appropriability regime in low technology industry), and group 4 (weak appropriability regime in low industry). The designated level of industry technology and appropriability regime is showed in Appendix A.

Since we used dummy dependent variables (product-oriented and process-oriented unexpected over-achievement), binary logistic regression models were used to test the impact of the independent variables on the unintended innovation performance, which contains the two binary dependent variables. The logistic regression model is presented as follows:

$$\ln\left(\frac{P}{1-p}\right) = z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_k x_k$$

Where p is the probability that y = 1; y alternatively represents the dummies for unintended innovation performance (product-oriented, process-oriented); x_j are the independent variables (j=1, …, k) and β_j denote the regression coefficients (j=1,…, k). So the probability of an unintended innovation performance (whether for product oriented or process oriented) for a given value of x_j will be given by the following expression:

$$\mathrm{p} = \frac{\exp(\beta_0 + \sum_j \beta_j x_j)}{1 + \exp(\beta_0 + \sum_j \beta_j x_j)}$$

This logistic regression model is estimated using the maximum likelihood method.

3.2. Sample and data

This study used the '2012 Korean Innovation Survey (KIS): Manufacturing industry', which entails the firm-level data on the innovation-related activities from 2009 to 2011. The KIS dataset includes both financial and non-financial information with its basis on OECD Oslo Manual. The survey is conducted once in three years by the "Science and Technology Policy Institute (STEPI)" of South Korea and is also approved by "Statistics Korea", which is a central government agency. With its well-known reliability and focus on innovation activities, extensive studies have used the KIS dataset for their empirical testing of hypotheses in the field of innovation studies (Chun and Mun, 2012; Eom and Lee, 2010; Kang and Kang 2014; Seo et al., 2015). The KIS 2012 covers the data of 4,086 manufacturing firms with the period from 2009 to 2011 and we screened the sample according to the following criteria. First, 3002 manufacturing firms were removed from our sample, as the firms did not carry out any innovation activities or did not respond to questions asking about whether firms have conducted the following activities or not: in-house R&D, external R&D, acquisition of machinery and facilities, acquisition of external knowledge, human resource training, market introduction of innovations, and design. Second, due to the missing values and outlier of the variables used in this study, 98 manufacturing firms were removed from our sample. As a result, we narrowed our final sample for analysis to 986 firms that contain all relevant information for the variables.

3.3. Variables

3.3.1. Dependent variable

In order to measure the dependent variable, this study operationalizes the unintended innovation performance as supernormal outcome throughout firm's product-oriented and process-oriented innovation activities which exceeds the firm's recognized ex-ante assessments of performance indicators. The recognized ex-ante assessment about performance indicators reflects the importance of performance indicators which takes into account the future benefits of technological development, historical experience, strategic directions and etc. With the importance on the performance indicators, firm's R&D investment and R&D activities is determined, and some firms may achieve or may not achieve the goals with their accompanied actions. Also, whereas the outcome of preset goals may be expected and foreseeable, the outcome which exceeds the preset goals may be unintended and unforeseeable. Thus, we measure the unintended innovation performance as the ex-post performance minus ex-ante assessment of importance in product or process oriented indicators.

To measure the ex-ante assessment of goals in product-oriented and process-oriented innovation activities, we have referred to the following question in the KIS survey: Please evaluate the importance degree of the goals related to your product-oriented or process-oriented innovation activities during the last three years (From 2009 to 2011). This question allows us to figure out the actual goal and purpose of product and process innovation activities and the degree of their importance. The degree of importance reflects the level of target goals and priority set by the firms that are pursuing innovation activities. In addition, ex-post performance in product-oriented and process-oriented innovation activities was measured by referring to the following question: Please evaluate the effectiveness degree of the goals, which were established for your product-oriented or process-oriented innovation activities during the last three years. This question is intended to reflect the ex-post performance of innovation activities. The two questions had the same items with four point Likert Scale (0: not utilized, 1: low, 2: medium, 3: high). The two questions asked eleven items related to innovation output. However, we consider seven items including: expanding product assortment, entering new markets or increasing market share, improving product quality, improving flexibility of production, increasing production capacity, reducing labor costs, and reducing use of materials and energy.

We first categorized seven items into product related (expanding product assortment, entering new markets or increasing market share, and improving product quality) and process related (improving flexibility of production, increasing production capacity, reduce labor costs, and reducing use of materials and energy) (Reichstein and Salter, 2006). As for the next step, we constructed product and process-oriented unintended innovation performance variables, in the form of binary variables. If the outcome (ex-post) exceeds the preset goals (ex-ante) in any item related to product innovation, product-oriented unintended innovation performance variable (Prod) takes the value 1 and 0 otherwise. Likewise, process-oriented unintended innovation performance variable (Proc) was constructed. In order to accurately measure the unintended innovation performance, we excluded the samples with the following cases. First, if the degree of importance (ex-ante) and the degree of effectiveness (ex-post) of a focal firm are the same meaning that the firm achieved what it has intended. Second, if the degree of importance (ex-ante) of a focal firm surpasses the degree of effectiveness (ex-post) meaning that the firm did not achieve what it has intended.

3.3.2. Independent variables

We constructed a binary variable cooperation (Coop), taking the value 1 if the firm has cooperated with any external organization during the period 2009-2011 and 0 otherwise. In KIS survey, firms are asked indicate whether they have been engaged in R&D cooperation involving product and process innovation activities. To examine the impact of partner types on the unintended innovation performance in R&D

cooperation, we retrieved additional data on partner types from KIS survey, which specifies the types of actors, who participated in product and process innovation activities via R&D cooperation. As such, the following categorization was adopted from the KIS dataset: (1) Affiliation; (2) Supplier (raw material, component, software); (3) Customer and user firms; (4) Competitor; (5) Private service firms (consulting, private research institute); (6) Universities; and (7) Government Research Institutes (hereafter, GRI). We used seven binary variables for partner types; each variable takes the value 1, if the focal firm has cooperated with the actors via R&D cooperation and 0 otherwise.

3.3.3. Control variables

Large firms tend to have advantages to achieve their innovation goals, as they have a large technological knowledge-base and complementary resources to reduce uncertainty (Damanpour, 1992; Stock et al., 2002). In contrast, small firms have a more flexible structure to manage knowledge sharing process and accept the changes across their internal and external boundaries (Damanpour, 1992; Seo et al., 2016), which bring about uncertainty toward their ex-ante expectation. Thus, we use firm size (Size) as a control variable. Firm size is measured by natural logarithm of the number of total employees who work in focal firms. As mentioned above, collaboration to gain access to external resources may increase uncertainty. However, uncertainty exists even when firms make internal R&D efforts. Sometimes, internal R&D could be more risker than the acquisition of external knowledge or licensing. This is the reason why we used “percentage of internal R&D” as a control variable. Percentage of internal R&D (PiR&D) is measured as the percentage of internal R&D expenditures over the total innovation expenditures during 2009-2011, obtained from the KIS survey. Total innovation expenditures is composed of internal R&D expenditure, external R&D expenditure, purchasing expenditure (including machines, equipment, and software), and other expenditures to acquire external knowledge and technologies. As innovation obstacles are obviously important hampering factors for accomplishing firms’ established innovation goals, we controlled for Innovation obstacle variable (Inn_Obs). As for the obstacles, the KIS asks firms to assess and report the factors that may have hampered their product and process innovation from 2009 to 2011. The measurement for innovation obstacle consists of 11 items based on the 4 point Likert scale that are categorized into four primary factors (financial, business capability, market, innovation needs). Innovation obstacle variable was employed in our empirical model as the aggregate score of 11 items divided by the maximum score. In order to control for industrial heterogeneity, we included industry dummies (Industry) that were divided into 24 industry divisions (2-digit) by the Korean Standard Industry Code (KSIC Rev. 9), which is based on the international standard industrial classification (ISIC rev.4).

Table 1.
Summary of variables

Description	Label	Type	Measure
Dependent variables			
Product-oriented Unintended innovation performance	Prod	Binary	Unintended innovation performance in terms of expanding product assortment, or entering new markets or increasing market share, or improve product quality) $1 = IF \begin{cases} (performance\ score - objective\ score)_{expand\ product\ asseortment} > 0 \\ or \\ (performance\ score - objective\ score)_{enter\ new\ market\ or\ increase\ market\ share} > 0 \\ or \\ (performance\ score - objective\ score)_{improve\ product\ quality} > 0 \end{cases}$ 0 otherwise.
Process-oriented Unintended innovation performance	Proc	Binary	Unintended innovation performance in terms of increasing flexibility of production, or reducing labor costs, or increasing production capacity, or reducing use of materials and energy $1 = IF \begin{cases} (performance\ score - objective\ socore)_{increase\ flexibility\ of\ production} > 0 \\ or \\ (performance\ score - objective\ score)_{reduce\ labor\ costs} > 0 \\ or \\ (performance\ score - objective\ score)_{increase\ production\ capacity} > 0 \\ or \\ (performance\ score - objective\ score)_{reduce\ use\ of\ material\ and\ energy} > 0 \end{cases}$ 0 Otherwise.
Explanatory and control variables			
Cooperation	Coop	Binary	1 if firm cooperated with external organizations during 3 years, 0 otherwise.
Cooperation with Affiliation	Affi	Binary	1 if firm cooperated with affiliation during 3 years, 0 otherwise.
Cooperation with Supplier	Supply	Binary	1 if firm cooperated with supplier during 3 years, 0 otherwise.
Cooperation with Customer and user firms	Customer	Binary	1 if firm cooperated with customer and user firms during 3 years, 0 otherwise.
Cooperation with Competitor	Comp	Binary	1 if firm cooperated with competitor during 3 years, 0 otherwise.
Cooperation with Private service firm	Private	Binary	1 if firm cooperated with private service firm (e.g. consultants) during 3 years, 0 otherwise.
Cooperation with Government Research Institute	GRI	Binary	1 if firm cooperated with GRI during 3 years, 0 otherwise.
Cooperation with University	Univ	Binary	1 if firm cooperated with during 3 years, 0 otherwise.
Firm Size	Size	Continuous	Natural logarithm of number of employees)
Percentage of Internal R&D	PiR&D	Continuous	Percentage of internal R&D expense over total innovation expenditure. Total innovation expenditure includes internal R&D, external R&D, capital goods purchase, and acquisition of new technology and knowledge.

Innovation Obstacle	Inn_Obs	Ordinal	Measured as the aggregated of 11 items score over total score
Industry classification	Industry	Binary	Two digit industry classification in KSIC.

4. Results

Table 2 summarizes descriptive statistics by comparing overall manufacturing industry with the sub-samples disaggregated by environmental characteristics. In order to assure the explanations of the below descriptive statistics, we further conducted mean test to compare groups (See Appendix B). Several important points emerge from these tables. HT firms tend to concentrate on both internal and external R&D for their technological innovation activities than LT firms. In this sense, GRIs and universities with a large technological knowledge-base tend to cooperate more with HT firms than LT firms. In fact, research-intensive GRIs actively participates in technology transfer and commercialization of academic research for HT firm. For these reasons, high-tech focal firms may be motivated by government incentives and lead position for new technology. At the same time, GRIs can benefit from the collaboration with high-tech firms by exploiting technology transfer rewards, receiving government incentives, and building their reputation as an active collaborator (Siegel et al., 2003; Friedman and Silberman, 2003). Although our descriptive statistics results indicate that the unintended innovation performance related to product and process in LT is on average relatively higher than that in HT, these results are not supported in our mean tests.

Table . 2
Descriptive statistics

Variable	Overall Manufacturing	High tech		Low tech	
		Strong	Low	Strong	Low
	Mean (s.d)	Mean (s.d)	Mean (s.d)	Mean (s.d)	Mean (s.d)
Dependent					
Prod	0.10 (0.30)	0.10 (0.30)	0.09 (0.28)	0.13 (0.33)	0.11 (0.31)
Proc	0.10 (0.29)	0.06 (0.24)	0.10 (0.30)	0.09 (0.28)	0.14 (0.34)
Independent					
Coop	0.33 (0.47)	0.38(0.49)	0.35(0.48)	0.29(0.46)	0.28(0.45)
Affi	0.10 (0.29)	0.08 (0.27)	0.12 (0.32)	0.10 (0.30)	0.09 (0.28)
Supply	0.11 (0.31)	0.15 (0.35)	0.10 (0.30)	0.11 (0.30)	0.10 (0.29)
Customer	0.14 (0.34)	0.14 (0.34)	0.16 (0.37)	0.11 (0.31)	0.10 (0.30)
Comp	0.09 (0.27)	0.12 (0.32)	0.08 (0.27)	0.07 (0.26)	0.06 (0.24)
Private	0.08 (0.26)	0.09 (0.28)	0.09 (0.28)	0.07 (0.25)	0.06 (0.22)
Univ	0.12 (0.32)	0.16 (0.36)	0.13 (0.33)	0.09 (0.28)	0.08 (0.27)
GRI	0.15 (0.35)	0.18 (0.38)	0.17 (0.37)	0.09 (0.28)	0.11 (0.31)
Control					
Size	3.82 (1.19)	3.69 (1.18)	4.03 (1.22)	3.69 (1.21)	3.69 (1.06)
PiR&D	62.47 (35.14)	65.42 (33.68)	64.83 (33.82)	58.43 (35.38)	57.79 (39.06)
Inn_Obs	0.17 (0.18)	0.19 (0.19)	0.17 (0.18)	0.15 (0.17)	0.18 (0.17)
Number of obs.	986	242	374	207	163

Table 3 displays the correlations among the variables included in the analysis. The coefficients among the variables are below 0.5 with the exception of the correlation between R&D cooperation partner types. The highest correlation value (0.591) is the cooperation with customer and user firms (Customer) and supplier (Supply). In addition, the correlation between customer and user firms (Customer) and affiliation (Affi) is 0.501. These correlation coefficients reflect that the R&D collaboration induces the participation of various actors to strengthen their competitiveness (Hagedoorn et al., 2000). However, the variance inflation factors (VIF) indicate the value less than 10 which shows that multi-collinearity is not a concern.

Table . 3

Correlation matrix for variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
Prod	1												
Proc	.205**	1											
Coop	.070*	.052	1										
Affi	.099**	.041	.468**	1									
Supply	.076*	.034	.507**	.359**	1								
Customer	.118**	.061	.559**	.501**	.591**	1							
Comp	.111**	.073*	.430**	.384**	.449**	.430**	1						
Private	.039	.047	.407**	.285**	.397**	.340**	.293**	1					
Uni	.030	.061	.517**	.224**	.370**	.303**	.225**	.423**	1				
GRI	.039	.060	.583**	.371**	.302**	.397**	.234**	.279**	.354**	1			
Size	-.036	.063*	.131**	.130**	.069*	.093**	.068*	.158**	.164**	.131**	1		
PiR&D	.002	-.061	-.137**	-.069*	-.153**	-.111**	-.131**	-.072*	-.0624*	-.029	.059*	1	
Inn_Obs	.045	.054	.089**	.113**	.128**	.145**	.157**	.122**	.138**	.080*	-.097**	-.133**	1

*correlation is significant at the 0.05 level (2-tailed).

**correlation is significant at the 0.01 level (2-tailed).

N = 986.

For clear presentation of the table, dummies were excluded from the table.

Logistic regressions were estimated by (1) using all the observations and by (2) categorizing all the observations into four groups (strong appropriability in high-tech industry, weak appropriability in high-tech industry, strong appropriability in low tech industry, and low appropriability in low tech industry). The estimation results for the all firms, high-tech firms, and low-tech firms are respectively shown in table 4, table 5, and table 7. To interpret the coefficients, marginal effects at the means of the independent variables (See table 4, 5, and 7) were calculated. Specifically, the marginal effect shows how a one-unit change in the independent variable affects the probability of the respective outcome dependent variable. To further ensure the robustness of our findings, we perform several checks using propensity score matching (PSM) methodology.

Table 4 presents the results of the two models for overall manufacturing sector. This model itself reasonably fits the data, as indicated by the percentage of correction predictions. The percentages of correction prediction shows 89.8% for product oriented unintended innovation performance, and 90.4% for process oriented unintended innovation performance. Also, two models χ^2 are statistically significant, indicating that the predictor variables have statistically significant relationships with the dependent variables including the product-oriented and process-oriented unintended innovation performance. The Nagelkerke pseudo R-square is 0.101 for product-oriented unintended innovation performance and 0.104 for process-oriented unintended innovation performance. Cooperation (Coop) is statistically significant to product-oriented unintended innovation performance at the $p < 0.05$ significant level, and its marginal effect is 5%. This result indicates that the cooperation activity provides higher possibility to maximize ex-post performance, which surpasses the initial target goals related with products. For the process-oriented unintended innovation performance, the cooperation (Coop) is not statistically significant. Overall, concentrating on in-house R&D activities, overcoming innovation obstacles and taking advantage of firm size are not enough to bring about unintended success, but external R&D activity may significantly contribute to unintended product innovation performance.

Table. 4
Estimates of the binary logistic model on the unintended innovation performance

Variables	Unintended innovation performance					
	Product oriented			Process oriented		
	B	S.E	Marginal Effects	B	S.E	Marginal Effects
Coop	0.589**	0.231	0.050**	0.327	0.240	0.025
Size	-0.165	0.099		0.145	0.095	
PiR&D	0.004	0.003		-0.004	0.003	
Inn_Obs	0.582	0.554		0.876	0.570	
Constant	-21.374	19862.566		-21.536	20017.680	
Industry		Included			Included	
-2Log likelihood		606.039			544.019	
Chi-square		49.836***			49.348***	
Nagelkerke R Square		0.101			0.104	
% Classification correct		89.8%			90.4%	

Notes : n= 986
S.E.: Standard error.
*Significant at $p < 0.10$, ** Significant at $p < 0.05$, *** Significant at $p < 0.01$

Table 5 presents the effect of partner types on unintended innovation performance in product and process innovation activities of the firms in high tech industry. All of chi-square values are statistically significant to confirm the contribution of the predictors. The Nagelkerke pseudo R-square is 0.115 for process-oriented innovation under weak appropriability regime and 0.223 for process-oriented innovation under strong appropriability regime. Table 6 shows the marginal effects of the independent variables that were used in logistic regression analyses. We found that the HT firms under strong appropriability condition are more likely to achieve unintended innovation outcome through cooperation with competitors, and HT firms which cooperate with complementary resource partners have higher possibility to achieve the unintended innovation outcome under weak appropriability condition. Under strong appropriability regime, the cooperation with competitor (Comp) has the positive likelihood of product-related unintended innovation performance (p-value < 0.05) and its marginal effect is 16.6%. Under weak appropriability regime, the R&D cooperation with Customer and user firms (Customer) and university (Univ) have the positive likelihood of product-related unintended innovation performance (p-value <0.05 for Customer and user firms, p-value<0.10 for universe). The marginal effect of the R&D cooperation with customer and user firms (Customer) on product-related unintended innovation performance is 9.1 %. The marginal effect of R&D cooperation with university (Univ) on product-related unintended innovation performance is 7.5%. R&D cooperation with private service firms (Private) has lower likelihood of process-related unintended innovation performance. R&D cooperation with university has positive possibility of unintended innovation performance. R&D cooperation with private service firms decreases the likelihood of process-related unintended innovation performance at 22.4%. R&D cooperation with university increases the likelihood of process-related unintended innovation performance at 9.3%. Among the control variables used in this model, focal firms' size (Size) is significantly negative at the 5% level, which is similar to the findings of Morck and Yeung (1992). The larger a company is, the lower the probability for a firm to achieve unintended innovation outcome.

Table. 5

Results of the logistic model on the product and process oriented unintended innovation performance in high tech industry.

	Strong Appropriability Regime				Weak Appropriability Regime			
	Product oriented		Process oriented		Product oriented		Process oriented	
Variables	B	S.E	B	S.E	B	S.E	B	S.E
Cooperation with								
Affi	1.183	1.055	0.862	1.220	0.603	0.659	-0.137	0.681
Supply	0.081	0.891	-1.671	2.125	-0.225	0.795	0.392	0.709
Customer	-0.264	0.977	-1.024	1.889	1.277*	0.656	0.301	0.645
Comp	1.789**	0.742	1.118	0.889	0.567	0.785	0.338	0.665
Private	-0.658	1.044	0.989	1.275	-0.994	0.864	-2.652**	1.167
Univ	-1.704	1.124	-0.768	1.177	1.054*	0.615	1.103**	0.537
GRI	-0.209	0.819	-0.944	1.151	-0.600	0.635	0.253	0.523
Size	0.009	0.214	0.524	0.270	-0.383**	0.188	-0.060	0.159
PiR&D	0.008	0.007	0.012	0.011	0.014*	0.007	-0.012**	0.005
Inn_Obs	1.247	1.046	4.095	1.363	-0.763	1.191	-0.082	0.986
Constant	-2.672**	1.073	-7.605***	1.794	-0.832	1.229	-0.622	1.067
Industry	Included		Included		Included		Included	
-2Log likelihood	140.069		91.555		194.186		224.503	
Chi-square	20.758*		20.922*		24340**		21.286*	
Nagelkerke R Square	0.169		0.223		0.142		0.115	
% Classification correct	90.1%		93.8%		91.4%		90.1%	

Notes : n= 242(strong), 374(weak)

S.E.: Standard error.

*Significant at p < 0.10, ** Significant at p < 0.05, *** Significant at p < 0.01

Table. 6
Post-Logit calculation of marginal effects in high technology industry

			Product oriented	Process oriented
HT	Strong	Affi	0.109	0.044
		Supply	0.007	-0.085
		Customer	-0.245	-0.052
		Comp	0.166**	0.057
		Private	-0.061	0.050
		Univ	-0.158	-0.039
		GRI	-0.019	-0.048
	Weak	Affi	0.043	-0.011
		Supply	-0.016	0.033
		Customer	0.091*	0.025
		Comp	0.040	0.028
		Private	-0.071	-0.224**
		Univ	0.075*	0.093**
		GRI	-0.043	0.021

Table 7 shows that the effect of partner types on the unintended innovation performance in low-tech industry. All of the chi-square values are statistically significant to confirm the contributions of the predictors. Nagelkerke pseudo R-square is 0.214 for product-oriented innovation under strong appropriability regime and 0.304 for product-oriented innovation under weak appropriability regime. Table 8 shows the marginal effects for the firms in low-tech industry. We found that LT firms cooperating with complementary resource partners increase the possibility of unintended innovation performance under both strong and weak appropriability conditions. In strong appropriability regime, the cooperation with Customer and user firms (Customer) provides the positive likelihood of the unintended innovation performance related to product innovation at the p-value < 0.05 and its marginal effect is 20.8%. And, the cooperation with private firm (Private) has the positive likelihood of the unintended innovation performance related to process innovation at the p-value < 0.05 and its marginal effect is 17%. The firm size (Size) has statistically significant and positive effect on the possibility of the process-oriented unintended innovation performance. Under weak appropriability regime, the R&D cooperation with competitors (Comp) and GRI has the positive likelihood of the unintended innovation performance related to process innovation (p-value < 0.05 and marginal effect of 19% (competitor), p-value < 0.10 and marginal effect of 25.5% (GRI)).

Consistent with the weak appropriability regimes in high-tech industry, the lower likelihood of firm size (Size) on the product-oriented unintended innovation performance was found to be statistically significant. This shows that firm size does not contribute the unintended product innovation performance under both high and low technology industry with weak appropriability regime. In addition, firm size has higher possibility for process related unintended innovation performance under low technology industry with strong appropriability condition. Process innovation activities require such implicit knowledge as know-how, learning experience, technical skill, and modification of equipment which can affect the entire production process. As a result, there exist difficulties in accurately measuring and predicting the results of various process innovation activities (Robertson et al., 2012). In particular, since large firms tend to be already equipped with capabilities to carry out process innovation activities in a relatively efficient manner, they are more likely to pursue process innovation activities that result in unintended innovation outcome (Robertson et al., 2012).

Table . 7

Results of the logistic model on the product and process oriented unintended innovation performance in low tech industry.

	In strong Appropriability Regime				In weak Appropriability Regime			
	Product oriented		Process oriented		Product oriented		Process oriented	
Variables	B	S.E	B	S.E	B	S.E	B	S.E
Cooperation with								
Affi	-0.155	0.834	0.459	0.981	0.818	1.078	-1.920	1.596
Supply	-0.963	1.151	-0.624	1.483	0.819	1.079	-1.399	1.443
Customer	2.034**	0.864	-0.902	1.360	-0.749	1.236	-0.223	1.073
Comp	0.809	0.842	0.040	1.143	0.676	1.314	4.111**	1.841
Private	0.112	1.155	2.358**	1.065	1.635	1.058	1.815	1.282
Univ	-0.857	0.941	-0.007	0.989	0.829	1.203	0.480	1.224
GRI	0.250	0.846	0.690	0.919	1.248	1.103	2.140*	1.175
Size	0.029	0.192	0.437**	0.222	-0.770*	0.406	0.137	0.288
PiR&D	0.009	0.008	-0.003	0.009	-0.016*	0.008	-0.004	0.007
Inn_Obs	0.919	1.326	0.699	1.592	-0.437	1.887	0.118	1.518
Constant	-22.679***	19490.325	-23.246***	18760.580	-0.068	1.695	-23.468	6511.898
Industry	Included		Included		Included		Included	
-2Log likelihood	134.886		100.803		83.407		102.447	
Chi-square	25.420*		26.152*		29.850**		30.223**	
Nagelkerke R Square	0.214		0.259		0.334		0.304	
% Classification correct	87.9%		90.8%		90.2%		87.1%	

Notes : n= 207(strong), 163(weak)

S.E.: Standard error.

*Significant at p < 0.10, ** Significant at p < 0.05, *** Significant at p < 0.01

Table. 8
Post-Logit calculation of marginal effects in low tech industry.

			Product oriented	Process oriented
LT	Strong	Affi	-0.015	0.033
		Supply	-0.098	-0.045
		Customer	0.208**	-0.065
		Comp	0.082	0.002
		Private	0.011	0.170**
		Univ	-0.087	-0.000
		GRI	0.025	0.049
	Weak	Affi	0.072	-0.229
		Supply	0.072	-0.166
		Customer	-0.066	-0.026
		Comp	0.059	0.190**
		Private	0.144	0.216
		Univ	0.073	0.057
		GRI	0.110	0.255*

As a robustness check, we added the average treatment effect (ATT) tests through propensity score matching (PSM), which is widely used in numerous disciplines to deal with selection bias in non-experimental setting. (e.g. Almus and Czarnitzki, 2003; Aerts and Schmidt, 2008; Czarnitzki and LopesBento, 2013). All our robustness checks are performed on the basis of logistic regression results. We designated the focal firms as control group, if they have not cooperated with other actors. We classified the focal firms as treated group, if they have cooperated with other actors. Outcome variable was the same dependent variable used in logistic regression analysis. Covariate variables included dummy variables on R&D partner types, firm size, percentage of internal R&D, innovation obstacle, and industry dummy variables. As a matching algorithm, we implement the nearest-neighbor procedure and used up to three neighbors to build the counterfactual outcomes. The results (see Appendix C) derived from the above methodological approach are similar to our logistic regression results.

5. Discussion

The central questions of this article were: (1) whether R&D cooperation affects the focal firm's unintended innovation performance in product and process innovation activities; and (2) how partner types shape their unintended innovation performance according to external conditions. For the first question, we identified that R&D cooperation enhanced the likelihood of unintended innovation outcome related to product innovation activities in the manufacturing sector. This finding is closely related to the previous argument that R&D cooperation is critical to vitalize superior knowledge sharing in order to create abnormal profits (Dyer and Singh, 1998; Hagedoorn, 1993; Yoon and Lee, 2016). Successful product innovation is directly linked to above average profit of market performance, and thus is complex in undertaking required overall management from solving technological problem to understanding nature of market (Balachandra and Friar, 1997). Therefore, our results support the argument that R&D cooperation facilitates resource allocation and provides focal firms with opportunities to (a) overcome the limit of internal capability to purse innovation; (b) create synergies for their product innovation activities; and (c) increase the probability of unintended innovation outcome. For the second question, this paper empirically analyzed the role of sectoral technological characteristics and appropriability conditions on unintended innovation performance by dividing the sample into four groups. The answer for this question is summarized in figure 2.

Figure 2. Choosing right partners for unintended success

		Focal firms' technological environment			
		High-tech		**Low-tech**	
		Strong appropriability	**Weak appropriability**	**Strong appropriability**	**Weak appropriability**
Unintended Innovation performance	**Product innovation**	• Competitor	• Customer • University	• Customer	N/A
	Process innovation	N/A	• University	• Consulting firm	• Competitor • GRI

In high-tech industry with strong appropriability conditions, focal firms may be able to freely communicate with their competitors, thereby strengthening their R&D cooperation activities and maximizing their synergy. In this sense, among various types of partners for R&D cooperation, competitors could be the best partner for cooperation, as they may have similar problems and commonality (See Figure 2). Also, they may leverage the uncertainty risks when developing emerging and future technologies. However, since they are operating within the same market, the cooperation on emerging and future technologies may induce a fierce competition between focal firms and partnering competitors. Despite the intensive competition, focal firms can overcome the issue of potential competitions by taking advantage of strong appropriability conditions that may protect the outcomes derived from the cooperation. At the same, such competitive environment allows focal firms to create a necessity and urgency for demand articulation, and motivates companies to focus on the customer demands and the experimentation of alternatives (Kodama, 2005; Lee et al., 2006).

Under weak appropriability where focal firms may have difficulties in securing legal protections on the outcomes of cooperation, focal firms need to strengthen their appropriability conditions by having a strong strategic emphasis on the access to complementary resources from the partners (Arranz and Arroyabe, 2008). In addition, development of new technologies and accumulation of technological capabilities for breakthrough innovations should be pursued by seeking to access to complementary resources from their partners. Such focus of cooperation may help focal firms to detect hidden opportunities in cooperation which allows them to achieve above-target goals. In fact, R&D cooperation with the customer and user firms may strengthen focal firms' promptness toward the fast-changing demands in the market by strengthening the trust relationship with their customers. Such cooperation with customers from demand-side will bring about lock-in effect which will contribute to the strengthening of focal firms' appropriability condition. The focal firm may gain to acknowledge potential market needs and source new ideas and, therefore, to reduce the risk associated with market introduction of their innovation products (Belderbos et al., 2006; Bäck and Kohtamäki, 2015). Also, focal firms may be able to collaborate with universities to gain a competitive edge over their competitors in new frontier and emerging technology. Likewise, universities in industrializing and knowledge-based economy have become increasingly entrepreneurial by introducing and commercializing breakthrough research and technology for process and product innovation (Etzkowitz, 2003). In fact, technology developed by universities is a by-product of a linear model of innovation with "supply-side oriented science and technology policy" with the aim of technical superiority and creation of new emerging technologies (Etzkowitz and Brisolla, 1999; Lee and Yoon, 2015). Furthermore, the cooperation with consulting firms in such weak appropriability conditions may help focal firms to realize their current technological level along with future strategic directions. In mature low-tech industries, effective safeguards for focal firms to protect their incumbent product are essential to re-strengthen their current market position such as building barrier to market entry.

Under relatively higher appropriability conditions in low-tech industry, collaborating with customer and user firms is crucial in maximizing the probability of unintended innovation performance in product-oriented innovation activities. Accordingly, cooperation with the customer and user firms should be established to be responsive to market demands and enhance the efficiency in their process-related innovation activities for the improvement of their profitability. Also, cooperation with raw material and machinery suppliers helps focal firms to absorb embodied knowledge to enhance the learning process of their production activities (Hansen and Serin, 1997). Likewise, such demand articulation allows focal firms to convert a vague set of external needs into well-defined products (Kodama, 1992; Kodama, 1995). At the same time, consulting firms help focal firms to enhance their production efficiency, which is a part of their process-related innovation activities. In particular, previous literature emphasized the important role of private consulting firms, as they provide focal firms with managerial insight and strategic directions (Benders et al., 2008; Glückler and Armbrüster, 2003; Ruef, 2002; Werr et al., 1997). It is critical for focal firms to collaborate with such private entities as private consulting firms, so that focal firms may learn about new business process to enhance their existing business process. Also, external knowledge acquisition through engineering consultants is able to provide focal firms' with a wide range of scientific and technical expertise (del Carmen Haro-Domínguez et al., 2007). In fact, cooperation with engineering consulting firms not only provides strategic directions for focal firms, but also contributes to focal firms' technological innovation activities by offering complementary resources in specific technological domains (Tether and Tajar, 2008). Consistent with previous studies, the results of this study show that consulting firms contribute to process-oriented innovation activities in low technology industry. Compared to the limited role of consultants for the focal firms in high-tech industry, the focal firms in low-tech industry could reap significant benefits from their consultants, as the focal firms in low-tech industry show their intrinsic weakness derived from their smaller technology base.

Mature resource-oriented firms constitute a large portion of the low-tech firms operating under weak appropriability conditions where the environment does not require focal firms to solely focus on technological innovation. As a result, the firms have strong interest in improving their efficiency for the enhancement of process-related innovation activities by adopting some high-technology components or new practices to achieve some unexpected breakthrough in the manufacturing of certain components and production processes. As a result, the focal firms may be able to improve their process operation, cost and efficiency (Porter and Linde, 1995). Process and efficiency-oriented activities have been key drivers for innovation in the low-tech and process industries for decades. Such results may be achieved by collaborating with government research institutes, as the institutes are quite concerned with the improvement of firms' process innovation activities (Yoon and Lee, 2013). In particular, as the firms in such industry have less motivation for technological innovation, collaborating with government research institutes to improve their cost structure may be a good option for focal firms. With relatively lower technological level of the industry, absorptive capacity may play a greater role. In this sense, understanding similar resources possessed by the counterparts is important for focal firms to keep track of enhancement and changes in process-oriented innovation activities. As such, the cooperation with competitors leaves some rooms for focal firms to capture a small piece of ideas and knowledge from their partnering actors which may result in unintended innovation performance. Above all, collaborating for innovative outcomes are not restricted to the high-tech firms, as technological innovation seems to be a general concern for many industries including mature industries that do not require much technologically sophisticated knowledge (Zhao, 2009).

6. Conclusion

Previous studies using extended resource-based view have dealt with various research issues on R&D cooperation that were not fully covered by resource-based view. However, such existing empirical studies adopting extended resource-based view have not integrated the notion of unintended innovation performance. In addition, although the notion of unintended innovation performance has been applied at to explain the accidental innovation by individual scientists (Simonton, 2004), such notion has not been applied to the context of inter-organizational learning. With this in mind, this study contributes to the extended resource-based view and inter-organizational learning literature by investigating the determinants of unintended abnormal performance.

As for managerial implication, R&D cooperation entails significant uncertainty, as focal firms lose the controllability over managing their resources. As a result, such uncertainty increases the probability of failure in R&D cooperation and decreases the probability of creating potential future benefits. However, our study results show that the selection of right partners by considering external environment can bring surprising and unintended success to focal firms in R&D cooperation. Whereas previous studies have addressed how R&D cooperation helps firms to achieve their intended goals, we focused on how unintended success or unpredictable outcomes are shaped by R&D cooperation. As witnessed from the effect of R&D cooperation on unintended innovation, access to complementary resources that are outside the organizational boundary helps focal firms to achieve unintended success in their innovation activities. In this sense, our result highlights the importance of removing the not-invented here syndrome, which represents the resistance of focal firms toward their partners in R&D cooperation. Policy to facilitate sharing of ideas (e.g. intellectual property protection mechanism) among a number of innovation actors (firms, suppliers, universities, competitors, etc.) should be implemented. Lastly, the results in our study may provide directions to policy makers on how to do match-making between firms and other innovation actors, in order to make best use of resources and capabilities and create synergies.

In addition, this study provides policy makers with a new perspective that not only competition is important, but also cooperation via coexistence is critical. Our empirical results showed that there is a higher probability for focal firms in high-tech industry and strong appropriate regime to achieve unintended innovation performance when they collaborate with their competitors. High-tech industry where technology is rapidly changing and competition is becoming more intense makes firms to concentrate on efficient utilization of resources to achieve competitive advantage. Thus, strengthening of appropriability regime could be realized by enhancing intellectual property right system, as it promotes the knowledge sharing among the firms within the same industry, and bring about unintended innovation outcome, which could be derived from appropriated relational rents and inbound spillover rents that are inherent to similar resources. Lastly, the role of universities and government research institutes as scientific knowledge providers in achieving breakthrough innovations should be highlighted. In particular, universities and government research institutes not only enhance the competitiveness of firms in high-tech industry, but also to those of low-tech industry. Such approach is based on the synergies created in a long-term manner with complementary resources. Especially the firms in mature industries that are growing slowly should consider collaborating with such scientific knowledge-based providers and advisor as universities and government research institutes.

The findings and implications presented in this study are beneficial to understand effects of different partner types and environmental conditions on unintended innovation performance in R&D cooperation. However, several limitations remain. Firstly, due to the lack of quantitative data on micro-level of R&D cooperation, this study could not address whether previous experience may have induced firms to increase their expectations, which may have effect on unintended innovation performance. In other words, it is worthwhile to investigate the role of firms' historical experience in shaping their expectation on unintended outcomes that are derived from selection of the partners. Also, opportunistic behavior in cooperation could be an important proxy variable to figure out whether unintended outcome was driven from coincidence or planning. Furthermore, the approach of this study to shed light on the unintended innovation performance has important implications for the scholars investigating open innovation. Most of the existing studies on open innovation focus on whether openness of a focal firm has a positive effect on focal firms' innovation performance or not. However, the studies do not address whether the focal firms' innovation performance was intended or not. In this sense, future studies could be replicated by applying the notion of unintended innovation performance in open innovation context. Secondly, since the unintended outcome itself is related to uncertainty, there is a need to further investigate the role of uncertainty in innovation. The majority of innovation management studies focus on how to reduce uncertainty. However, from our study, we showed that such uncertainty may be used as opportunities to achieve unexpected and unintended breakthroughs. Lastly, the survey data used in this study consists of the firms that have been carrying out innovation activities during a certain period. Future studies should be replicated by using a panel data to investigate how complementarity or persistence between innovation actors shapes focal firms' unintended innovation performance. This may provide a number of implications from the perspective of firms' accumulated capability (Martínez-Ros and Labeaga, 2009). Future studies should collect and use a large amount of sample in time series and in multiple cross-country settings to improve the robustness of the analyses results and draw more generalizable conclusions.

Appendix A. Industry classification according to technological intensity and appropriability regimes.

Technological intensity	Appropriability regimes	Industry	Appropriability Score
HT	Strong[a]	Manufacturing of Pharmaceuticals, Medicinal Chemicals and Botanical Products	0.449477
		Manufacturing of Medical, Precision and Optical Instruments, Watches and Clocks	0.233665
		Manufacturing of chemicals and chemical products except pharmaceuticals and medicinal chemicals	0.316839
		Manufacturing of electrical equipment	0.271111
	Weak[a]	Manufacturing of Other Machinery and Equipment	0.214547
		Manufacturing of Electronic Components, Computer, Radio, Television and Communication Equipment and Apparatuses	0.193233
		Manufacturing of Motor Vehicles, Trailers and Semitrailers	0.100680
		Manufacturing of Other Transport Equipment	0.088803
LT	Strong[b]	Manufacturing of Furniture	0.224867
		Other manufacturing	0.146718
		Manufacturing of Beverages	0.203007
		Manufacturing of Wood and of Products of Wood and Cork ; Except Furniture	0.103174
		Manufacturing of Fabricated Metal Products, Except Machinery and Furniture	0.110599
		Manufacturing of Food Products	0.107281
		Manufacturing of Other Non-metallic Mineral Products	0.104489
	Weak[b]	Tanning and Dressing of Leather , Manufacturing of Luggage and Footwear	0.100000
		Manufacturing of Textiles, Except Apparel	0.099912
		Manufacturing of Basic Metal Products	0.098845
		Manufacturing of Rubber and Plastic Products	0.073865
		Manufacturing of Pulp, Paper and Paper Products	0.065668
		Manufacturing of wearing apparel, Clothing Accessories and Fur Articles	0.045068
		Printing and Reproduction of Recorded Media	0.036796
		Manufacturing of coke, hard-coal and lignite fuel briquettes and Refined Petroleum Products	0.091836

[a] If appropriability score at industry level is higher than median value in high technology group, the industry belongs to strong appropriability condition, otherwise low appropriability condition (median value is 0.224710).
[b] If appropriability score at industry level is higher than median value in low technology group, the industry belongs to strong appropriability condition, otherwise low appropriability condition (median value is 0.100000)

Appendix B. Mean differences according to appropriability regimes and technological intensity of industries

Variables	Strength of appropriability regimes				Technological intensity of industries			
	Mean difference between HT and LT in strong appropriability industries		Mean difference between HT and LT in weak appropriability industries		Mean difference between strong and weak in high tech industries		Mean difference between strong and weak in low tech industries	
	$Mean_{HT} - Mean_{LT}$	t-value	$Mean_{HT} - Mean_{LT}$	t-value	$Mean_{strong} - Mean_{weak}$	t-value	$Mean_{strong} - Mean_{weak}$	t-value
Prod	-.02713	.894	-.02487	.870	.01774	-.741	.02001	-.583
Proc	-.02980	1.189	-.03950	1.254	-.03962	1.797^{*}	-.04932	1.485
Coop	.08961	1.998^{*}	.07419	-1.728^{*}	.03403	.392	.01861	.695
Affi	-.02294	.849	.03176	-1.15	-.03913	.118	.01556	-.507
Supply	.04248	-1.338	.00612	-.217	.04448	.111	.00812	-.255
Customer	.02525	-.806	.05881	-1.915	-.02674	.361	.00682	.209
Comp	.04324	-1.553	.02154	-.911	.03281	.191	.01111	-.422
Private	.01914	-.753	.03035	-1.316	.00122	.958	.01242	-.490
Univ	.06524	-2.075^{**}	.04591	-1.679^{*}	.03136	.281	.01203	-.408
GRI	.08590	-2.645^{***}	.06069	-1.932^{*}	.00656	.834	-.01864	.592
Size	-.00580	.051	.34346	-3.288^{***}	-.34492	3.485^{***}	.00434	-.036
PiR&D	6.99154	-2.142^{*}	7.03479	1.996^{**}	.59528	-.214	.63854	-.163
Inn_Obs	.04298	-2.387^{*}	-.01055	.619	.02026	-1.272	-.03328	1.782^{*}

*** $p < 0.001$ ** $p < 0.02$ * $p < 0.1$

Appendix C. Results of average treatment effect

Group	Outcome	Treatment	Treated	Controls	Difference	S.E.	T-stat
HT-strong	Product-oriented	Comp	.666	0	.666**	.333	2.00
HT-weak	Product-oriented	Customer	.180	.065	.114*	.059	1.94
		Univ	.148	.076	.072*	.043	1.66
	Process-oriented	Private	.031	.243	-.211***	.080	-2.62
		Univ	.375	0	.375**	.182	2.05
LT-strong	Product-oriented	Customer	.347	0	.347***	.101	3.43
	Process-oriented	Private	.357	0	.357***	.132	2.69
LT-weak	Process-oriented	Comp	.400	0	.400**	.163	2.45
		GRI	.277	.077	.200*	.124	1.77

* Denotes significance at the 10% level

** Denotes significance at the 5% level

*** Denotes significance at the 1% level

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