Beyond absorptive capacity in open innovation process: the relationships between openness, capacities and firm performance

Abstract

The literature has shown that open innovation (OI) can be a winning strategy in improving firm performance. However, in order to adopt and implement it, managers need to resolve practical problems, such as understanding the role played by OI capacities and openness on firm performance. In response to these needs, this study aims to investigate the hierarchical relationships between openness, OI capacities and performance using a structural equation model (SEM) approach. This paper also attempts to compare the levels of openness between firms in different industries to discover similarities and differences in OI phenomena. The analysis of data obtained from a survey of Korean firms shows significant interrelations between openness, OI capacities and firm performance. Our results go further in developing understanding of the building blocks on which successful OI is built and particularly suggest that desorptive capacity which underpins the out-bound OI process, is in turn strongly supported by knowledge management capacity. It is hoped that the results of this study can enrich our understanding of the OI mechanism and provide managerial and policy implications.

***Keywords*:** Open Innovation (OI), firm performance, structural equation model, Korea.

1. Introduction

Open Innovation (OI), the term coined by Chesbrough (2003), has become a widespread business strategy across many industries (Gassmann et al., 2010, Mortara and Minshall, 2011, West et al., 2014). Early case studies (e.g., Dyer et al., 2004, Huston and Sakkab, 2007) have shown how this emergent innovation strategy can be applied in practice, and recent quantitative analyses based on large data sets have shown evidence of significant interrelationships between OI and firm performance (e.g., Kim and Park, 2010, Mazzola et al., 2012, Roper et al., 2013, Podmetina et al., 2014, Schroll and Mild, 2012).

However, the specific mechanism underpinning OI has remained largely unexplored. Although some researchers have investigated how organisational (e.g., internal R&D) and external factors (e.g., public policy and market turbulence) are associated with OI (Dahlander and Gann, 2010), little attention has been paid to the inter-play between the different capacities necessary for managing knowledge in the OI process (Robertson et al., 2012, Brunswicker and van de Vrande, 2014). In the literature, various knowledge exploration and exploitation capacities have been mentioned - including, ‘search’ (or ‘accessive’) (Laursen and Salter, 2004, Fontana et al., 2006, Lichtenthaler and Lichtenthaler, 2009, Spithoven et al., 2011, Robertson et al., 2012), ‘desorptive (or signalling)’ (Spence, 2002, Fontana et al., 2006, Lichtenthaler and Lichtenthaler, 2009, Robertson et al., 2012) and ‘integrating’ capacities (Chiaroni et al., 2009, Lichtenthaler and Lichtenthaler, 2009, Mortara et al., 2012, Robertson et al., 2012, West and Bogers, 2014).. However, the understanding of these OI related capacities is so far fragmented and incomplete. Until now, both search and integrative capacity as competences underpinning the broader 'absorptive capacity' (Cohen and Levinthal, 1990) have been actively investigated in the context of in-bound OI. However, other capacities related to out-bound or coupled OI have been given little attention (Brunswicker and van de Vrande, 2014). Second, OI studies which attempted to apply capacity frameworks have remained mostly at a theoretical level. Lichtenthaler and Lichtenthaler (2009) and Robertson et al. (2012) indicated that other capacities, such as ‘integrative’ and ‘desorptive’, complement 'absorptive' capacities in the implementation of OI, but the validity of these theoretical suggestions have rarely examined in empirical studies.

Third, it is not yet clear how these OI related capacities are linked with each other. As noted by Robertson et al. (2012) and Brunswicker and van de Vrande (2014), who asserted that a higher order of capacity for managing other more basic OI capacities (or sub-capacities) may play an important role in OI implementation. However, there have been few attempts to understand possible interrelationships between subordinate OI capacities or quantify a higher order capacity. Last, the linkage between OI capacities and firm performance is not clear: for example, what is the most important capacity? This understanding could be highly important, particularly for managers. After recognising the influence of OI capacities, they will be able to adequately reallocate resources in their organisations to improve performance.

To address these research gaps, this paper attempts to explore the mechanisms underpinning the OI process by establishing a hierarchical model encompassing firms' openness, capacities and firm performance, and tests it using the partial least square (PLS) structural equation model (SEM). The study also attempts to discuss differences between firms in different industries using our proposed, a high order OI capacity, ‘Openness Indices'.

The remainder of this paper comprises five sections. In the next section, relevant literature on OI and related capabilities are reviewed. A hypothesized SEM is proposed in section 3, and section 4 describes data and methodology. Section 5 presents the results of the analysis and hypotheses tests, and a discussion of the results. Limitations and future research areas are suggested in the final section of the paper.

2. Research Background

2.1 Open innovation process and related capacities

OI is defined as "the use of both purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for the external use of innovation" (Chesbrough et al., 2006, p1). Firms can benefit in a variety of ways from opening up their boundaries: for example, they can exploit the complementary assets of their partners, maximize income by selling unused intellectual properties (IP), save on the time and costs for developing innovation, attract potential customers by involving

them in the production process, and establish new technology standards by forming partnerships (Dahlander and Gann, 2010, Vanhaverbeke and Cloodt, 2014, West et al., 2014). As OI stresses the flow of information through permeable boundaries, different capacities are required in OI's three process of knowledge flow: 1) in-bound process when knowledge flows into the firm from the outside, 2) out-bound process when internal knowledge flows outside, or 3) coupled process when both in- and out-bound process occur at the same time (Gassmann and Enkel, 2004, Enkel et al., 2009).

In the in-bound process knowledge is acquired from a number of external sources, such as suppliers, customers, competitors and universities to complement internal innovation resources (Chesbrough and Crowther, 2006, Enkel et al., 2009). However, to benefit from external knowledge and engage in the knowledge acquisition process, firms first have to develop their 'absorptive capacity' (Cohen and Levinthal, 1990, Laursen and Salter, 2006). Arbussa and Coenders (2007) paraphrased a firm's absorptive capacity as the capability to scan the external environment for new technology and the capability to integrate new external knowledge into its innovation process. In this regard, sub-capacities, such as 'search' and 'integrative' capacity play important roles in the in-bound process (Arora and Gambardella, 1994, Mortara et al., 2012, Robertson et al., 2012, West and Bogers, 2014). Search capacity can be defined as a general ability to look for potential valuable sources of information (Spence, 2002, Arbussa and Coenders, 2007), and it helps firms to identify appropriate information from broad external sources. Firms might set up intelligence systems and activities for this purpose as happened at Kodak (Mortara et al., 2010). Integrative capacity refers to the ability that incorporates the relevant external knowledge into the innovation process (Lichtenthaler and Lichtenthaler, 2009, Robertson et al., 2012), and thereby it helps digesting external knowledge and to transform it into new knowledge. These two sub-capacities establish the absorptive capacity.

The out-bound OI process aims to exploit internal knowledge in a variety of ways both in current markets and in innovative new markets (Van Der Meer, 2007, Mortara and Minshall, 2014). In the out-bound OI process, firms with strong 'desorptive capacity' voluntarily disclose knowledge to less informed economic agents (Spence, 2002, Penin, 2005, Lichtenthaler and Lichtenthaler, 2009). Firms often reveal important

pieces of knowledge voluntarily through scientific publications, conferences, patents and the Internet. There are many reasons for doing so, such as to gain feedback from suppliers and users, to expand networks, reputation and business opportunities and to increase higher order knowledge (Penin, 2005). By ‘signaling’ their technical and scientific capability, firms can attract potential partners and establish new opportunities for collaboration. Panagopoulos (2003) suggested that firms are more likely to collaborate with external partners if some minimal level of knowledge protection is guaranteed.

Lastly, in coupled OI processes, knowledge can flow both inwardly and outwardly (Gassmann and Enkel, 2004, Enkel et al., 2009). As knowledge moves in and out simultaneously, it is very important to manage the knowledge flow, inspecting and following up on what external knowledge has been acquired and what internal knowledge has been signalled externally. This systematic management of knowledge not only enables firms to deal with ambi-directional knowledge flow efficiently (Ahn et al., 2013), but can also help them to implement other capacities related to in-bound and out-bound OI. In this regard, we argue that a firm's knowledge management capacity, which not only mediates openness and performance but also affects 'search' (in-bound OI) and 'desorptive' capacity (out-bound OI), is a key factor in coupled OI.

2.2 Openness and firm performance

Research has shown a significant relationship between openness and firm performance. Laursen and Salter's (2006) seminal paper employed a search as a proxy variable for openness by introducing the 'breadth of search' and 'depth of search' concepts as two distinctive measures of openness. Their study showed that external search and linkages with external partners are positively associated with sales of new or improved products. Their approach has been developed further in many subsequent studies. For example, Chiang and Hung (2010) showed that search breadth can affect incremental innovation whilst depth influences radical innovation. Chen et al. (2011) also found a significant association between a greater innovation scope and depth and innovation performance.

In literature several types of openness have also been investigated. Kim and Park (2010) investigated the effect of external R&D and found its significant influence on innovation output. Faems et al. (2010) investigated 'technology alliance portfolio diversity' and found its positive association with product and financial innovation performance. Parida et al. (2012) showed that 'technology sourcing' is positively associated with radical innovation performance whist 'technology scouting' is associated with incremental innovation. There was also an attempt to investigate the direct effect of OI adoption without the use of openness proxy variables. For example, Mazzola et al. (2012) examined twelve different in-bound, coupled and out-bound OI modes and found that their influence on firm performance can be both positive and negative.

Prior work has revealed some empirical evidence of the advantages of OI strategies, but it has also revealed that the implementation of OI does not automatically imply improved firm performance (Cheng and Huizingh, 2014). Indirect OI measures have been often adopted and showed relatively clearly their impact on firm performance. Amongst these, the most widely adopted are that involving the ‘breadth’ and ‘depth’ of OI, which respectively describe the intensity of external information source and their variety (Laursen and Salter, 2006). Some other direct measures, such as external R&D investment (Kim and Park, 2010) and the adoption of any individual OI activity (Mazzola et al., 2012), did not show such consistency. The contradictory results available to date may originate from some difficulties in identifying appropriate metrics for OI (Podmetina et al., 2014, West et al., 2014) and the complexities involved in the implementation of OI throughout the firm (Dahlander and Gann, 2010). The use of directly measured variables may increase reliability and reproducibility of the results. However, it is not easy for researchers to clearly separate the effect of OI from the firm's entire innovation process. Since various external factors (e.g., public policy and regulation) on top of internal conditions (e.g. internal R&D, culture etc.) can simultaneously affect the adoption OI, direct variables may only result in a partial account of reality. This implies that indirectly measure may be better suited to identify how each innovation process can affect firm performance.

3. Research foundation

3.1 Hypotheses

Based on the literature review, this paper attempts to analyse the hierarchical relationships between latent variables in the OI process: i.e., openness, OI capacities and firm performance. We construct a model (see Figure 1) consisting of the following three 'blocks':

(1) Openness: the propensity of the firm to implement OI practices

(2) OI related capacities: search and integrative[1] (in-bound OI), knowledge management (coupled OI) and desorptive (out-bound OI)

(3) Firm performance

Our research model assumes that the variables in each block are hierarchically interrelated. The logic behind this assumption can be explained as follows. First, a firm's degree of openness can affect its establishment of OI capacities, in the sense that innovation strategy is dependent upon its attitude towards innovation. According to the theory of reasoned action, "attitude towards an object is viewed as related to intention to perform a variety of behaviours with respect to that object" (Fishbein and Ajzen, 1975, p14). In this regard, a firm that has already established a positive attitude towards OI will be more likely to have well developed OI capacities. Hence:

H1) A firm's openness is positively associated with open innovation capacities.

Second, capacities in the OI process can be interrelated. In in-bound OI, after acquiring the necessary external information, a firm needs to integrate it with internal information to generate a higher level of knowledge that will be used for internal innovation. Hence, we hypothesise that 'search' capacity influences 'integrative' capacity.

H2) 'Search' capacity is positively associated with 'integrative' capacity.

Also, as the knowledge flow is a key factor in OI implementation, effective knowledge management will influence both search (in-bound) and desorptive (out-bound) capacity.

[1] We suggest that an absorptive capacity is a high order capacity encompassing search and integrative capacity.

By checking knowledge flow thoroughly a firm can identify what knowledge is insufficient (so is to be complemented) and which knowledge has to be shared and which maintain internally. Hence:

H3) 'Knowledge management' capacity is positively associated with search and desorptive capacity.

Lastly, the capacities which by proxy represent the different OI processes will influence firm performance. 'Search' and 'integrative' capacity enable firms to increase the stockpile of knowledge and to exploit specialised external information by accessing complementary assets (Levinthal and March, 1993, Teece et al., 1997), and this in turn will improve performance (Berchicci, 2013). Also, 'desorptive' capacity (i.e. exposing internal knowledge and making it ready to external partners) not only enables firms to crystalize their internal knowledge (Penin, 2005), but also provides firms with additional income by exploiting unused IPs (Chesbrough, 2003, Laursen and Salter, 2014). Further, as 'knowledge management' can affect both 'search' and 'desorptive', it may influence performance directly and indirectly via these two capacities. We employ an overall firm performance, in the sense that openness can affect every aspect of a firm's strategy and innovation. Hence:

H4) Each OI capacity positively contributes to firm performance enhancement.

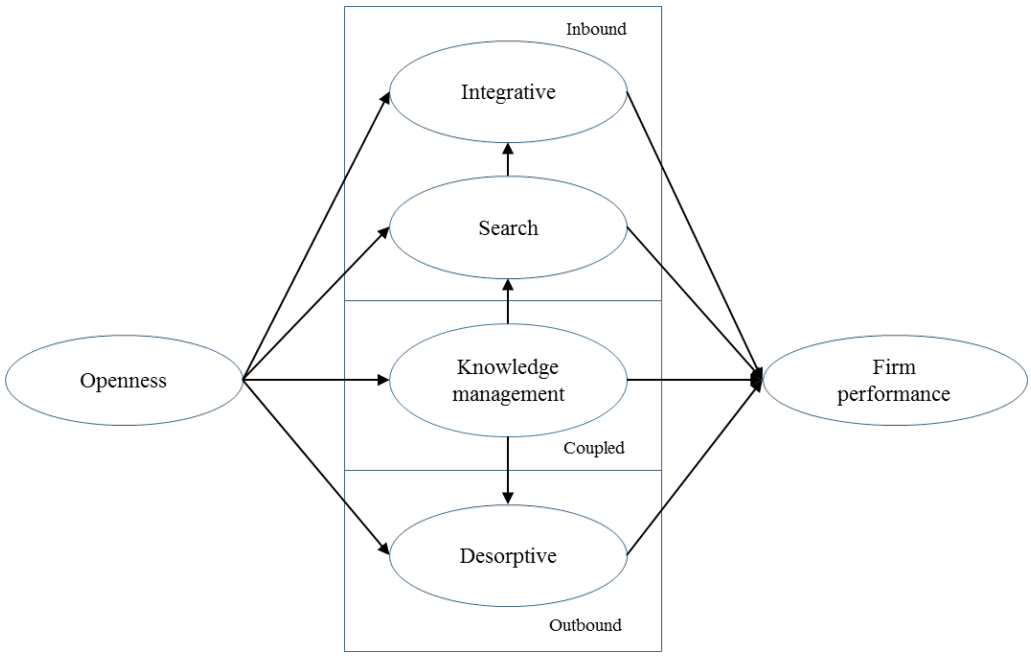


Figure 1 The research model

3.2 Variable measurement

Since the variables in the research model are latent ones, they were measured using multiple manifest variables (see Appendix for the summary of questions). The firm's degree of openness was defined as 'the propensity of a firm for implementing OI' and measured by 1) the inclination towards establishing collaboration with external parties over a totally self-managed innovation, 2) the inclination towards sharing knowledge with the external world, 3) top managers' inclination towards finding external contributors to innovation, and 4) the level of trust between parties.

Capacities and firm performance were also measured by multiple manifest variables. 'Search capacity' was measured in terms of the relationship of the firm with seven sources of information: other organisations, markets, media, trade fair/conference and others. It was measured based on the variety of technology-intelligence activities carried out by a firm such as participation in trade fairs and conferences, analyses of competitors' products/technology, and searches for the availability of external technology before internal technology development. 'Integrative capacity' was measured in terms of two proxy variables: the degree of external technology playing a key role in the company's product development and the degree of external technology applied to various parts in internal R&D. 'Knowledge management capacity' was measured in terms of the management of the R&D outputs: allocated responsibilities for managing the innovation results, availability of systematic tools for managing innovation results, and provision of regular training for managing results. 'Desorptive capacity' was measured in terms of the use of the following activities to voluntarily disclose knowledge: publishing in business/academic journals, exposure of internal knowledge to the outer world via participation in conferences/meetings/trade associations, listing patents domestically/internationally, and listing internally developed knowledge in technology transfer centres/institutes.

Finally, we measured firm performance using various indicators, including strategic, financial and technological performance, such as achievement of business strategic purpose, an increase in organisational learning, an increase in total revenue, a

decrease of development cost, an increase of operating profits, an increase in technological level, an increase of export and an increase in the degree of in-house development. The definitions of each factor, its selected measurement variables and its related references are summarised in Table 1.

Table 1 Definition of each factor and measurement variables

Factor	Definition	Measurement Variables	Reference
Openness	Propensity of a firm for purposive inflows and outflows of knowledge	· Readiness to collaborate · Readiness to share experience · Top manager's willingness to collaborate · Trust external parties	(Chesbrough et al., 2006, Minshall et al., 2010)
Search capacity	A general attitude of looking at potential valuable sources of information	· Importance of University channel · Importance of Institutional channel · Importance of Market channel · Importance of Specialized channel · Importance of human networks · Searching the patent and journal database · Attending trade fairs and conferences	(Laursen and Salter, 2004, Fontana et al., 2006, Arbussa and Coenders, 2007)
Integrative capacity	Embedding external knowledge into internal innovation process	· Embedding external knowledge as a core role · Applied to various parts in R&D	(Bougrain and Haudeville, 2002, Lichtenthaler and Lichtenthaler, 2009, Robertson et al., 2012)
Knowledge management capacity	Inspecting knowledge outflow (or managing the results of internal innovation)	· Securing of dedicated staff for effective technology management · System introduced for effective technology management · Regular training of dedicated staff for system introduced	(Cohen et al., 2002, Chesbrough et al., 2006)
Desorptive capacity	Activity carried out by firms aimed at voluntarily disclosing knowledge	· Business/ academic publications · Conferences/ meetings/ trade associations · Patents listed in domestically and internationally · Technologies listed at technology transfer center/ institute	(Spence, 2002, Fontana et al., 2006, Lichtenthaler and Lichtenthaler, 2009, Ahn et al., 2013)
Firm Performance	General firm performance	· The achievement of business strategic purpose · Increase in organisational learning · Increase in total revenue · Decrease in development cost · Increase in operating profits · Increase in technological level (engineer's ability and experience) · Increase in export · Increase in localizing of technology (the degree of in-house development)	(Van de Vrande et al., 2009, Mazzola et al., 2012)

4. Data and Method

4.1 Data

In order to examine our hypotheses, we have carried out a survey of Korean firms. The survey included questions on the industrial sector, the role of the respondents within the firms and questions directed to evaluate variables proposed in Table 1, measured on a five-point Likert scale, where higher numbers represent better performance or greater significance.

The survey was distributed to 508 companies, of which 258 firms got funds for R&D from Korean government in the last 5 years. Across our sample, 250 organisations are listed by the Economy Research Institute which has the highest reputation in Korea. The survey was completed by staff from different levels in the organisations (i.e. managers and researchers). Feedback on the results was offered as an incentive for the participation. 66 questionnaires have been returned (13%). The descriptive statistics are summarized in Table 2 and Table 3. Since each respondent could select more than one industrial sector, the number of responses relative to the sector classification is higher than that of the responses received. For instance, the responses of those who selected three sectors of company activities were used as three cases, each case coded as a different industry. Of the responses, 32 (48.48%) were from large firms, 24 (36.36%) from medium sized firms, and 10 (15.15%) from small firms. 19 organizations (28.79% of total respondents) were listed in the KOSPI (Korea Composite Stock Price Index) market, 15 (22.763%) in the KOSDAQ (Korea Securities Dealers Automated Quotations) market, and 19 (28.79%) did not reveal their ownership status. Most large companies in Korea have been listed in KOSPI market and firms with high technology have usually been listed in KOSDAQ which are similar to Dow Jones and NASDAQ in the USA. Among the firms which are not listed in stock market lists, 28.79% of the firms received venture company certificate and 6.06% received innovative SME certificate (Inno-biz) by the government whilst other 28.79% did not reveal their status. Regarding respondents, 5 (7.58%) were of managerial level (i.e. CEO, CTO, CFO, other executive managers), 58 (87.88%) of researcher level, and 1 (1.15%) was unidentified.

Table 2 Summary statistics of respondents

Firm size Cases (Freq.)		Stock listing Cases (Freq., Multiple choice)		Respondents Cases (Freq.)	
Large firms	32(48.48%)	KOSPI	19(28.79%)	Manager	5(7.58%)
Medium sized firms	24(36.36%)	KOSDAQ	15(22.73%)	Research	58(87.88%)
Small firm	10(15.15%)	Venture company	19(28.79%)	Others	2(3.03%)
-	-	Inno-biz	4(6.06%)	No response	1(1.15%)
-	-	No response	19(28.79%)	-	-
Total	66	Total	76	Total	66

Table 3 Frequency of industrial sectors in the observed sample (Multiple choice)

Industry sector	No (Freq.)	**Industry sector**	No (Freq.)
Biotechnology	10(15.15%)	IT Services	5(7.58%)
Medical Devices/Equipment	6(9.09%)	Computers/Peripherals	4(6.06%)
Healthcare Services	10(15.15%)	Telecommunication	5(7.58%)
Retailing/Distribution	2(3.03%)	Networking/Equipment	19(28.79%)
Business Products/ Services	4(6.06%)	Software	16(24.24%)
Electronics/instrumentation	2(3.03%)	Industrial/Energy	16(24.24%)
Financial Services	4(6.06%)	Media/Entertainment	6(9.09%)
Others	11(16.67%)		
Total			120

4.2 Statistical techniques

The structural equation model (SEM) has been generally used as an appropriate technique for testing a theory about the relationships between various latent factors (Bollen and Long, 1993, Zeng et al., 2010). SEM allows the estimation of both direct and indirect effects among factors. Further, we can obtain indices of individual groups based on the factor score obtained from segmented groups (Sohn and Mok, 2008).

We adopted a PLS (partial least square) method to estimate the parameters of the proposed SEM. We preferred PLS over the maximum likelihood (ML) approach which

is frequently used as an estimation procedure for SEM (Fornell and Bookstein, 1982, Fornell, 1992, Sohn and Moon, 2003). This is because ML has weak points, in the sense that it needs the assumptions of multivariate normality, interval scaling, and large sample sizes, while PLS does not require such assumptions (Fornell and Bookstein, 1982, Fornell, 1992, Sohn and Moon, 2003).

Before analysing SEM, confirmatory factor analysis (CFA) has to be conducted for the purpose of validating the relationships between defined measurement variables and the factors (Anderson and Gerbing, 1988). Further, in order to compare the level of openness according the nature of firms; we suggest indices for each factor. For example, firm performance factor was related to the eight measurement variables in the context of SEM, as shown in Figure 2.

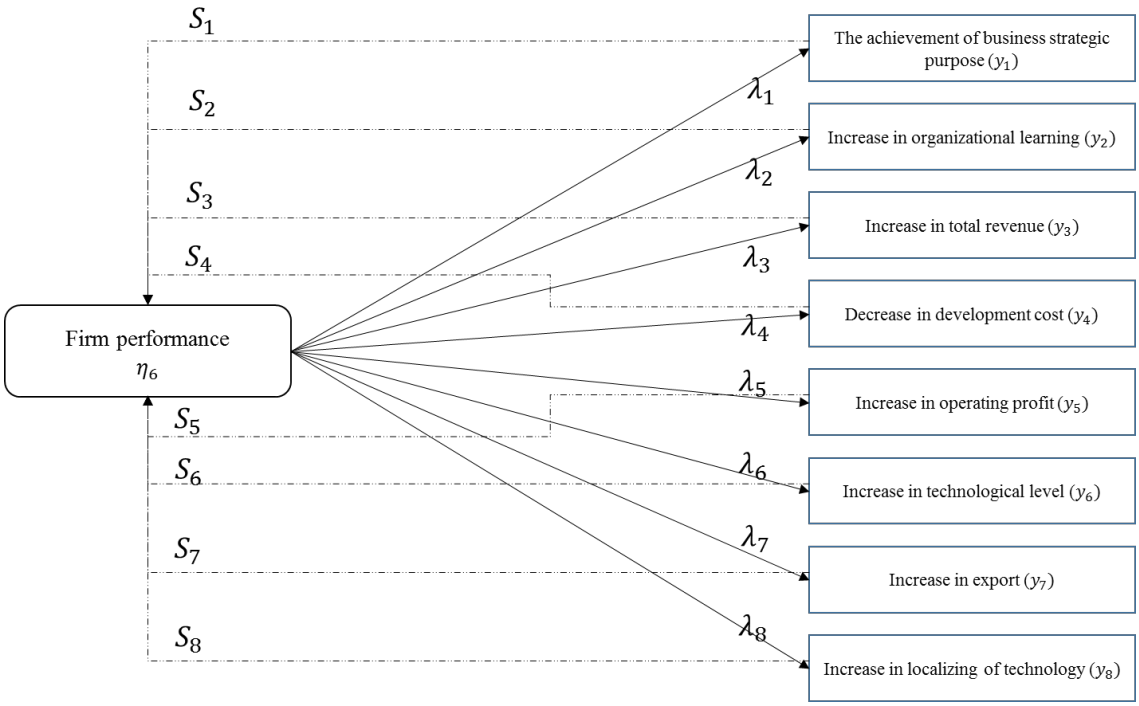


Figure 2 The concept of index: An example of firm performance

Here S_j means the regression score and λ_j indicates the loading value. The relationship between firm performance and the eight observed measurement variables for individual respondent can be formulated as:

$$\eta_6 = s_1 \times y_{1i} + s_2 \times y_{2i} + s_3 \times y_{3i} + s_4 \times y_{4i} + s_5 \times y_{5i} + \ldots + s_8 \times y_{8i} \quad (1)$$

(where, η_6 is the latent variable (Firm performance), and s_j is the regression score in the PLS procedure.)

In order to find a scaled index varying from 0 to 100, the following formula can be used:

$$\text{Index} = \frac{\text{E}(\eta_i) - \min(\eta_i)}{\max(\eta_i) - \min(\eta_i)} \times 100 \quad (2)$$

Where $\text{E}(\eta_i)$ is the expected η_i of individual respondent, and $\max(\eta_i)$ and $\min(\eta_i)$ indicate the expected maximum and maximum value of the latent variable, respectively. Using the formula (2), we are not only able to calculate the index of a specific factor but also able to compare the levels of each factor between different firm groups (Lee et al., 2007, Sohn and Jung, 2010, Sohn and Kim, 2010).

5. Results

5.1 Construct test results

In order to test the relationship between each factor and its measurement variables, CFA based on Cronbach's alpha value (Hair et al., 2010) were conducted. When checking loading value, 'importance of university channel', 'importance of specialized channel', 'importance of others channel', and 'searching the patent and journal database' have low value (i.e., lower than 0.5), thus we remove these measurement variables to increase convergent validity (Bagozzi and Yi, 1988). Detailed information of CFA is shown in Table 4. In Table 4, the Cronbach's alpha values for all latent factors are higher than 0.80, which represent the reliabilities of the relationship between the measurement variables and associated factor.

Table 4 The Results of Confirmatory Factor Analysis

Latent Factors	Measurement Variables	First estimation		Second estimation	
		Loading value	Alpha	Loading value	Alpha
Openness	· Readiness to collaborate	0.8853	0.882	0.8899	0.882
	· Readiness to share experience	0.9178		0.9218	
	· Top manager's willingness to collaborate	0.6744		0.6806	
	· Trust external parties	0.6665		0.6524	
Search capacity	· *Importance of University channel*	0.2838	0.737	-	0.798
	· Importance of Institutional channel	0.6461		0.9563	
	· Importance of Market channel	0.8733		0.9686	
	· *Importance of Specialized channel*	0.4224		-	
	· *Importance of human networks*	0.2341		-	
	· *Searching the patent and journal database*	0.5157		-	
	· Attending trade fairs and conferences	0.8733		0.9154	
Integrative capacity	· Embedding external knowledge as a core role	0.9538	0.918	0.9563	0.918
	· Applied to various parts in R&D	0.9688		0.9686	
Knowledge management capacity	· Securing of dedicated staff for effective technology management	0.9082	0.805	0.8949	0.805
	· System introduced for effective technology management	0.8456		0.8410	
	· Regular training of dedicated staff for system introduced	0.7774		0.7677	
Desortive capacity	· Business/ academic publications	0.8980	0.814	0.8972	0.814
	· Conferences/ meetings/ trade associations	0.8642		0.8591	
	· Patents listed in domestically and internationally	0.7198		0.7382	
	· Technologies listed at technology transfer centre/ institute	0.6965		0.7125	
Firm performance	· Business strategic purpose	0.7220	0.864	0.7300	0.864
	· Increase in organisational learning	0.6728		0.6691	
	· Increase in total revenue	0.7114		0.7183	
	· Decrease in development cost	0.7013		0.7089	
	· Increase in operating profits	0.6671		0.7136	
	· Increase in technological level	0.7927		0.7903	
	· Increase in export	0.6758		0.7101	
	· Increase in localizing of technology	0.5937		0.6043	

Note: Italic measurement variables which showed low loading values were eliminated in the second estimations.

5.2 Index Analysis

1) Indices

Using the suggested indexing approach, we evaluated the indices of the six latent factors. Table 5 shows the weight of each measurement variable that was used for index calculation of each latent variable. The results are shown in Figure 3. Except for firm performance, the integrative capacity index was the highest, followed by

'openness', 'knowledge management', and 'search', while 'desorptive' index was the lowest. The results suggested that out-bound OI is rare, whilst in-bound has often occurred more intensively. These findings are in line with those found in the literature (e.g., Van de Vrande et al., 2009, Chesbrough and Brunswicker, 2013).

Table 5 Weight of measurement variables

Latent Factors	Measurement Variables	Weights
Openness	Readiness to collaborate	0.3807
	Readiness to share experience	0.3803
	Top manager's willingness to collaborate	0.2427
	Trust external parties	0.1984
Search capacity	Importance of Institutional channel	0.2926
	Importance of Market channel	0.4334
	Attending trade fairs and conferences	0.4399
Integrative capacity	Embedding external knowledge as a core role	0.4798
	Applied to various parts in R&D	0.5587
Knowledge management capacity	Securing of dedicated staff for effective technology management	0.5065
	System introduced for effective technology management	0.3316
	Regular training of dedicated staff for system introduced	0.2920
Desoprtive capacity	Business/ academic publications	0.3560
	Conferences/ meetings/ trade associations	0.3461
	Patents listed in domestically and internationally	0.3156
	Technologies listed at technology transfer center/ institute	0.2204
Firm performance	Business strategic purpose	0.1811
	Increase in organisational learning	0.1901
	Increase in total revenue	0.1433
	Decrease in development cost	0.1591
	Increase in operating profits	0.1253
	Increase in technological level	0.2377
	Increase in export	0.1872
	Increase in localizing of technology	0.1813

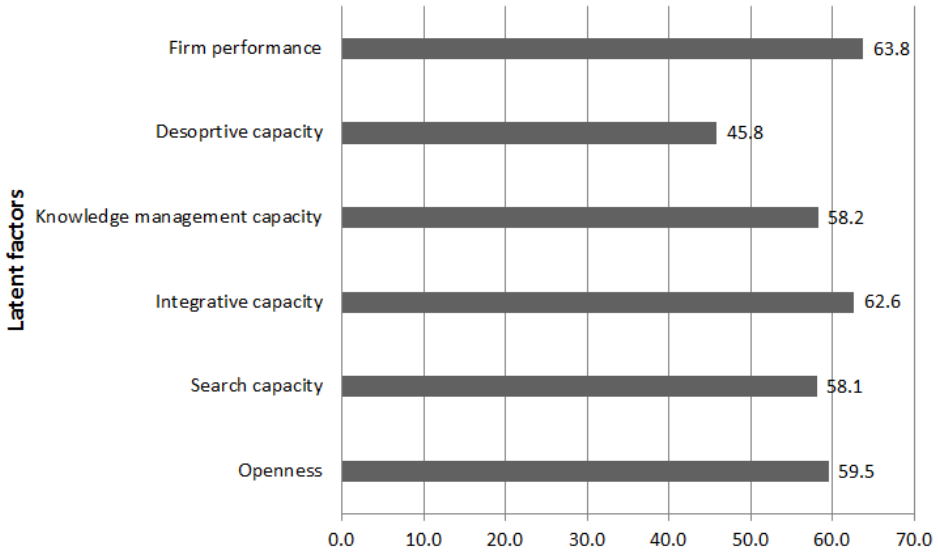


Figure 3 Overall indices of all factors

2) Openness indices according to the type of business

We compared the levels of openness (i.e., openness index) according to the business sector which surveyed firms belong to: manufacturing, OEM (Original Equipment Manufacturer), technology transfer, service and product sales. The question about the main business models was a multiple choice, hence any firm could choose more than one business sector. If a firm chose two business sectors, the datum was duplicated but the index was obtained for each individual business sector. Figure 4 shows the resulting indices. Manufacturing has the lowest index (i.e., the lowest degree of openness), while a service has the highest, followed by product sales and OEM.

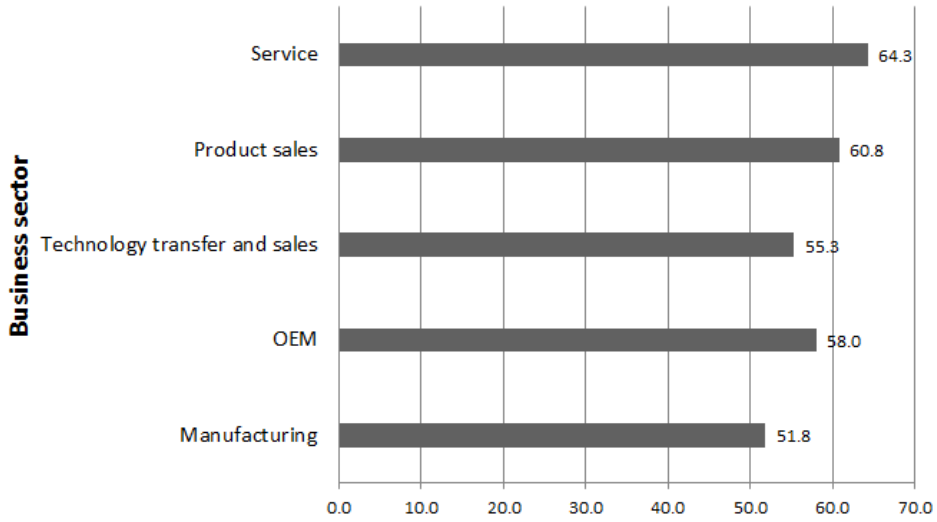


Figure 4 Openness Index over Business Sector

Secondly, we compared the levels of openness indices according to both listing in stock market and firm size as given in Figures 5 and 6. As shown in Figure 5, the KOSDAQ-listed firms have the highest openness index (67.9). Also the results show that medium-sized firms establish a more active attitude than large firms, whilst the gap between small and large firms is not substantial (see Figure 6).

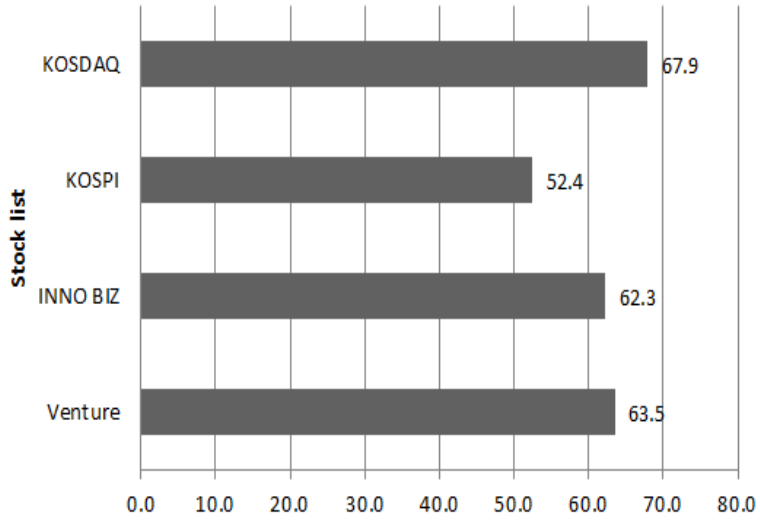


Figure 5 Openness Indices according to stock listing

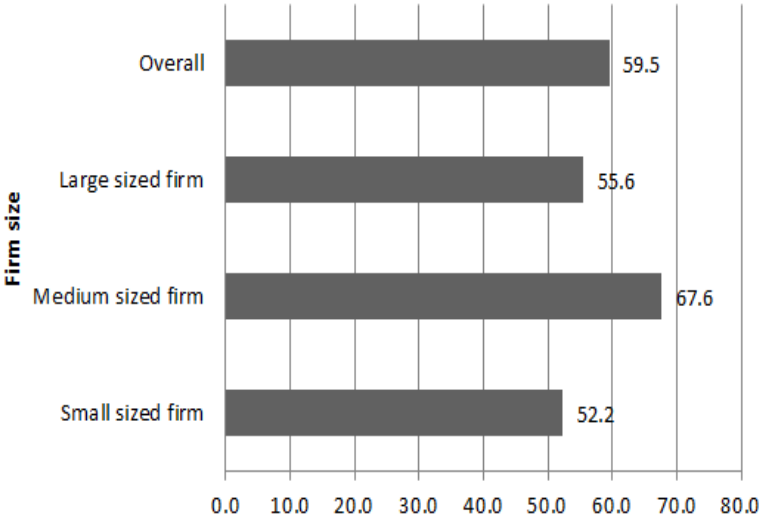
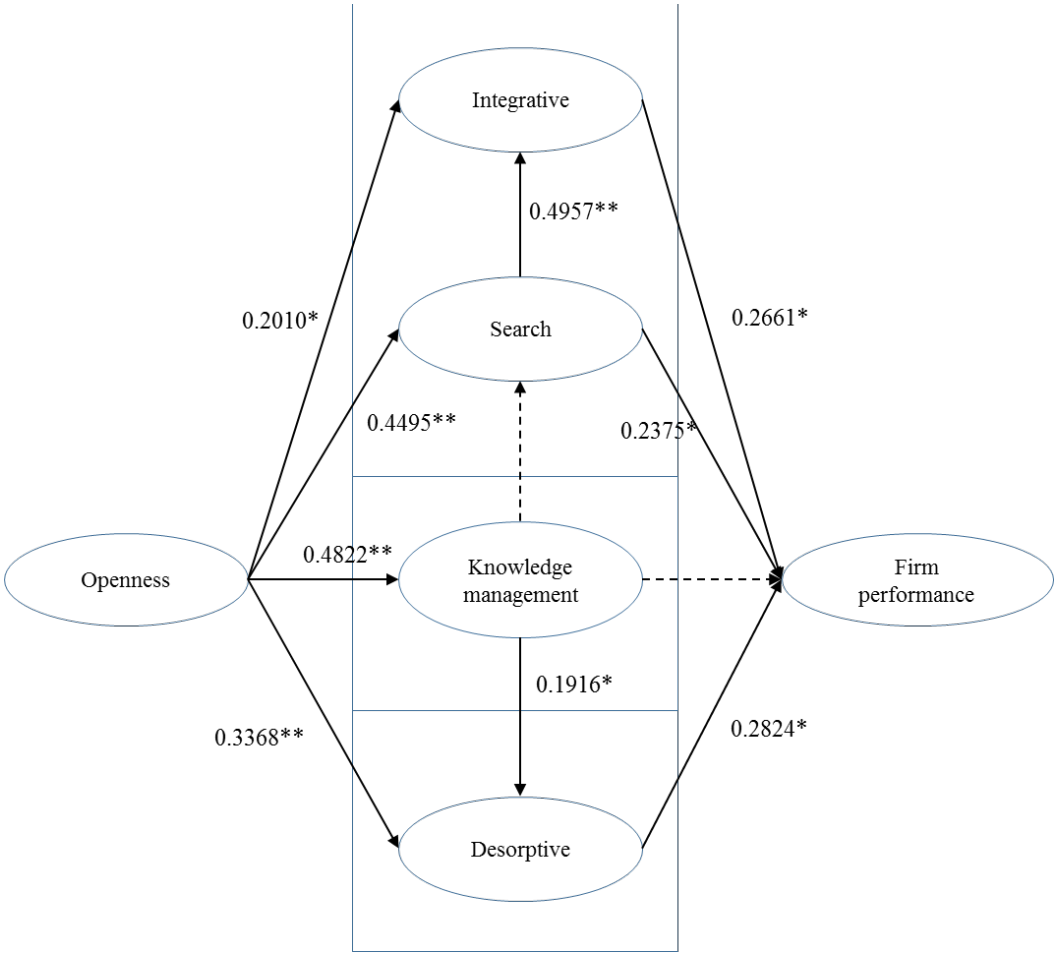


Figure 6 Openness indices according to firm size

5.3 Structural equation model results

We applied the PLS procedure to estimate the path coefficients of the proposed SEM in Figure 1. The significance of the path coefficient was evaluated by T-test with 1,500 bootstrap re-sampling and the results are shown in Figure 7.



Note: (1) significance: * p<0.1 / ** p<0.05 (2) p-value by T-test with 1,500 Bootstrap re-sampling
(3) A dotted line indicates statistically insignificant path

Figure 7 Results of partial least square estimation

All path coefficients appeared to be significant at the 10% level, except for two paths between 1) knowledge management and search capacity and 2) knowledge management and firm performance (see Figure 3). Openness positively influenced directly on other latent factors and affected performance indirectly. 'Knowledge management' did not have a direct effect on firm performance, but did have a positive impact indirectly via 'desorptive capacity'. However, contrary to expectation, 'knowledge management' did not show a positive direct association with 'search' capacity. These results can support H1 and H2, but partially validate H3 and H4.

5.4 Direct and indirect effects analysis

We also analysed direct and indirect effects of the factors to find the one most influential on firm performance. Here, the direct effect is the path coefficient, while the indirect effect is calculated by multiplying each path coefficient from one latent factor to a target factor. A total effect is the sum of the direct and indirect effect of each factor. As shown in Table 6, openness directly or indirectly influenced on all latent factors and particularly it had the greatest effect on 'knowledge management'. 'Search', 'integrative' and 'desorptive capacity' had a direct influence on technology performance and 'openness', whilst 'knowledge management' had only indirect influence on it. Among OI capacities, 'Search capacity' had the greatest total effect on firm performance.

Table 6 Direct and indirect effect analysis

Factor		Factor	Direct	Indirect	Total
Openness	→	Desorptive	0.3368	0.0924	0.4292
Openness	→	Knowledge management	0.4822		0.4822
Openness	→	Search	0.4495		0.4495
Openness	→	Integrative	0.2010	0.2228	0.4238
Search	→		0.4957		0.4957
Openness	→	Firm Performance	-	0.3407	0.3407
Desorptive	→		0.2824	-	0.2824
Knowledge management	→		-	0.0541	0.0541
Search	→		0.2375	0.1319	0.3694
Integrative	→		0.2661	-	0.2661

6. Discussion

This paper has attempted to look inside of innovation process by investigating the relationships between a firm's propensity towards openness, OI capacities and firm performance. The PLS SEM analysis results based on survey data suggest that the proposed hierarchical relationship is valid in the OI process. Also, by introducing a set of metrics we attempted to evaluate the degree of openness and assess how each knowledge-building capacity directly or indirectly impacts a firm's technological performance. The following conclusions can be drawn from the findings of this study.

Firstly, a firm's positive and active attitude towards openness can affect all kinds of OI capacities related to in-bound, coupled and out-bound OI. A firm can

increase its openness propensity when it voluntarily collaborates, shares experience, trusts external partners and when its managers feel more inclined towards collaboration. This increased openness will then encourage and stimulate various OI related abilities, such as 'searching', 'integrating', 'knowledge management' and 'desorptive' capacities.

Secondly, OI capacities triggered by a firm's openness directly and indirectly affect firm performance. Except for knowledge management, all OI capacities directly influenced firm performance, while knowledge management capacity indirectly influenced firm performance via desorptive capacity. This suggests that these capacities are essential elements in improving firm performance. By developing various capacities firms can engage in diverse commercialisation routes (Ahn et al., 2013, Ahn et al., 2015). This confirms the strength of the OI philosophy (Chesbrough et al., 2014, West et al., 2014) showing that opening firm boundaries will offer many new opportunities compared to closed innovation processes where internal knowledge is exploited mostly in existing markets following a linear innovation path (Mortara et al., 2011). Knowledge creates new value by crossing firms' boundary in many ways, and the various capacities are all needed to operationalise OI in full. It is fundamentally also true that a firm's openness attitude will enable a firm to engage in a new value creation process by helping it to overcome psychological hurdles (e.g., not-invented-here or not-shared-here syndrome) (Katz and Allen, 1982, Burcharth et al., 2014, Antons and Piller, 2014), which in turn contributes to performance enhancement (Laursen and Salter, 2006, Ahn et al., 2015) Thirdly, the relationships between search, integrative and firm performance confirms the importance of absorptive capacity in the OI process. Knowledge imported from external information sources may not of itself directly contribute to performance enhancement (Spithoven et al., 2011). Since not all knowledge in innovation is explicit, tacit knowledge has to be interpreted and reprocessed in order to be exploited for internal innovation (Freel, 2003, Salter et al., 2014). Thus, only after being properly processed and integrated with internal knowledge, this value added knowledge will be able to contribute performance enhancement (Salter et al., 2014, Spithoven et al., 2011).

Fourthly, out-bound OI does play an important role in improving performance. As our index analysis results indicate (see Figure 3), the 'desorptive' (out-bound OI) index was the lowest, suggesting its infrequent adoption in the sample, but, its direct effect on

performance ranked the highest of all the tested capacities (see Table 6). This suggests that despite its infrequent adoption and hurdles in its implementation (e.g., high costs for IP management) the effect of out-bound OI on firm performance cannot be ignored. In fact, as this type of OI aims to directly commercialise knowledge by selling it to other organisations, it may well make a major contribution to a corporation's performance. This also indicates that scholars, who have so far focused much attention on the in-bound knowledge flow and its associate absorptive capacity, should rather concentrate in understanding in more depth the elements and subordinate capacities relating to OI. We particularly contributed to this aspect by showing the strong link between desoprtive capacity and knowledge management capacity.

In fact, knowledge management did not affect search capacity but did affect desorptive capacity. In out-bound OI, firms have to expose some internal information, but this can decrease their technological confidentiality while increasing uncertainty levels (Bianchi et al., 2011; Laursen and Salter, 2013; Oakey, 2013). Thus, due to the risks involved in out-bound OI, its implementation is likely to be more influenced by systematic management which will play a gatekeeper role in the knowledge transfer process.

Lastly, the degree of openness was different according to firm type. We suggested an index analysis based on the proposed equation in section 4.2. Using this approach, the indices of various factors were measured and compared according to the nature of the firm and industry. It is interesting to note that, as seen in Figure 4, service firms tend to be more open in various business sectors. This can be explained if we consider that service firms are, by nature, open, as they need to share information and knowledge with their suppliers and customers as part of their day-to-day business activity. In general, service firms did not have a proper R&D department. Therefore, they tend to obtain knowledge and information from outside. Figure 5 and 6 also show interesting results. KOSPI firms showed a lower openness score than other types of firms, and large firms showed a lower score than medium-sized firms. These results have something in common. In general, large established firms are listed in the KOSPI stock list, while high-tech small and medium-sized enterprises (SMEs) are listed in KOSDAQ. Thus, it is suggested that in comparison with SMEs large firms are likely to be less open. As larger firms tend to have better internal R&D resources than smaller ones, they may

not depend critically on external information or partners, and this in turn establishes a strong leaning towards internal innovation. Yet, as Figure 6 shows, among SMEs, medium sized firms showed a higher openness score than small firms. This is in line with the findings in the literature (e.g., van de Vrande et al., 2009), in the sense that internal R&D demanding certain resources plays an important role in enhancing absorptive capacity (Cohen and Levinthal, 1990; Spithoven et al., 2011) and systematic IP management also demands substantial experience and resources (Ahn et al., 2015). Thus, medium-sized firms rather than small firms can take a more open attitude towards OI.

7. Implications and limitations

We hope that the results of this study will provide feedback information for policy makers who want to stimulate innovation in industry. If they use the suggested approach, they can easily recognize and compare not only the level of openness but also the level of each OI capacity in different groups. The model in Figure 2 represents a starting point for a wide span comparison of OI implementation approaches. It could be strengthened by including a more detailed set of OI activities and it could be applied in different contexts. For example future studies might extend the application of the model to larger samples of companies, enabling a global comparison of the level of openness in firms and industries. In addition the results presented here could be expanded by further analysing the relationship between openness, knowledge building and performance in each individual industrial sector.

Though there are potential benefits from this research, the study suffers from some research limitations. First, although PLS which is robust to small sample was used with bootstrap re-sampling, analysis of larger samples will more clearly show similarities and differences between firms with different characteristics and increase the general applicability of the result. Second, data was collected only from one country. Since innovation reflects socio-cultural background of a country (Edwards et al., 2005), a higher level of understanding will be obtained by carrying out a comparative study of two or more countries. Last, longitudinal data can be used to discover the long-term

effects of OI. In our results, no direct relationship was found between knowledge management capacity and firm performance and between knowledge management and searching. Since there can be time lag between fundamental innovation activities and end performance, knowledge management might affect searching and firm performance in the long run. However, as cross-sectional data was used, we could not examine whether this interpretation was correct. Future research addressing these limitations will enhance our understanding of OI.

Acknowledgement

The authors convey their thanks to the editor-in-chief, Prof. James Fleck and anonymous reviewers for their invaluable comments.

References

Ahn, J. M., Minshall, T. & Mortara, L. 2015. Open innovation: a new classification and its impact on firm performance in innovative SMEs. *Journal of Innovation Management,* 3**,** 33-54.

Ahn, J. M., Mortara, L. & Minshall, T. 2013. The effects of open innovation on firm performance: a capacity approach. *STI Policy Review,* 4**,** 74-93.

Anderson, J. C. & Gerbing, D. W. 1988. Structural equation modeling in practice: A review and recommended two-step approach. *Psychological Bulletin,* 103**,** 411-423.

Antons, D. & Piller, F. 2014. Opening the Black Box of" Not-Invented-Here": Attitudes, Decision Biases, and Behavioral Consequences. *The Academy of Management Perspectives***,** amp. 2013.0091.

Arbussa, A. & Coenders, G. 2007. Innovation activities, use of appropriation instruments and absorptive capacity: Evidence from Spanish firms. *Research Policy,* 36**,** 1545-1558.

Arora, A. & Gambardella, A. 1994. Evaluating Technological Information and Utilizing It - Scientific Knowledge, Technological Capability, and External Linkages in Biotechnology. *Journal of Economic Behavior & Organization,* 24**,** 91-114.

Bagozzi, R. P. & Yi, Y. 1988. On the evaluation of structural equation models. *Journal of the Academy of Marketing Science,* 16**,** 74-94.

Berchicci, L. 2013. Towards an open R&D system: Internal R&D investment, external knowledge acquisition and innovative performance. *Research Policy,* 42**,** 117-

127.

Bollen, K. A. & Long, J. S. 1993. *Testing Structural Equation Models,* Newbury Park, CA, Sage Publications.

Bougrain, F. & Haudeville, B. 2002. Innovation, collaboration and SMEs internal research capacities. *Research Policy,* 31**,** 735-747.

Brunswicker, S. & Van De Vrande, V. 2014. Exploring Open Innovation in Small and Medium-sized Enterprises. *In:* CHESBROUGH, H., VANHAVERBEKE, W. & WEST, J. (eds.) *New Frontiers in Open Innovation.* Oxford: Oxford University Press.

Burcharth, A. L. D. A., Knudsen, M. P. & Søndergaard, H. A. 2014. Neither invented nor shared here: The impact and management of attitudes for the adoption of open innovation practices. *Technovation*.

Chen, J., Chen, Y. & Vanhaverbeke, W. 2011. The influence of scope, depth, and orientation of external technology sources on the innovative performance of Chinese firms. *Technovation,* 31**,** 362-373.

Cheng, C. C. J. & Huizingh, E. K. R. E. 2014. When Is Open Innovation Beneficial? The Role of Strategic Orientation. *Journal of Product Innovation Management*.

Chesbrough, H. 2003. *Open innovation : the new imperative for creating and profiting from technology,* Boston, Mass., Harvard Business School Press.

Chesbrough, H. & Brunswicker, S. 2013. Managing Open Innovation in Large Firms. Stuttgart: Fraunhofer Institute for Industrial Engineering.

Chesbrough, H. & Crowther, A. K. 2006. Beyond high tech: early adopters of open innovation in other industries. *R & D Management,* 36**,** 229-236.

Chesbrough, H., Vanhaverbeke, W. & West, J. 2006. *Open innovation : researching a new paradigm,* Oxford, Oxford University Press.

Chesbrough, H., Vanhaverbeke, W. & West, J. 2014. *New Frontiers in Open Innovation,* Oxford, Oxford University Press.

Chiang, Y. H. & Hung, K. P. 2010. Exploring open search strategies and perceived innovation performance from the perspective of inter-organizational knowledge flows. *R & D Management,* 40**,** 292-299.

Chiaroni, D., Chiesa, V. & Frattini, F. 2009. Investigating the adoption of open innovation in the bio-pharmaceutical industry: a framework and an empirical analysis. *European Journal of Innovation Management,* 12**,** 285-305.

Cohen, W. M. & Levinthal, D. A. 1990. Absorptive-Capacity - a New Perspective on Learning and Innovation. *Administrative Science Quarterly,* 35**,** 128-152.

Cohen, W. M., Nelson, R. R. & Walsh, J. P. 2002. Links and impacts: The influence of

public research on industrial R&D. *Management Science,* 48**,** 1-23.

Dahlander, L. & Gann, D. M. 2010. How open is innovation? *Research Policy,* 39**,** 699-709.

Dyer, J. H., Kale, P. & Singh, H. 2004. When to ally and when to acquire. *Harvard Business Review,* 82**,** 108-115.

Enkel, E., Gassmann, O. & Chesbrough, H. 2009. Open R&D and open innovation: exploring the phenomenon. *R & D Management,* 39**,** 311-316.

Faems, D., De Visser, M., Andries, P. & Van Looy, B. 2010. Technology Alliance Portfolios and Financial Performance: Value-Enhancing and Cost-Increasing Effects of Open Innovation. *Journal of Product Innovation Management,* 27**,** 785-796.

Fishbein, M. & Ajzen, I. 1975. *Belief, attitude, intention and behavior: An introduction to theory and research,* Reading, Mass, Addison-Wesley.

Fontana, R., Geuna, A. & Matt, M. 2006. Factors affecting university–industry R&D projects: The importance of searching, screening and signaling. 35**,** 309-323.

Fornell, C. 1992. A national customer satisfaction barometer: the Swedish experience. *the Journal of Marketing***,** 6-21.

Fornell, C. & Bookstein, F. L. 1982. Two structural equation models: LISREL and PLS applied to consumer exit-voice theory. *Journal of Marketing Research***,** 440-452.

Freel, M. S. 2003. Sectoral patterns of small firm innovation, networking and proximity. *Research policy,* 32**,** 751-770.

Gassmann, O. & Enkel, E. Towards a Theory of Open Innovation: Three Core Process Archtypes. R&D Management of Conference, 6-9 July 2004 Lisbon, Portugal. 1-18.

Gassmann, O., Enkel, E. & Chesbrough, H. 2010. The future of open innovation. *R & D Management,* 40**,** 213-221.

Hair, J. F. J., Black, W. C., Babin, B. J. & Anderson, R. E. 2010. *Mulivariate Data Anlaysis,* Upper Saddle River, N.J., Prentice-Hall.

Huston, L. & Sakkab, N. 2007. Implementing open innovation. *Research-Technology Management,* 50**,** 21-25.

Katz, R. & Allen, T. J. 1982. Investigating the Not Invented Here (Nih) Syndrome - a Look at the Performance, Tenure, and Communication Patterns of 50 R-and-D Project Groups. *R & D Management,* 12**,** 7-19.

Kim, H. & Park, Y. 2010. The effects of open innovation activity on performance of SMEs: the case of Korea. *International Journal of Technology Management,* 52**,** 236-256.

Laursen, K. & Salter, A. 2004. Searching high and low: what types of firms use universities as a source of innovation? *Research Policy,* 33**,** 1201-1215.

Laursen, K. & Salter, A. 2006. Open for innovation: The role of openness in explaining innovation performance among UK manufacturing firms. *Strategic Management Journal,* 27**,** 131-150.

Laursen, K. & Salter, A. J. 2014. The paradox of openness: Appropriability, external search and collaboration. *Research Policy,* 43**,** 867-878.

Lee, S. Y., Yoon, J. Y., Kim, T. H. & Sohn, S. Y. 2007. A strategic analysis of Korean engineering education based on two satisfaction scores. *Journal of Engineering Education,* 96**,** 157-165.

Levinthal, D. A. & March, J. G. 1993. The myopia of learning. *Strategic management journal,* 14**,** 95-112.

Lichtenthaler, U. & Lichtenthaler, E. 2009. A Capability-Based Framework for Open Innovation: Complementing Absorptive Capacity. *Journal of Management Studies,* 46**,** 1315-1338.

Mazzola, E., Bruccoleri, M. & Perrone, G. 2012. The effect of inbound, outbound and coupled innovation on performance. *International Journal of Innovation Management,* 16.

Minshall, T., Mortara, L., Valli, R. & Probert, D. 2010. Making "Asymmetric" Partnerships Work. *Research-Technology Management,* 53**,** 53-63.

Mortara, L., Ford, S., Probert, D. & Minshall, T. 2012. Inbound Open Innovation: a Technology Acquisition Process Model. . *Open Innovation, New Insights and Evidence.* Imperial College, London.

Mortara, L. & Minshall, T. 2011. How do large multinational companies implement open innovation? *Technovation,* 31**,** 586-597.

Mortara, L. & Minshall, T. 2014. Patterns of Implementation of OI in MNCs. *In:* CHESBROUGH, H., VANHAVERBEKE, W. & WEST, J. (eds.) *New Frontiers in Open Innovation.* Oxford: Oxford University Press.

Mortara, L., Napp, J., Ford, S. & Minshall, T. 2011. Open innovation activities to foster corporate entrepreneurship. *In:* CASSIA, L., MINOLA, T. & PALEARI, S. (eds.) *Entrepreneurship and Technological Change.* Cheltenham, UK: Edward Elgar.

Mortara, L., Thomson, R., Moore, C., Armara, K., Kerr, C., Phaal, R. & Probert, D. 2010. Developing a Technology Intelligence Strategy at Kodak European Research: Scan & Target. *Research-Technology Management,* 53**,** 27-38.

Panagopoulos, A. 2003. Understanding when universities and firms form RJVs: the importance of intellectual property protection. *International Journal of*

Industrial Organization, 21**,** 1411–1433.

Parida, V., Westerberg, M. & Frishammar, J. 2012. Inbound Open Innovation Activities in High-Tech SMEs: The Impact on Innovation Performance. *Journal of Small Business Management,* 50**,** 283-309.

Penin, J. 2005. Patent versus ex post rewards: a new look. *Research Policy,* 34**,** 641–656.

Podmetina, D., Fiegenbaum, I., Teplov, R. & Albats, E. 2014. Towards open innovation measurement system - a literature review. *The XXV ISPIM Conference on 8-11 June 2014.* Dublin, Ireland.

Robertson, P. L., Casali, G. L. & Jacobson, D. 2012. Managing open incremental process innovation: Absorptive Capacity and distributed learning. *Research Policy,* 41**,** 822-832.

Roper, S., Vahter, P. & Love, J. H. 2013. Externalities of openness in innovation. *Research Policy,* 42**,** 1544-1554.

Salter, A., Cricuolo, P. & Ter Wal, A. 2014. Coping with Open Innovation: Responding to the Challenges of External Engagement in R&D. *California Management Review,* 56**,** 77-94.

Schroll, A. & Mild, A. 2012. A critical review of empirical research on open innovation adoption. *Journal fur Betriebswirtschaft,* 62**,** 85-118.

Sohn, S. Y. & Jung, C. S. 2010. Effect of creativity on innovation: do creativity initiatives have significant impact on innovative performance in Korean firms? *Creativity Research Journal,* 22**,** 320-328.

Sohn, S. Y. & Kim, M. J. 2010. Strategies for revitalization for intelligent robot industry in Korea based on structural equation model. *Industrial Robot: An International Journal,* 37**,** 97-105.

Sohn, S. Y. & Mok, M. S. 2008. A Strategic Analysis for Successful Open Source Software Utilization based on a Structural Equation Model. *Journal of Systems and Software,* 81**,** 1014-1024.

Sohn, S. Y. & Moon, T. H. 2003. Structural equation model for predicting technology commercialization success index (TCSI). *Technological Forecasting and Social Change,* 70**,** 885-899.

Spence, M. 2002. Signaling in retrospect and the informational structure of markets. *American Economic Review,* 92**,** 434-459.

Spithoven, A., Clarysse, B. & Knockaert, M. 2011. Building absorptive capacity to organise inbound open innovation in traditional industries. *Technovation,* 31**,** 10-21.

Teece, D. J., Pisano, G. & Shuen, A. 1997. Dynamic capabilities and strategic management. *Strategic Management Journal,* 18**,** 509-533.

Van De Vrande, V., De Jong, J. P. J., Vanhaverbeke, W. & De Rochemont, M. 2009. Open innovation in SMEs: Trends, motives and management challenges. *Technovation,* 29**,** 423-437.

Van Der Meer, H. 2007. Open Innovation - The Dutch Treat: Challenges in Thinking in Business Models. *Creative and Innovation Management,* 16**,** 192-202.

Vanhaverbeke, W. & Cloodt, M. 2014. Theories of the firm and open innovation. *In:* CHESBROUGH, H., VANHAVERBEKE, W. & WEST, J. (eds.) *New Frontiers in Open Innovation.* Oxford: Oxford University Press.

West, J. & Bogers, M. 2014. Leveraging external sources of innovation: a review of research on open innovation. *Journal of Product Innovation Management,* 31**,** 814-831.

West, J., Salter, A., Vanhaverbeke, W. & Chesbrough, H. 2014. Open innovation: The next decade. *Research Policy,* 43**,** 805-811.

Zeng, S. X., Xie, X. M. & Tam, C. M. 2010. Relationship between cooperation networks and innovation performance of SMEs. *Technovation,* 30**,** 181-194.

Appendix: The summary of survey questions

Latent Factors	Questions related to the variables
Openness	Please indicate the propensity of the firm. Please answer with the 5 point interval scale (The higher score, the higher agreement) 1. The firm has a culture encouraging collaborations with external organisations. 2. The firm has a willingness to share experiences through collaboration 3. The top managers in the firm are proactive for collaboration with external organisations. 4. In general, the firm trusts external partners.
Search capacity	Over the last three years, to what extent has the following information source been used importantly? Please answer with the 5 point interval scale (The higher score, the higher importance) 1. Universities or higher education institutes 2. Marketing channels, such as clients, customers and suppliers. 3. Specialised channels, such as technical standards, regulations, etc. 4. Human networks, such as CEO/CTO's informal meeting, human network, newly employed workers. 5. Expert level information, such as patent or journal database 6. General information media, such as trade fairs, conferences, the internet. 7. Other institutional channels, such as other organisations, public/private research institutes
Integrative capacity	To what extent do you agree the following statements? Please answer with the 5 point interval scale (The higher score, the higher agreement) 1. Over the last three years the information/technology adapted from outside has played an important role in developing products or improving processes. 2. Over the last three years the information/technology adapted from outside has widely used for product development or process improvement.
Knowledge management capacity	To what extent do you agree the following statements? Please answer with the 5 point interval scale (The higher score, the higher agreement). 1. Over the last three years, my company has had enough manpower which is exclusively responsible for innovation outcome (technology and/or IPs) management. 2. My company is planning to employ an efficient systematic tool for innovation outcome management. 3. My company has a regular training program for innovation outcome management personnel and/or system.
Desoprtive capacity	Over the last three years, to what extent has the following signalling activity (i.e., innovation results dissemination) been importantly used? Please answer with the 5 point interval scale (The higher score, the higher importance) 1. Academic journal/business magazine publish 2. Conferences/ meetings/ trade associations 3. Patents listed in domestically and internationally 4. Technologies listed at technology transfer centre/ institute
Firm performance	To what extent do you agree the following statements? Please answer with the 5 point interval scale (The higher score, the higher agreement). Over the three years compared with average-level competitors in the same industry, the firm has successfully achieved… 1. A business strategic purpose 2. An increase in organisational learning 3. An increase in total revenue

	4. A decrease in development cost 5. An increase in operating profits 6. An increase in technological level 7. An increase in export 8. An increase in localizing of technology