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Longitudinal effects of open R&D strategy on firm performance: Comparative study of the UK and Korea

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This paper attempts to investigate the longitudinal relationships between open R&D strategies and firm performance in different national contexts. Based on two panel data sets, the UK Community Innovation Survey (CIS) 2004-2008 and the Korean Innovation Survey (KIS) 2005-2010, the paper identifies longitudinal trends in open R&D and finds evidence of their significant relationship with firm performance. The findings of this paper will provide valuable insights for managers in multi-national corporations (MNCs) and policy makers establishing firm strategies or national level R&D policy.

1. Introduction

Since 2003 when Chesbrough coined the term, 'open innovation (OI)', OI has become an important research topic in the field of innovation management (Chesbrough, 2003, Dahlander and Gann, 2010). The popularity of the OI model has encouraged its adoption in leading firms across the globe, resulting in the interaction between and collaboration with external innovation actors.

The majority of the studies conducted so far have focused on finding illustrative examples of open R&D strategy or capturing its general characteristics. As OI is a relatively young approach, little is known about how the adoption and implementation of open R&D strategies have changed over time (Mortara and Minshall, forthcoming). To date, many studies have analyzed cross-sectional data-sets (e.g., Laursen and Salter, 2006, Van Der Meer, 2007), but the long-term trends and effects of the adoption of open R&D strategies have been underexplored. Thus, there is no clear understanding yet of whether there has been a significant longitudinal contribution of open R&D to firm performance and whether there is a trend in the propagation of open R&D practice. Though ten years have passed since the original book on OI (Chesbrough, 2003), there might not yet be sufficient evidence on which to base clear conclusions on trends.

Further, different contexts, including economic fundamentals and national culture, may play an important role in forming open R&D implementation patterns. As noted by Edwards et al. (2005), a higher level of understanding of innovation can be achieved by acknowledging the complex interactions between firms and their environment. Even if open R&D were a global business norm, its implementation patterns might vary in different national settings. Yet, with the exception of a few papers (e.g., De Backer et al., 2008, Lichtenthaler and Ernst, 2009) that have investigated OI in more than one European country, the focus of most previous studies has remained the analysis of cross-sectional data in a single country.

Accordingly, this study aims to explore and compare longitudinal changes in open R&D trends and impacts in two different innovative countries, the UK and Korea using data from the UK Community Innovation Survey (CIS) of 2004, 2006 and 2008 and the Korean Innovation Survey (KIS) of 2005, 2008 and 2010.

The remainder of this paper comprises five sections. The first describes the theoretical background in order

to develop hypotheses focused on the relationship between open R&D strategy and firm performance. The data and method are then described and the results are discussed. The paper concludes with implications and limitations of the research.

2. Backgrounds and hypotheses

2.1 Literature review

Recent years have witnessed the wide adoption of open R&D strategies (Chesbrough, 2003). By increasingly and more deliberately exploring and exploiting external knowledge, firms have broadened their knowledge resources by accessing complementary assets, maximised incomes from intellectual properties (IPs), saved time and cost, attracted new customers and established new technology standards (Dahlander and Gann, 2010, Savitskaya et al., 2010, West and Gallagher, 2006).

The early papers concentrated on describing case studies of OI adoption and many subsequent works have revealed some of the significance of open R&D strategy. Laursen and Salter (2006) examined the effect of openness on the sales of new or improved products and this approach was also adopted by Roper et al. (2013). Both studies showed that external search and linkages with external partners are positively associated with sales of new or improved products. Mazzola et al. (2012) examined the effects of twelve different open R&D strategies on financial and innovation performance and found that the effect can be both positive and negative. Almirall and Casadesus-Masanell (2010) simulated the effect of open R&D in two different settings: where partnerships are fixed or flexible. They showed that a high level of openness can bring better performance, particularly in a dynamic environment where firms can change their partners freely. Hung and Chou (2013) investigated the influence of external technology acquisition (i.e., in-bound) and external technology exploitation (i.e., out-bound) and found that only external technology acquisition positively affects firm performance. Ahn et al. (2013) investigated the influence of Lichtenthaler and Lichtenthaler's (2009) six capabilities related to open R&D on sales and profits and found that according to a firm's characteristics the associational directions between these capabilities and financial performance can be seen to be different in cross-sectional data, suggesting a potential dynamic effect of open R&D.

As ten years have elapsed since OI first became popular (Chesbrough, 2003), it is now a suitable time to start reviewing whether open R&D strategy is on the increase and what are its effects in the long term. Regarding its increase, there have been few attempts so far to review the phenomenon and the data is still contradictory: Roper et al. (2013) found no indication that externalities from openness resulted in an increase of open R&D practice in Ireland plants over the period 1994-2008. However, Chesbrough and Brunswicker (2013) found a significant increase in OI adoption based on the survey of large firms in the EU and the US.

Moreover, there is empirical evidence that OI is being adopted in many countries including the UK (Laursen and Salter, 2006) and Korea (Lee et al., 2010). However, there is no detailed information about similarities and differences in open R&D strategies in these countries.

2.2 Hypotheses

In this paper, we investigate the longitudinal effect of open R&D strategy and to do this we assume that characteristics of openness are universally significant in the dynamic relationship between openness and performance. Based on the findings of the literature, the current study investigates three different open R&D strategy activities: external search, collaboration with external partners, and the use of appropriability strategy.

First, the search of external information allows firms to increase the 'stockpile' of knowledge and to exploit specialized external knowledge (Levinthal and March, 1993, Mitchell and Singh, 1996), which in turn could enhance performance (Berchicci, 2013). As noted by Laursen and Salter (2006), firms exploring external knowledge broadly and deeply can develop the capabilities necessary to adapt to change and to innovate. This external search can even enhance firms' absorptive capacity, in the sense that firms can interpret and integrate external knowledge more easily based on their accumulated stockpile of knowledge (Cohen and Levinthal, 1990, Spithoven et al., 2011, West and Bogers, 2013). Hence:

> *Hypothesis 1) The breadth of external search is positively associated with firms' performance in the long term.*
> *Hypothesis 2) The depth of external search is positively associated with firms' performance in the long term.*

Second, collaboration with external partners enables firms to access complementary assets (Teece, 1986). Owing to the increasing complexity of technology, collaborating with external specialists rather than involvement in the entire innovation process can be more efficient (Chesbrough, 2003). Interdependency between partners can compensate for mutual weaknesses and make synergies (Narula, 2004, Rothwell and Dodgson, 1994). Many empirical studies (e.g., Berchicci, 2013, Cassiman and Veugelers, 2006) have also shown that the combination of internal and external R&D can increase firms' ability to engage in innovation and consequently enhance performance.

Hence:

> *Hypothesis 3) The breadth of collaboration is positively associated with firms' performance in the long term.*

Hypothesis 4) The depth of collaboration is positively associated with firms' performance in the long term.

Third, in order to profit from innovation, firms have to establish an appropriability regime (Teece, 1986). Knowledge leakage is one of the critical risks in open R&D strategy (Laursen and Salter, 2013). In order to deal with the paradox of openness (i.e., undesired sharing and spill overs) firms need to legally protect their innovation using patents and other forms of IP protection, such as lead time advantage or increasing tacitness (Bogers, 2011, Laursen and Salter, 2013). Hence:

Hypothesis 5) The breadth of appropriability strategy is positively associated with firms' performance in the long term.
Hypothesis 6) The depth of appropriability strategy is positively associated with firms' performance in the long term.

In addition, we assume that the implementation of open R&D (i.e., external search activities, collaboration with external partners and the use of appropriability strategy) has been increased in the long term. It may be possible that recent globalisation trends and the development of ICT (information and communication technology) have lowered the transaction cost required for open R&D (Chesbrough et al., 2006), thus enabling firms to search for external information and collaborate with external partners more easily. Further, we entertain the possibility of the accretionary implementation of open R&D strategies. Firms may have learned relevant skills necessary for open R&D over time, thus establishing an organisational routine (Nelson and Winter, 1982). So, even if open R&D strategies did not have an effect on performance, their implementation might have occurred due to this organisational path dependency (Cyert and March, 1963, Gavetti et al., 2012). Hence:

Hypothesis 7) External search, collaboration and appropriability strategy have significantly changed over time.

3. Data and Method

3.1 Data

In order to see the longitudinal effects of open R&D strategy in different contexts, this paper analysed two different data sets, the CIS and the KIS data. The questions and structures in both data sets are based on the Organization for Economic Co-operation and Development's (OECD) Oslo Manual (OECD, 1997), and consequently to a large extent they are similar.

UK data[1]

For the CIS data, a panel data including CIS 4 (2004), CIS 5 (2006) and CIS 6 (2008) created by the UK Data Archive was used. From the 12,162 observations of 4,054 firms at three different points in time, a total of 5,284 observations of 1,428 firms were selected. The selection was based on the exclusion of entries with unanswered questions regarding open R&D strategy activities and extra ordinary outliers of internal R&D.

Korean data

For the KIS data (KIS 2005, 2008 and 2010 data), 507 observations of 169 firms at three different time points were used. The same data exclusion rule was applied to the KIS data as used for the CIS data. Although the KIS data deals with four different innovation activities, this paper analysed only product and process innovation related activities that appear in both the UK and Korean data.

3.2. Variables

With regard to openness metrics, Laursen and Salter's (2006) seminal paper suggested a way of measuring firms' openness by counting the number of information sources (breadth) and the degree of their importance (depth), and these scales have been adopted in many later studies (e.g., Schweitzer et al., 2011, Roper et al., 2013). Using and expanding on Laursen and Salter's (2006) breadth and depth concepts, we examined six different open R&D related activities.

First, 'breadth of search' indicates how widely firms explore external information [2] . All the external information source variables in the raw data were transformed into binary variables (0:not used, 1:used) and then added up to indicate twelve levels (0:none of the information sources used to 11:eleven different information sources used).

Second, 'depth of search' refers to how deeply firms use external information source. The respondents' answers assessing the importance of external information sources were transformed into binary variables (0:not, low or medium-level importance, 1:high importance) and then added up in order to make a 'depth of search' variable (i.e., 0 to 11 according to the number of information sources significantly used).

Third, 'breadth of collaboration' refers to how broadly firms co-operate with external partners. This variable refers to the formal engagement of the company with external partners[3]. As in the case of 'breadth of search', a firm gets a score of 0 when it does not collaborate at all and 8 when it collaborates with

[1] Department for Business, Innovation and Skills and Office for National Statistics, UK Innovation Survey, 1996-2008: Secure Data Access [computer file], Colchester, Essex; UK Data Archive [distributor], July 2011, SN:6699

[2] within firms, suppliers, customers, other firms, consultants, universities, public research institutes, conferences, industry association, technical standards, journals

[3] within enterprise group, suppliers, customers, competitors, consultants, universities, public research institutes

eight different partners.

Fourth, 'depth of collaboration' indicates how deeply firms collaborate with external partners. This variable was made in the same way as 'depth of search', but was analysed only in the KIS data because the UK CIS data does not have information about the importance of collaboration partners. However, since the UK CIS data does not include information about 'depth of collaboration', we were not able to fully examine the effect of this variable.

Fifth, 'breadth of appropriability' indicates how broadly firms use appropriability strategies[4]. As in the case of external search, raw data were transformed and then added up to indicate 0 (no appropriability strategy used) to 8 (eight different appropriability strategies used).

Sixth, 'depth of appropriability' indicates to what degree firms use appropriability strategies. A score of 0 indicates 'no significant use of any protection method', while a score of 8 indicates 'the significant use of all eight protection methods'. However, as in the period under observation there were changes [5] in the questions of the UK CIS data regarding 'appropriability strategy', both 'breadth of appropriability' and 'depth of appropriability' could not be completely evaluated. Thus, we additionally included the breadth of four[6] IP protection methods that appear in all the CIS data.

Seventh, 'external R&D intensity' refers to the ratio of firms' expenditure on external R&D to total revenue.

Eighth, we controlled 'internal R&D intensity' which indicates the ratio of firms' internal R&D expenditure to total revenue, in the sense that internal R&D plays dual role as a producer of new information as well as an enhancer of a firm's ability to learn from already existing information (i.e., absorptive capacity) (Cohen and Levinthal, 1990).

Lastly, as dependent variables, we examined two different general performances, financial and growth. Due to their reliability and easy accessibility as publicly announced data, this paper employs objective general performance variables. Financial performance was measured using a natural logarithm of total revenue, and growth was measured using a natural logarithm of the total number of employees.

3.3 Method

In order to see panel effects, we use the following equation to examine three different models: pooled ordinary least square (OLS), fixed effect and random effect.

$$\square\square\square\square\square\square\square\square\square\square\square\square = \square 0 + \square = 1\square\square\square\square\square\square\square\square\square\square\square + \square = 1\square\square\square\square\square\square + \square\square\square$$

(Where, 'i' is an index of observation, 't' is an index of time periods, OPENkit is observed time variant open R&D variable, Zsi is unobserved time invariant explanatory variable, $\square\square\square$ is disturbance term)

In order to select an unbiased panel model, the Hausman test was conducted to diagnose whether fixed or random effect models are consistent. When a random model effect was selected, the Breusch-Pagen Lagrange Multiplier test was conducted to see whether there is a panel effect (i.e., to identify whether OLS model is better). As errors can be serially correlated over time in a panel data (Wooldridge, 2002), we reported corrected standard errors after checking the correlations of the residuals over time.

4. Results and discussions

4.1 Open R&D strategies in the UK

Table 1 shows the descriptive statistics of open R&D strategy activities in the UK over time. While 'depth of search', 'breadth of appropriability' and 'depth of appropriability' have increased in the given time period, 'internal R&D intensity' has decreased. Other open R&D variables ('breadth of search' and 'breadth of collaboration') faltered in 2006 data, but they rose again, plotting a U-shape pattern. To examine whether these changes over time are statistically significant, one-way ANOVA (analysis of variance) was conducted. According to the homogeneity of variances, we reported either the p-value of ANOVA or Welch test. The ANOVA results confirm that all the open R&D activities have changed significantly over time. Thus, hypothesis 7 was accepted.

N=1428	2004		2006		2008		ANOVA[a] Welch[b] p-value
	Mean	St.D	Mean	St.D	Mean	St.D	
BSEAR	8.221	2.482	8.113	2.602	8.57	2.870	0.000[b****]
DSEAR	1.800	1.698	2.011	1.765	2.151	1.797	0.000[a****]
BCOL	0.917	1.870	0.814	1.712	1.797	2.034	0.000[b****]
DCOL	-	-	-	-	-	-	-
BAPP	4.274	2.992	4.456	2.984	-	-	0.017[a*]
DAPP	1.379	1.962	1.713	2.177	-	-	0.000[b****]
B4IPS	1.403	1.704	1.610	1.738	0.495	0.980	0.000 [b***]
IRND	2.310	5.735	2.139	5.993	1.422	4.514	0.003[b**]
ERND	1.263	6.275	0.654	2.341	0.540	2.769	0.200

Variable description:
BSEAR=breadth of search, DSEAR=depth of search, BCOL=breadth of collaboration, DCOL=depth of collaboration, BAPP=breadth of appropriability, DAPP=depth of appropriability, B4IPS=breadth of four IP methods, IRND=internal R&D intensity, ERND=external R&D intensity
Significance level: **** (0.001), ** (0.01), * (0.05), + (0.1)

Table 1. Open R&D trends in the UK

Table 2 shows the regression results between total sales and open R&D activities. Due to the changes of the CIS questionnaire and differences with the KIS data, we examined three different models for comparison. Model 1, including appropriability variables, was analysed based on the CIS 4(2004) and 5(2006), and Model 2, excluding these variables, was analysed using the CIS 4~6. In Model 3, 'B4IPS' (i.e.,

[4] design, trademarks, patents, confidentiality agreement, copyrights, secrecy, complexity, lead-time advantage
[5] The use of eight different appropriablity strategies (e.g, patents, trademark and lead time advantage) were asked in the CIS 4(2004) and 5(2006), but the use of only four appropriability strategies (as a binary question) were asked in CIS 6 (2008).
[6] patent, registered design, trademark and copyright

'breadth of four IP protection method use') was added. Through all the models, fixed effect was selected by the Hausman test. Therefore, time-invariant variables (e.g., intercept) were eliminated. The results of Model 2 and 3 show that internal R&D can be negatively associated with total sales, while, 'breadth of collaboration' can contribute positively to an increase in total sales. Thus, we could only accept hypotheses 3.

Dependent variable: Sales	Model 1 (CIS4~5)	Model 2 (CIS4~6)	Model 3 (CIS4~6)
BSEAR	-0.0003 (0.0201)	-0.0107 (0.0132)	-0.0091 (0.0187)
DSEAR	-0.0070 (0.0237)	0.0081 (0.0187)	0.0035 (0.0212)
BCOL	0.0056 (0.0124)	0.0267^{+} (0.0160)	0.0249^{+} (0.0145)
DCOL	-	-	-
BAPP	0.0072 (0.0110)	-	-
DAPP	0.0145 (0.0197)	-	-
B4IPS	-	-	-0.0217 (0.0237)
IRND	-0.0571* (0.0275)	-0.0266** (0.0086)	-0.0275** (0.0087)
ERND	0.0028 (0.0427)	0.0015 (0.0307)	0.0023 (0.0159)
Significance level: **** (0.001), **(0.01), * (0.05), $^{+}$(0.1) Corrected standard errors are reported in parentheses.			

Table 2. Panel data analysis on sales (UK)

The relationships between employment and open R&D strategy activities were analysed as shown in Table 3. As in the case of sales, three different models were used. Model 4 based on CIS 4 and 5 included appropriability variables in its analysis, while Model 5 and 6 based on the entire CIS data dropped these variables. In Model 6, 'B4IPS' was additionally included. For Model 4 and 6 the fixed effect was chosen, but the random effect was selected for Model 5. The Breusch-Pagen Lagrange Multiplier test confirms that there is a significant panel effect in Model 5. Thus, we reject the use of a pooled OLS model (instead of random effect model). Our results show that 'breadth of collaboration' and 'internal R&D intensity' can be positively associated with an increase in employment. Thus, in the context of our sample we only accept hypothesis 3.

Dependent variable: employment	Model 4[a] (CIS4~5)	Model 5[b] (CIS4~6)	Model 6[a] (CIS4~6)
Intercept		4.6768*** (0.1033)	-
BSEAR	0.0031 (0.0101)	-0.0019 (0.0087)	-0.0041 (0.0099)
DSEAR	0.0031 (0.0090)	0.0083 (0.0101)	0.0047 (0.0113)
BCOL	0.0051 (0.0075)	0.0282*** (0.0075)	0.0210** (0.0077)
DCOL	-	-	-
BAPP	0.0048 (0.0077)	-	-
DAPP	-0.0041 (0.0101)	-	-
B4IPS	-	-	-0.0098 (0.0126)
IRND	0.0007 (0.0031)	0.0092* (0.0044)	0.0123** (0.0047)
ERND	-0.0179 (0.0192)	-0.0079 (0.0071)	-0.0051 (0.0085)
Significance level: **** (0.001), **(0.01), * (0.05), $^{+}$(0.1) Model specification: [a] (fixed effect model), [b] (random effect model) Corrected standard errors are reported in parentheses.			

Table 3. Panel data analysis on employment (UK)

4.2 Open R&D strategies in Korea

Table 4 shows the descriptive statistics of open R&D strategy activities over time. While 'breadth of search', and 'internal R&D' has increased in the given time period, 'breadth of collaboration' has decreased. 'Depth of search', 'breadth of appropriability' and 'depth of appropriability' showed inverted U-shaped patterns, while 'depth of collaboration' showed an opposite pattern. To examine whether these changes over time are statistically significant, ANOVA was conducted. The ANOVA results confirm that 'breadth of search', 'breadth of collaboration', 'depth of collaboration', 'breadth of appropriability', 'depth of appropriability' and 'internal R&D intensity' have been significantly changed over time, partially accepting hypothesis 7.

N=169	2005		2008		2010		ANOVA
	Mean	St.D	Mean	St.D	Mean	St.D	
BSEAR	6.46	4.663	7.91	4.438	7.97	4.313	0.002***
DSEAR	2.40	2.780	2.90	2.542	2.83	2.659	0.176
BCOL	1.55	2.672	1.27	2.238	1.10	2.005	0.020*
DCOL	0.69	1.390	0.44	1.005	0.48	1.058	0.099^{+}
BAPP	2.93	2.871	3.55	3.145	3.23	2.918	0.066^{+}
DAPP	1.50	1.831	2.10	2.777	1.70	2.034	0.047*
IRND	1.63	3.287	3.20	4.756	3.68	8.033	0.003***
ERND	0.36	1.362	0.78	3.539	0.59	1.783	0.285
Significance level: **** (0.001), **(0.01), * (0.05), $^{+}$(0.1)							

Table 4. Open R&D trends in Korea

Table 5 shows the regression results between total sales and open R&D strategy activities. Since the UK CIS data does not include information about 'depth of collaboration', we reported two different models with (Model 2 and 4) and without (Model 1 and 3) this variable. Also, owing to changes in questions regarding 'appropriability strategy', we reported two different models including (Model 3 and 4) and excluding (Model 1 and 2) the appropriability strategy variables for the purpose of comparison. For all the models, fixed effect were selected based on the Hausman test. Our results show that 'breadth of search' and 'breadth of appropriability' can contribute longitudinally to an increase in total sales, validating hypotheses 1 and 5.

Dependent variable: Sales	Mode 1	Mode 2	Model 3	Model 4
BSEAR	0.1997*** (0.0594)	0.1988** (0.0600)	0.1674** (0.0590)	0.1668** (0.0596)
DSEAR	-0.0030 (0.0618)	0.0002 (0.0672)	0.0110 (0.0636)	0.0129 (0.0682)
BCOL	-0.0566 (0.0519)	-0.0484 (0.0550)	-0.0915 (0.0637)	-0.0866 (0.0568)
DCOL	-	-0.0246 (0.0720)	-	-0.0151 (0.0729)
BAPP	-	-	0.1584* (0.0646)	0.1580* (0.0646)
DAPP	-	-	-0.0860 (0.0661)	-0.0849 (0.0664)
IRND	0.0128 (0.0224)	0.0128 (0.0223)	0.0120 (0.0224)	0.0120 (0.0223)
ERND	-0.0118 (0.0264)	-0.0112 (0.0261)	-0.0236 (0.0257)	-0.0233 (0.0254)
Significance level: **** (0.001), **(0.01), * (0.05), $^{+}$(0.1) Corrected standard errors are reported in parentheses.				

Table 5. Panel analysis on sales (Korea)

A similar analysis was conducted on the number of employees, as shown in Table 6. As in the case of total

sales, two different models with (Model 6 and 8) and without (Model 5 and 7) 'depth of collaboration' and other two different models including (Model 7 and 8) and excluding (Model 5 and 6) 'appropriability' variables were used for comparison with the UK case. For Model 5 fixed effect was chosen, and random effect was selected for the other Models. The Breusch-Pagen Lagrange Multiplier test confirms that there is a significant panel effect. Our results show that 'breadth of search', 'breadth of appropriability' and 'internal R&D intensity' can be negatively associated with employment, while 'breadth of collaboration' can be positively associated with it, validating hypothesis 3.

Dep. variable: employment	Mode 5[a]	Mode 6[b]	Model 7[b]	Model 8[b]
Intercept	-	7.7206*** (0.2151)	7.7490*** (0.2164)	7.7489*** (0.2164)
BSEAR	-0.1234*** (0.0344)	-0.1419*** (0.0262)	-0.1231*** (0.0282)	-0.1231*** (0.0288)
DSEAR	0.0270 (0.0366)	0.0190 (0.0371)	0.0079 (0.0352)	0.0080 (0.0384)
BCOL	0.0497 (0.0364)	0.0921* (0.0357)	0.1097*** (0.0307)	0.1098** (0.0358)
DCOL	-	0.0042 (0.0711)	-	-0.0003 (0.0711)
BAPP	-	-	-0.0837* (0.0389)	-0.0837* (0.0389)
DAPP	-	-	0.0616 (0.0437)	0.0616 (0.0436)
IRND	-0.0321* (0.0152)	-0.0298* (0.0141)	-0.0278+ (0.0142)	-0.0278+ (0.0142)
ERND	0.0256 (0.0241)	0.01983 (0.0211)	0.0240 (0.0217)	0.0240 (0.0215)

Significance level: **** (0.001), ** (0.01), * (0.05), + (0.1)
Model specification: [a] (fixed effect model), [b] (random effect model)
Corrected standard errors are reported in parentheses.

Table 6. Panel data analysis on employment (Korea)

4.3 Comparisons between the UK and Korea

We started our analysis with three assumptions, 1) open R&D strategy activities change over time, 2) all open R&D strategy activities are positively associated with firm performance and 3) this positive relationship does not vary between countries. However, the results show that these three assumptions were only partially valid in the context of our samples.

With one exception (i.e., 'depth of collaboration' in the KIS data), the results confirm that in both data sets all the tested open R&D strategy activities changed during the given time periods. Yet, the different patterns of change developed in the two countries, thus invalidating our third assumption. The UK data shows that internal R&D intensity decreased over time, whilst all the tested open R&D activities increased (despite some slow down in the CIS 5) in the long-term. However, in the KIS data internal R&D intensity increased over time, whilst some open R&D activities, such as 'breadth of collaboration' and 'depth of search', showed a decrease or an inverted U-shaped change. These results show the different open R&D strategy development patterns in the two countries. While the tested open R&D strategies had been widely and deeply employed in the UK, only 'breadth of search' showed a significant increase in the KIS data. This phenomenon may be explained in three ways. First, as an increasing internal R&D shows, Korean firms may be more dependent on internal resources for innovation. Thus, in Korea while more closed R&D strategy plays an important role in innovation, open R&D strategy may be less widely and deeply adopted. Second, knowledge exploration may be more favoured by Korean firms, whilst UK firms employ various strategies. The fact that only 'breadth of search' increased over time in the KIS data may support this view. Third, the global economic crisis could be a reason for a decrease in open R&D strategies in the KIS data. Since all the analysed UK data was collected before the crisis whilst the KIS data covered the period of the economic crisis, this difference may have generate the different trends and made Korean firms more cautious and less open.

Although a direct comparison and interpretation was not easy because of limited availability of some variables (e.g., 'depth of collaboration' or 'breadth of appropriability') in the UK data, our results suggest that the influences of open R&D strategy activities on firm revenue and growth were different in the two countries. In the UK data only 'breadth of collaboration' showed a significant and positive association with financial performance (sales), but in Korea 'breadth of search' and 'breadth of appropriability' were positively associated with sales. As in the case of mean value changes in the open R&D strategy activities, these findings may suggest that open R&D strategy in Korea has focused on exploring external knowledge, whilst that in the UK has been based more on collaboration between innovation actors.

In terms of the influence of open R&D on growth (employment), it was very differently configured in the two countries. In the UK data, as in the case of financial performance, 'breath of collaboration' was positively associated with a dependent variable (employment). In the KIS data both 'breadth of search' and 'breadth of appropriability', which positively influenced sales, were negatively associated with employment. However, 'breadth of collaboration' was positively associated with employment in both the UK and KIS data. These results suggest the complexity of open R&D strategies; some open R&D strategies may play different roles in sales and employment. For example, knowledge exploration (i.e., 'breadth of search') may not contribute to employment growth, but another strategy, such as collaboration with external partners (i.e., 'breadth of collaboration') can contribute positively to the creation of jobs.

5. Conclusions

This paper has explored the dynamic trends in open R&D strategies by comparing UK and Korean panel data. In the context of our sample, it was shown that 1) the open R&D strategy activities changed over time, 2) they can be both positively and negatively associated with firm performance and 3) they developed in different ways in two different countries. Our results may help senior managers and policy makers to recognise that open R&D strategy has to be implemented in such a way as to reflect the

characteristics of innovation systems in a particular country.

Though there are potential benefits offered by this research, this study suffers from some limitations. First, since only the variables that appear in both data sets were chosen, the boundary of analysis was inevitably limited. Further, as 'appropriability variables' and 'depth of collaboration' were not fully investigated in the UK data, only a limited comparison was possible. Second, our samples cover all types of manufacturing firms and provide general implications, but do not provide information as to how firm type (e.g., large vs. small firms) affects the adoption and implementation of open R&D strategy. Lastly, the time periods for the analysis did not coincide exactly. Although both data overlap in terms of the period, the KIS data cannot be free from the influence of the most recent global economic crisis (2008–2013). Future studies addressing these limitations can reveal clearer difference between the two countries and advance our understanding on the relationship between open R&D strategy and performance.

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