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Innovation Quality and Internationalization of R&D in Europe

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Abstract

This paper studies how international dispersion of R&D activities affects the innovation quality in large and medium size European firms. The internationalization of R&D is a growing phenomenon and it is especially prevalent among European firms. We use patent data from over 600 firms and measure the geographic distribution of their R&D activities using the locations of patent inventors. We analyze the innovation quality effects of international R&D by using several alternative innovation quality measures. The results indicate that internationally distributed R&D activities improve firms? innovation performance, but having very dispersed R&D organization may negate some of the gains. The choice of innovation quality measure is also shown to have an effect on the estimated relationship between innovation quality and R&D internationalization.

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ABSTRACT

This paper studies how international dispersion of R&D activities affects the innovation quality in large and medium size European firms. The internationalization of R&D is a growing phenomenon and it is especially prevalent among European firms. We use patent data from over 600 firms and measure the geographic distribution of their R&D activities using the locations of patent inventors. We analyze the innovation quality effects of international R&D by using several alternative innovation quality measures. The results indicate that internationally distributed R&D activities improve firms' innovation performance, but having very dispersed R&D organization may negate some of the gains. The choice of innovation quality measure is also shown to have an effect on the estimated relationship between innovation quality and R&D internationalization.

Keywords: R&D internationalization, innovation quality

JEL: O32, F23, L25

1. Introduction

The internationalization of corporate research and development (R&D) activities is an important and growing phenomenon (Cantwell and Janne 2000; Kuemmerle 1999b; Picci 2010; von Zedtwitz and Gassmann 2002). This paper studies how the international dispersion of R&D activities affects the innovation quality in European firms. In the early literature the firms' decisions on R&D internationalization and R&D locations was understood to be motivated by market seeking objectives. More recently, international R&D is considered to be driven also and perhaps even more importantly by knowledge seeking motives and better access to new technological knowledge (Kuemmerle 1999a; Le Bas and Sierra 2002; Lewin, Massini and Peeters 2009; Patel and Vega 1999). Despite the prevalence of knowledge seeking international R&D, the firm-level innovation performance and quality effects of geographically distributed R&D remain largely unstudied in the current literature. This paper contributes to this literature by studying European firms that present an interesting case of high R&D internationalization. Another novelty is that we measure the quality of innovations using patent citations and also using several alternative measures, which have not been used in the previous studies.

The earlier empirical studies, for example Penner-Hahn and Shaver (2005) and Chen, Huang and Lin (2012) have found internationalization to have a positive effect on the innovation quantity and quality in Japanese and Taiwanese firms. Similar studies by Singh (2008) and Lahiri (2010) have studied the effects of geographically distributed R&D using US data, but these studies offer conflicting results. Moreover, Kuemmerle (1999b) showed that while the US firms were pioneers in starting R&D facilities abroad, the European firms have caught up later on. The European firms internationalized their R&D activities rapidly in the 1990s and they now have even higher levels of R&D internationalization than their American or Japanese competitors (Archibugi and Michie 1995; Cantwell and Janne 2000; Gerybadze and Reger 1999; UNCTAD 2005). Common market within EU has further facilitated the internationalization of European firms, but the cultural and language borders remain important. This context promotes the European firms as an important case of high internationalization of corporate R&D, but despite these circumstances, the earlier studies have relied on US data leaving the European perspective unexplored so far.

The analysis in study uses patent data to locate the corporate R&D activities across countries and analyzes the innovation quality of internationally distributed R&D in large and medium size European firms. Our interest is especially in the international distribution of R&D and we do not consider the geographic distribution within countries, thus our approach is similar to Chen, Huang and Lin (2012). In contrast, Singh (2008) and Lahiri (2010) study the dispersion of R&D analyzing the geographic distance and also the cross-regional distribution of R&D. However, especially in Europe the national, cultural, and language borders are often more central for defining the markets and for the flow of knowledge than geographic distance, thus emphasizing the need for international analysis especially (Peri 2005; Picci 2010).

The international distribution of R&D activities can affect firm's innovation performance through several channels. The knowledge seeking view of international R&D (Chung and Alcácer 2002; Florida 1997; Le Bas and Sierra 2002) suggests that geographically distributed R&D units can access different sources of knowledge and integrate this knowledge within the firm and thus improve firm's innovation capacity. As earlier literature has shown, the knowledge spillovers are to large extend local (Audretsch and Feldman 1996; Branstetter 2001; Jaffe, Trajtenberg and Henderson 1993), and local presence is needed to access these spillovers more efficiently. Another potential gain for firms is that the number of available engineers and scientist may be limited in the firm's domestic labor market and access to larger international labor markets may improve the firm's innovation capacity. An opposite view (Argyres and Silverman 2004) argues that centralizing the R&D activities will create economies of scale and improve innovation output. Yet other researchers (Chen, Huang and Lin 2012; Lahiri 2010; Singh 2008) have argued that the relationship between innovation quality and geographic distribution of R&D depends on organizational practices, knowledge integration capabilities and other characteristics of the firm. Prior empirical studies provide an incomplete and mixed picture on which effects are dominating and more research is clearly required. Moreover, the existing literature is based on analysis of patent citations which are by far not the only innovation quality measure available.

The empirical results of this study suggest that international dispersion of R&D improves the quality of innovations in European firms. A dispersed R&D organization comes with increasing costs that may overturn the benefits of international R&D at a very high level of international dispersion. The alternative innovation quality indicators confirm the finding that international R&D improves innovation quality, but the choice of quality measure seems to affect the shape of estimated relationship between R&D internationalization and innovation quality.

The rest of this paper is organized as follows. The second section presents earlier literature and theory related to internationalization of R&D. The third section presents the data and the variables. Next, the descriptive statistics are presented. Fifth section presents our results and sixth section concludes the paper.

2. Theory and literature review

While there is long literature on internationalization and firm performance in general, there is less knowledge on the internationalization of R&D particularly. Although the themes are related, the R&D internationalization has followed different pattern as internationalization of manufacturing or sales and thus it needs to be analyzed separately. Previous literature shows that corporate R&D activities have been less globalized than corporate manufacturing activities, but since the 1990s the R&D has become more internationally distributed (Gerybadze and Reger 1999; Patel and Vega 1999; Picci 2010). Yet, the corporate R&D is still more concentrated in the home countries of the firms and overall concentrated in some highly developed countries (Kuemmerle 1999b).

2.1. Gains from internationally distributed R&D

Internationally distributed R&D makes a wide range of resources and significant potential gains available for the firms. One of the gains is improved knowledge sourcing opportunities. Local presence in different countries gives a firm a better access to local scientists, informal knowledge networks and universities (von Zedtwitz and Gassmann 2002). Studies have shown that overseas subsidiaries indeed access and use heavily the local knowledge pools (Almeida 1996; Frost 2001). Moreover, having R&D units in different locations allows a firm to create a diverse knowledge base within the firm which can facilitate innovation and lead to new ideas and new combinations of existing knowledge (Patel and Pavitt 1997). Another important aspect of international R&D, which can also improve the firm's innovation performance, is knowledge spillovers (Granstrand, Håkanson and Sjölander 1993; Kuemmerle 1999a). Because knowledge spillovers have largely a local nature, the R&D units benefit from collocation with industry peers more than other corporate activities which encourages firms to locate R&D units close to competitors (Alcácer 2006; Audretsch and Feldman 1996; Branstetter 2001; Jaffe, Trajtenberg and Henderson 1993). The more internationalized the corporate R&D activities are, the larger are the knowledge pool and potential spillovers which a firm can access.

Moreover, a shortage of skilled labor and scientists or other needed R&D resources in the home country may lead firms to offshore their R&D activities. However, international sourcing for skilled labor is likely to depend on the home country of the firm. Firms in small countries may find the domestic labor markets more restricting than firms from countries with larger domestic labor markets. According to Gassmann and von Zedtwitz (1999) high technology firms in small countries were internationalizing their R&D activities early because of the pressures of international demand and domestic labor markets.

Market seeking view of foreign direct investment (FDI) suggests that the R&D internationalization may be used to gain access to new markets and utilize the innovations developed in the home market (Penner-Hahn and Shaver 2005). International R&D facilities may be needed to adapt the existing domestically developed innovations to the conditions of foreign markets. Local R&D units may also allow the firm to bring new products more quickly to the local markets. For example, Lewin, Massini and Peeters (2009) found that this speed to market motive was an important factor for the choice of R&D location. Local R&D may improve the market access also because it may give the firm better knowledge of local laws and regulations (von Zedtwitz and Gassmann 2002). The market seeking international R&D may create new applications for existing technologies and it is likely to have positive effects on sales growth and other aspects of firm performance as well.

Other motives for international R&D include better adaptation to customer requests and preferences and improved local public image (von Zedtwitz and Gassmann 2002). Local presence may enable firms to make innovation work more cooperative with the customers. Since customers can provide an important source for new ideas and product developments (von Hippel 2005) and as these ideas may not be easily transferable, the innovation quality may benefit from local presence. Weterings and Boschma (2009) find that collaboration with customers has beneficial impact on firm's innovation performance, however, the geographic proximity does not seem to be crucial in their study.

Furthermore, international R&D may enable the firm to lower the R&D costs by utilizing country specific cost advantages such as buying inputs in a low cost country or by taking advantage of country specific R&D subsidies (von Zedtwitz and Gassmann 2002). However, in their study Lewin, Massini and Peeters (2009) find that while improving the efficiency of innovation process is important factor when innovation is offshored, the labor cost savings are not among the most important reasons.

2.2. Costs of internationally distributed R&D

In addition to the above mentioned gains, the internationally distributed R&D may also create extra costs for the firm. Evidently, general R&D activities as all corporate activities have potential for economies of scale, but if the firm's R&D facilities are spread out too wide and thin the firm cannot reach these economies (Argyres and Silverman 2004). R&D activities can also be subject to economies of scope as research projects in different technological fields may support each other (Henderson and Cockburn 1996). These benefits may also be lost with highly dispersed R&D organization.

Moreover, increased geographic dispersion of R&D activities increases the requirements for firm's internal communication and coordination. The overseas R&D units may need certain degree of autonomy to be able to access local knowledge networks and create new innovations (Ghoshal and Bartlett 1988), which, however, sets problems for firm-level coordination. Failings in coordination may lead to duplicated research efforts and waste of resources. The coordination problems in distributed organizations may become more severe with communication problems that the internationalization can create.

Geographic and cultural distances within the firm make the communication and inter-unit learning more time consuming and difficult. This is especially true for R&D units, because communicating R&D often means transferring tacit knowledge which may require face-to-face meetings which become more infrequent as the geographic distance grows. It has been argued that efficient learning requires either geographic, cognitive or social proximity (Boschma 2005), all of which are likely to become more difficult as the international dispersion increases.

The coordination and knowledge sharing among R&D units is also central to exploiting the presence in overseas R&D network to its' full potential. Once new knowledge is sourced from a local knowledge network, the knowledge needs to be integrated with the existing knowledge base of the firm. If newly acquired knowledge does not have use in the local R&D unit, the knowledge may be wasted unless it is transferred among units so that it becomes available in the firm's other R&D units (Lahiri 2010; Penner-Hahn and Shaver 2005). If the motive of internationalization of R&D is knowledge sourcing rather than market seeking, the need for integration of knowledge is especially emphasized. The firm's knowledge integration capability depends on the local unit's scientific and communicational skills, thus further stressing the importance of communication and coordination.

A further cost related to distributed R&D organization is the fact that high degree of organizational dispersion may increase knowledge leakages out of the firm (Sanna-Randaccio and Veugelers 2007). A strain to the within firm communication is also created by Not-invented-here syndrome which may deter the firm from utilizing the inventions made by the competitors or own subsidiaries with their entire potential. However, this problem may be more severe in firms where the organization is more centrally integrated and experience with international R&D may prove helpful (Ambos and Ambos 2011; Gassmann and von Zedtwitz 1999). Overall, the above mentioned costs are likely to increase as the R&D activities become more internationally distributed.

2.3. Previous empirical studies

Based on theory, there are both significant benefits and costs related with international R&D and it remains an empirical question which effect dominates. This question has begun to receive attention in recent studies. For example Singh (2008), Lahiri (2010) and Chen, Huang and Lin (2012) have analyzed the innovation quality effects on R&D distribution. In these studies the innovation quality is measured using the patent citations. Singh (2008) studies the innovation quality effects of geographically distributed R&D using US patent data. The study is conducted at a patent level and the results suggests that patents that result from distributed R&D have lower quality, but cross-regional knowledge sourcing and personal ties improve the quality. Furthermore, Argyres and Silverman (2004) and Furman et al. (2006) also find that geographically distributed R&D organization is associated with lower innovation quality, which they measure with the number of citations and patents.

Some conflicting results are presented in papers by Lahiri (2010), Chen, Huang and Lin (2012) and Penner-Hahn and Shaver (2005). A firm level study on quality effects of geographically distributed R&D is conducted by Lahiri (2010), who uses US Patent Office (USPTO) patent data for world's largest semiconductor firms. She finds that regionally and internationally distributed R&D has an inverted U-shape relation with innovation quality. Using USPTO data, Chen, Huang and Lin (2012) study Taiwanese IT firms and the international distribution of R&D and find that it has positive, S-shaped, relation with average innovation quality, which is measured with average number of citations per patent. Penner-Hahn and Shaver (2005) find that international R&D increases the patent output in Japanese pharmaceutical firms, but only when the firms possess previous innovation capabilities. Overall, these previous empirical studies provide a mixed picture on the quality effects of international R&D and the results are based solely on citation and patent counts.

3. Data and main variables

3.1. Patent data as indicator of R&D location

The patent data have been used in numerous studies on firm and country level to study the magnitude, reasons and effects of R&D internationalization (Le Bas and Sierra 2002; Patel and Pavitt 1991; Patel and Vega 1999; Thomson 2013). Patent databases offer wide range of information on innovation activities worldwide. The patent information is available for a long time period and across almost all countries. The technology classification added by independent patent examiners provides information on the technical field of innovations. The limitations of patent based innovation indicators are also well known. Patents protect only technological inventions and hence many inventions, such as organizational innovations, cannot be patented. Moreover, patents are not the only way for firms to protect their inventions and many firms choose to use trade secrecy or lead time and do not patent their inventions. As consequence, the propensity to patent varies considerably across industries. Moreover, the value distribution of patents is large and skewed. The advantages and disadvantages of patent data have been discussed in more detail for example in Patel and Pavitt (1991) and Le Bas and Sierra (2002).

Studying R&D internationalization using patents is convenient, because the patent applications can be assigned to a country based on the country of inventor, the country of applicant or the country where the application is filed. However, firm's patenting strategy affects who is named as the applicant of the patent. The application may be filed by the subsidiary where the invention is developed or it may be filed by the parent firm. Also, the patent office where a priority patent is filed is affected by the patenting strategy of the firm. For example, in some fields, such as the ICT sector, it is common to file the priority applications at UPSTO even if the firm has its' main activities elsewhere (Chen, Huang and Lin 2012). Therefore, the applicant's home country or location of the patent office does not give accurate picture where the inventions are developed. However, the patent application also includes the names and locations of patent's inventors. The addresses of the inventors give more accurate picture where the inventions are developed, although it is possible that an inventor has recently moved to another country and wrong address is listed in the application. In this case the inventor location can be misinformative. However, according to a case study by Bergek and Bruzelius (2010) inventor information gives fairly reliable picture on the location of the R&D work.

Our patent data comes from PATSTAT database and we use the patent filings to European Patent Office (EPO). Using EPO patent filings allows us at least partly to bypass the problem that foreign firms are usually more thinly presented in a single national patent office data. At EPO all firms from countries that are members of European Patent Convention should have equal standing. However, country specific factors may still affect whether firms file at EPO or national patent office. Some countries have been members of the European Patent Convention for a longer time and some national patent offices have higher filing fees than others, which affect the propensity of firms to file at EPO (De Rassenfosse and de la Potterie 2007). However, we consider only firms from countries that are members of the patent convention during the whole observation period and we control for year and firm specific effects which should make sure that the country specific differences in patenting strategies do not affect our result.

Using EPO patents may however limit our sample since not all patent filings by European firms reach the EPO phase. On the other hand, EPO patents have a good coverage of the inventor addresses and the forward and backward patent citations which are the main patent information that we use. This would not be the case for all national patent applications in PATSTAT that often have missing backward citation or inventor location information.

One limitation of this study is that by analyzing patents we are only able to measure new-to-market innovations. If the firms locate their R&D facilities abroad to imitate their competitors and not to create new-to-market innovations, then our patent-based measure does not give accurate picture of the R&D organization. Thus, by studying patent applications we can only learn about R&D that creates new-to-market innovations.

3.2. Index of R&D internationalization

To measure the international dispersion of R&D activities we construct a dispersion index. The dispersion index is counted for each firm in each year based on the inventor countries of patents that are applied in that year. We define the international dispersion index as one minus the Herfindahl index (Lahiri 2010; Singh 2008). The index is calculated as follows:

$$\text{R\&D dispersion index} = 1 - \sum_{k} N_k^2 \quad (1)$$

Where N_k is the share of firm's patent applications arising from inventors in country k.

$$N_k = \frac{PAT_k}{\sum_{k} PAT_k} \quad (2)$$

The dispersion index takes values between zero and one, where high values indicate high degree of international dispersion in R&D activities. The previous literature has also used other indexes and alternatively, we could use an entropy measure of geographic dispersion which is used for example by Chen, Huang and Lin (2012). The difference between these indexes is that the dispersion index sets more value on large shares, while the entropy measure gives relatively more weight on small shares. However, in practice the difference is not very large as the correlation between the two measures is almost 98% in our sample.

3.3. Patent citations as an indicator of innovation quality

The value distribution of patents is skewed and hence the prior research has often used patent citations to better capture the economic value of firms' innovations (Hall, Jaffe and Trajtenberg 2005; Harhoff et al. 1999; Trajtenberg 1990). We measure firm's innovation quality with the number of citations the firm's patent applications receive. After the patent application is filed and published, the application may be referenced by other patent applications, when the later inventions are based on or related to the earlier invention. These citations may be added by the applicant or by the patent office's examiner. The number of citations the patent receives has been shown to be associated with several aspects of patent quality, such as the economic and social value of the patent, firm's market value and patent renewal rate (Hall, Jaffe and Trajtenberg 2005; Harhoff, Scherer and Vopel 2003; Singh 2008; Trajtenberg 1990). The patent can receive citations over a very long time period, which we do not have time to observe. Thus we concentrate our interest on the citations received within 3 first years after the patent application is published[1].

The citation information in PATSTAT database covers well the patents applied in US, Germany, European Patent Office and WIPO, but the data are imperfect for many other patent offices. We use the EPO patent filings, so firm's country of origin should not affect the forward citation propensity. Moreover, we repeat our analysis using the number of patent filings and other innovation quality measures which are not subject this bias.

3.4. Alternative measures of innovation quality

Forward citations are only one of many different innovation quality measures. Alternative patent based measures of innovation quality include for example raw patent counts, patent renewals, patent family size, patent scope and so on (Harhoff, Scherer and Vopel 2003; Lerner 1994; Pakes and Schankerman 1984; Squicciarini, Dernis and Criscuolo 2013). OECD maintains a Patent Quality Indicators database that includes the above mentioned and several other patent quality indicators for all EPO patents. We use the patent family size and composite quality index described in Squicciarini, Dernis and Criscuolo (2013) to test the robustness of our forward citation based results.

Patent family size is the number of jurisdictions in which patent protection is filed for the same invention. Family size has been shown to be highly correlated with the value of patents and especially large international patent families have been found to highly valuable (Harhoff, Scherer and Vopel 2003; Lanjouw, Pakes and Putnam 1998). The family size is measured here by the number of patent offices at which the invention has been protected (Squicciarini, Dernis and Criscuolo 2013).

[1] The model was also estimated with all observed citations controlling for year effects to account for the different citation periods available for different patents. The main results remained unaltered.

The composite patent quality index consists of four quality indicators: number of forward citations within 5 years after publication, patent family size, number of claims and the patent generality index. The index covers only granted patents. The number of claims in a patent filing reflects the technological breadth of the patent but the number of claims may also imply higher patent fees, which corresponds to higher expected value of the patent. The generality index measures the technology class distribution of forward citations received. A patent that receives citations from patent applications in many different IPC technology classes is considered to be more general and valuable than patent that receives citations from patents in a single technology class. (Squicciarini, Dernis and Criscuolo 2013)

3.5. Control variables

We use several control variables in our estimations. Some of the firm level control variables are based on balance sheet data which is obtained from Bureau van Dijk's Orbis database. We control for the R&D intensity of the firms by including the ratio of R&D expenditure to sales as an explanatory variable. R&D intensity is commonly used as a proxy for firm's absorptive capacity and it is expected to affect the innovation quality positively (Cohen and Levinthal 1989; 1990). Missing R&D expenditure figures are replaced with zero and dummy variable is created to indicate these observations. The number of citations, which is the innovation quality measure, could be driven by large number of patent filings and not the innovation quality. Thus, we want to control for the number of patent filings, so that we can estimate the innovation quality separately.

We also measure the technological diversity of the firms by using the patent technology (IPC) codes at three-digit level. The diversity is measured using the same dispersion index (equation 1) which was used to measure the international dispersion of R&D organization. We also control for the size of the firm by including the log of firm sales as control. The previous literature has found firm size to have both positive and negative effects on innovation (Cohen and Levinthal 1989; Henderson and Cockburn 1996). Firm age is also often found to have an effect on innovation and hence age is included as control. Another control is added by including the average number of inventors mentioned in a patent filing as control. The R&D team size may have direct effect on innovation quality through more heterogeneous knowledge pool and wider knowledge network (Singh 2008). Lastly, year dummies are also included.

4. Descriptive statistics

Our sample covers 601 firms in 19 European countries in years 2003-2009. The sample includes independent or stock listed firms that have consolidated balance sheet data available in Bureau van Dijk's Orbis database. We restrict the analysis on medium size and large firms with sales over 10 million Euros. In order to use the patent data to study the international distribution of R&D activities we need to limit our attention to the firms that have applied for patents. To get a reliable measure of R&D internationalization we only consider firms that have at minimum 10 EPO patent applications during our observation period[2]. To avoid home bias in the patent applications, we include only firms from countries that have been members of European Patent Convention for the whole observation period. Patent data are consolidated and the parent firm is assumed to be the ultimate owner of its' subsidiaries' patents.

Table 1 below summarizes some descriptive statistics for the main variables in our data. The financial variables have been deflated using GDP deflator to year 2005 real prices. On average our sample firms have 35 citations per year with 48 patent applications. The average patent family size is 5.77 and the patent quality index has an average value of 0.266. In our sample, the annual sales are 7.4bn Euros on average and the R&D expenditures are approx. 5.5% of the sales. The main explanatory variable is the R&D dispersion index. It has an average value of 0.28, with highest value of 0.84 and many firms with no international dispersion in their R&D activities. Figure 1 shows the evolution of R&D dispersion index over time. As the figure shows the corporate R&D activities have become increasingly dispersed over time.

TABLE 1 here

FIGURE 1 here

Next, table 2 summarizes the correlations between the main variables. Statistically significant correlations are denoted with asterisk. R&D dispersion index is positively correlated with the number of citations and other innovation quality indicators, but the correlation is weaker

[2] Cut-off levels of 20 and 50 patents were also tested. The main results remained unaltered.

with the patent family size and innovation quality index. Finally, table 3 lists the number of observations per country. The German firms form the largest group, with France, UK, Switzerland and Italy following next.

TABLES 2 and 3 here

5. Results

The main dependent variable, quality of innovations, is measured using the number of citations firm's patent applications receive within 3 years after publication, which is a count variable. As there is overdispersion in our data the Poisson regression is not appropriate and therefore we use negative binomial regression model in our estimations.

We estimate the innovation quality effect of internationally distributed R&D on the firm level for each year. To facilitate causal inference, we lag all the explaining variables by one year. Hence, our sample for innovation performance estimation covers years 2004-2009. The explanatory variables are the R&D dispersion index, number of patent filings, R&D intensity, firm's sales, technological diversity index, firm's age, average number of inventors per patent and year dummies. We estimate both fixed and random effect negative binomial models.

Table 4 presents the results for basic model specifications showing both fixed effect (FE) and random effect (RE) results. Model 0 is the baseline model specification which excludes the R&D internationalization variable. Model 1 includes the R&D dispersion index as explanatory variable and Model 2 includes also the squared index. The results indicate that international dispersion of R&D activities improves the innovation quality, but the coefficient of the squared term is negative and significant, which suggests that as the international dispersion increases the quality improvements get smaller and at high level internationalization the innovation quality decreases. The relationship between R&D internationalization and innovation quality is illustrated further in figure 2.

TABLE 4 here

FIGURE 2 here

Also other explanatory variables have significant effects on innovation quality. Unsurprisingly, the number of patent filings and R&D intensity have a positive effect on number of citations. Firm and R&D team size also have a positive effect while the firm age has a negative coefficient.

We test the robustness of our main results using alternative measures for innovation performance. We use the average patent family size of firm's patents as one quality indicator and a composite quality index is also tested. The dependent variables are the average quality index and the log of average family size of firm's patents in each year. The patent quality index is computed for granted patents only and hence the number of observations is slightly lower in this model. Technological diversity index is not among the explaining variables in these estimations, as the quality index is formed using the generality of patents and number of claims which are closely related with the technological distribution. All the explaining variables are again lagged by one year. The estimation results are reported in table 5.

The results suggest a positive relationship between R&D internationalization and innovation quality measured by composite patent quality index. However, the R&D internationalization's coefficient is not significant in the family size fixed effect model, which based on the Hausman test statistic is the correct specification for the family size regression. In contrast to the earlier results in table 4, the squared term of R&D internationalization is not significant in any of the alternative model specifications and hence it is not included in the results of table 5. Based on these results, it seems that depending on the innovation performance measure the effect of internationalization may be either linearly positive, take inverted U-shaped form or be statistically insignificantly positive.

TABLE 5 here

Lastly, we also use the number of patent filings as a measure of firm's innovation performance and estimate negative binomial models with fixed and random effects. The control variables are the same as in models 1 and 2. The results in table 6 show that the internationalization of R&D activities increases the number of patent filings in the following year. The squared term is significantly negative in the random effect negative binomial model but not in the fixed effect model.

TABLE 6 here

6. Conclusions

This study has investigated the relationship between internationalization of corporate R&D activities and innovation quality using data on over 600 large and medium size European firms in time period 2003-2009. This study contributes to the current literature by analyzing the innovation performance effects of R&D internationalization and by using several alternative innovation quality measures. Moreover, we concentrate our analysis on European firms which have not been the main interest in the earlier studies, even though the R&D internationalization has been reported to be especially prevalent among European firms. We also use EPO patent data that has not been used in the prior studies.

Our empirical results show that locating R&D units in different countries improves the innovation quality in European firms. However, the costs of dispersed R&D organization increase as the R&D activities become more internationally diversified. The results indicate that these costs negate some of the performance gains and the relationship between international R&D and innovation quality takes an inverted U-shape form when the innovation quality is measured with patent citations. Hence, firms that spread their R&D activities too widely are not able to reach all the benefits the international presence provides and their innovation quality suffers. Nevertheless, the R&D internationalization in most firms is still clearly lower than the ideal level the results suggest.

We conduct several robustness tests to confirm our results. In general, the robustness tests indicate a positive relationship between R&D internationalization and innovation quality. However, using alternative innovation quality indicators, such as patent family size, does not support the inverted U-shaped relationship between innovation quality and R&D internationalization, but they suggest a positive linear or in some cases insignificant relationship. While most of prior studies have solely used the citation counts, our results suggest that citation based analysis may give a partial picture of the performance effects of international R&D.

The results of this study should be read with some limitations in mind. Firstly, the choice of R&D locations is an endogenous decision by the firm. We use lagged explanatory variables to mitigate the problem, but this approach does not completely solve the issue. Secondly, by measuring innovations with patent data we fail to capture many new-to-firm innovations which are undoubtedly important part of firm’s innovation output.

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Table 1. Descriptive statistics

Variable	Mean	SD	Median	Min	Max
Citations	35.352	128.950	4	0	2213
Patents	47.988	159.449	8	0	2303
Citations/Patents	0.603	0.685	0.463	0	8.750
Quality index	0.266	0.078	0.257	0.048	0.677
Family size	5.770	2.908	5.156	1	29
R&D internationalization	0.284	0.264	0.257	0	0.843
Technological diversity	0.549	0.307	0.641	0	0.969
Sales	7367.5	20026.7	1066.8	11.2	314750
R&D/Sales	0.055	0.160	0.017	0	3.683
Firm age	62.435	57.914	47	0	490
Team size	2.495	1.143	2.333	0	14

Notes. 3099 observations. Financial variables in millions of Euros, in year 2005 real prices.

Table 2. Correlation matrix

	Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1.	Citations										
2.	Patents	0.9225*									
3.	Citations/Patents	0.1537*	0.0587*								
4.	Quality index	0.0162	-0.0173	0.2440*							
5.	Family size	0.0997*	0.0238	0.2634*	0.4131*						
6.	R&D internationalization	0.2382*	0.2408*	0.0229	0.0269	0.1615*					
7.	Technological diversity	0.1589*	0.1764*	0.0643*	0.0171	0.0383*	0.3353*				
8.	Sales	0.2634*	0.2886*	0.0364*	0.0368	0.0390*	0.1681*	0.1903*			
9.	R&D/Sales	0.0335	0.0168	0.1701*	-0.0226	0.1739*	0.0124	-0.0044	-0.0674*		
10.	Firm age	0.0968*	0.1201*	-0.0525*	0.0058	-0.0289	0.0989*	0.1118*	0.0566*	-0.1339*	
11.	Team size	0.1182*	0.0707*	0.2160*	0.0573*	0.3127*	0.1325*	0.1006*	0.0605*	0.2209*	-0.0049

Notes. 3099 observations. * statistically significant correlations at 0.05 level.

Table 3. Number of observations by country

Country	Obs.	%
Austria	73	2.37
Belgium	91	2.96
Denmark	107	3.28
Finland	174	5.65
France	413	13.26
Germany	835	27.03
Greece	3	0.10
Hungary	11	0.36
Ireland	57	1.79
Italy	249	8.09
Luxemburg	14	0.45
Netherlands	144	4.68
Portugal	4	0.13
Slovenia	11	0.36
Spain	60	1.95
Switzerland	281	9.13
Sweden	184	5.95
Turkey	20	0.65
United Kingdom	368	11.83
Total	3099	100.00

Table 4. Negative binomial model with citations as dependent variable

Dependent Variable:	Model 0		Model 1		Model 2	
Citations	FE	RE	FE	RE	FE	RE
R&D Int. Disp.			0.426***	0.457***	0.968***	1.092***
			(0.100)	(0.092)	(0.272)	(0.257)
R&D Int. Disp. Square					-0.806**	-0.948***
					(0.377)	(0.358)
Patents	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Technological Div.	0.501***	0.694***	0.419***	0.602***	0.396***	0.574***
	(0.091)	(0.086)	(0.093)	(0.088)	(0.094)	(0.088)
R&D Intensity	0.292*	0.518***	0.278*	0.504***	0.272*	0.496***
	(0.151)	(0.119)	(0.152)	(0.119)	(0.151)	(0.119)
R&D Missing	-0.101	-0.152**	-0.085	-0.128**	-0.082	-0.124**
	(0.072)	(0.062)	(0.072)	(0.062)	(0.072)	(0.062)
Log Sales	0.219***	0.253***	0.204***	0.238***	0.205***	0.238***
	(0.023)	(0.018)	(0.023)	(0.018)	(0.023)	(0.018)
Log Team Size	0.187**	0.288***	0.149*	0.248***	0.134	0.231***
	(0.081)	(0.074)	(0.081)	(0.075)	(0.082)	(0.075)
Log Age	-0.036	-0.050*	-0.037	-0.051**	-0.033	-0.048*
	(0.034)	(0.026)	(0.034)	(0.026)	(0.034)	(0.026)
Constant	-1.402***	-1.883***	-1.319***	-1.799***	-1.351***	-1.819***
	(0.235)	(0.184)	(0.235)	(0.184)	(0.235)	(0.184)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Nbo of obs	3099	3099	3099	3099	3099	3099
Nbo of firms	601	601	601	601	601	601
Log likelihood	-6584.702	-9537.444	-6575.630	-9525.177	-6573.334	-9521.666

Notes. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are reported in parentheses.

Table 5. Panel model with patent quality index and patent family size as dependent variables

	Model 3 Quality index		Model 4 Log Family Size	
	FE	RE	FE	RE
R&D Int. Disp.	0.025**	0.022***	0.058	0.128***
	(0.010)	(0.008)	(0.041)	(0.037)
Log Patents	-0.002	-0.005***	-0.013	-0.001
	(0.003)	(0.002)	(0.012)	(0.009)
R&D intensity	-0.033	-0.004	-0.092	0.109*
	(0.025)	(0.012)	(0.073)	(0.058)
R&D missing	0.002	0.001	0.013	-0.043*
	(0.008)	(0.005)	(0.033)	(0.026)
Log Sales	0.003	0.003**	-0.038	0.011
	(0.007)	(0.002)	(0.029)	(0.009)
Log Team size	0.011	0.018***	0.016	0.103***
	(0.008)	(0.006)	(0.030)	(0.028)
Log Age	0.000	-0.001	-0.007	-0.019
	(0.010)	(0.002)	(0.044)	(0.012)
Constant	0.254***	0.254***	1.830***	1.352***
	(0.065)	(0.014)	(0.265)	(0.077)
Year dummies	Yes	Yes	Yes	Yes
Nbo of obs	2402	2402	2953	2953
Nbo of firms	570	570	601	601
R-square (overall)	0.064	0.074	0.012	0.119
Hausman test	6.59		116.83	
p-value	(0.8838)		(0.0000)	

Notes. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are reported in parentheses.

Table 6. Negative binomial model with patent applications as dependent variable

Dependent Variable:	Model 5		Model 6	
Patents	FE	RE	FE	RE
R&D Int. Disp.	0.200***	0.279***	0.458**	0.575***
	(0.069)	(0.066)	(0.179)	(0.176)
R&D Int. Disp. Square			-0.396	-0.449*
			(0.253)	(0.248)
Technological Div.	0.159**	0.296***	0.149**	0.283***
	(0.062)	(0.061)	(0.062)	(0.062)
R&D Intensity	0.204	0.407***	0.205	0.408***
	(0.137)	(0.112)	(0.137)	(0.112)
R&D Missing	0.031	-0.033	0.033	-0.030
	(0.049)	(0.046)	(0.049)	(0.046)
Log Sales	0.170***	0.260***	0.171***	0.260***
	(0.022)	(0.016)	(0.022)	(0.016)
Log Team Size	-0.040	0.003	-0.046	-0.004
	(0.056)	(0.054)	(0.056)	(0.054)
Log Age	0.056	0.025	0.056*	0.025
	(0.034)	(0.025)	(0.034)	(0.025)
Constant	0.347	-0.453***	0.341	-0.457***
	(0.222)	(0.166)	(0.222)	(0.166)
Year Dummies	Yes	Yes	Yes	Yes
Nbo of Obs.	3099	3099	3099	3099
Nbo of Firms	601	601	601	601
Log Likelihood	-7330.269	-10608.22	-7329.043	-10606.572

Notes. *** p<0.01, ** p<0.05, * p<0.1. Standard errors are reported in parentheses.

Figure 1. Evolution of the R&D internationalization over time

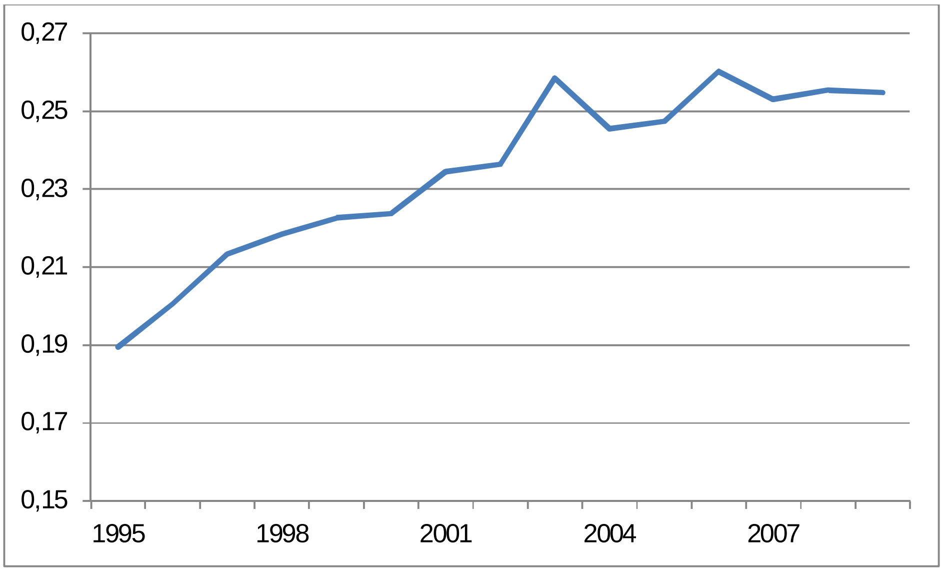

Figure 2. Estimated relationship between innovation quality and R&D internationalization