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Research collaboration and R&D outsourcing: Different R&D personnel requirements in SMEs

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ABSTRACT

The literature on 'open' innovation emphasises the need to engage in external knowledge relations in order to innovate. Particularly for SMEs, research cooperation and R&D outsourcing can offer possibilities to complement the often limited internal research resources. However, they also bring in their wake requirements in terms of absorptive capacity and managerial skills of the internal R&D personnel.

The paper focuses on the different requirements in terms of availability and training of research managers and R&D experts for research cooperation versus R&D outsourcing in SMEs. An empirical analysis of micro-level data provided by the OECD business R&D survey for Belgium reveals that the relation between R&D personnel requirements and research collaboration and R&D outsourcing depends upon the SME size. Therefore, to study this subject appropriately a distinction between very small, small, and medium-sized firms is relevant. Very small firms engage significantly less in research cooperation than medium-sized firms and the propensity to engage in research cooperation is positively associated with the share of PhD holders among the research managers and R&D experts. For R&D outsourcing a lower involvement is noted in medium-sized firms, and the propensity to outsource increases with the formal qualification level of the R&D personnel and with R&D training. Among the SME, small firms are most engaged in research cooperation and in R&D outsourcing. In the case of research cooperation they rely on highly qualified experts. For R&D outsourcing activities both the presence of research managers and R&D experts is important.

1. Introduction

Research cooperation and R&D outsourcing are important ways to explore new research areas with relatively low capital and lower risk involvement in case of failure. However, decisions to engage in these activities make firm boundaries permeable in order to attract and use external knowledge and technology. They bring in their wake important implications for the organisation of innovation processes (van de Vrande et al., 2009) and should be seen in relation to the management, research expertise and qualification and training of internal R&D personnel. Based on initial work by Narula (2001) it can be expected that there are marked differences in terms of internal firm requirements for R&D management between activities related to research collaboration on the one hand and R&D outsourcing on the other hand. These differences can be situated both at the level of managerial resources and in terms of in-house capacity in order to utilise the results (Veugelers, 1997; Narula, 2001, Lucena, 2011). Aspects which are of particular importance for SMEs since these are faced with scale limitations and, in a context of open innovation, increasingly have to devote resources to other aspects of the value chain in order to effectively market the internally developed and externally sourced knowledge (van de Vrande et al., 2009).

Both research cooperation and R&D outsourcing in SMEs involve challenges to handle the increasing complexity and management of innovation and extend beyond the traditional R&D department (van de Vrande et al., 2009). This can be related to the crucial importance of human resources for R&D activities in firms (Allen and Katz, 1992). Innovation adoption in SMEs is particularly affected by the people around them and by the skills and knowledge of the internal personnel (Sawang and Unsworth, 2011). For the time being, in a context of open innovation and for SMEs, the management of innovation is rather going through a process of trial and error than that it is part of professional management (Gassmann et al., 2010).

The focus of this paper is on the identification of differences in the internal requirements of SMEs in terms of research managers

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and R&D experts as well as their qualification and training according to firm engagement in R&D outsourcing versus research collaboration. Moreover, the research takes into account the heterogeneity of SMEs by differentiating between very small, small, and medium-sized enterprises. The focus on external knowledge relations in SMEs, the role of human resources for R&D, and size differences among SMEs are underdeveloped items in the literature on open innovation (Gassmann et al., 2010; Spithoven and Teirlinck, 2010).

The paper is structured as follows. Based on a literature review on research cooperation and R&D outsourcing in SMEs and the requirements in terms of research managers and R&D experts, Section 2 formulates the research question, Section 3 describes the dataset, and in Section 4 the empirical findings are presented. Section 5 highlights the main conclusions.

2. Literature review and research hypotheses

2.1. Research collaboration and R&D outsourcing

The growing complexity, huge budgets and risks related to innovation, the increased knowledge intensity , and the mounting competitive pressure for developing new products and processes, forces the R&D active company to look outside the firm's boundaries to complement its internal R&D efforts (Chesbrough, 2003; Coombs et al., 2003; Howells et al., 2003; Huang and Rice, 2009). External networking is an important way to do so and can take different forms of which research cooperation and R&D outsourcing are two prominent ones (von Hippel, 1988; Colombo and Garrone, 1996; Lazaric and Marengo, 2000; Chesbrough et al., 2006).

Research cooperation refers to both formal collaborative projects and informal networking activities with individuals and organisations (Chesbrough et al., 2006). It involves both knowledge generation contributing to the internal knowledge base (Cohen and Levinthal, 1990) and knowledge exchange of internally developed knowledge (Arora and Gambardella, 1994; Veugelers and Cassiman, 1999; Chiesa, 2001; Coombs et al., 2003). Firms may engage in cooperation in order to acquire missing knowledge, complementary resources of finance, to spread risks, to enlarge social networks, or to reduce costs (Hoffman and Schlosser, 2001; Mohr and Spekman, 1994). The firm's propensity to engage in research cooperation tends to increase with the internal R&D budget (Veugelers, 1997).

R&D outsourcing is also at the heart of the open innovation paradigm which emphasises that firms cannot (and should not) conduct all R&D activities internally and have to capitalise on external knowledge which can be licensed or bought (Gassmann, 2006). Veugelers (1997) highlights that the technology strategy of a company needs to emphasise the link between in-house development and external acquisition. In the absence of it, in-house R&D groups may hamper rather than stimulate effective external linkages. The choice between internal and external R&D is connected to the centrality of the technological competences to the firm's activities and R&D outsourcing is undertaken where doing so is cost-effective and does not threaten the competitive advantages of the company (Narula, 2001, 2004).

Research cooperation and R&D outsourcing are amply studied as facilitators to explore new research areas with relatively less capital and lower risk involvement in case of failure. However, far less is known about differences between research cooperation and R&D outsourcing in terms of requirements regarding occupation, qualification, and training of R&D personnel. To investigate these discrepancies differences in knowledge acquisition through research cooperation and R&D outsourcing are taken as a starting point.

To deal with knowledge acquisition one should, firstly, consider the nature of knowledge. Knowledge 'complexity' and 'tacitness' (Gosain, 2007; Simonin, 1999) are the most cited underlying dimensions of the nature of knowledge. Knowledge complexity can be defined as 'the number of interdependent routines, individuals, technologies and resources linked to a particular knowledge' (Simonin, 1999, p. 470). Knowledge tacitness (Gosain, 2007, p. 259) refers to 'how easy or difficult it is to codify and articulate the information that needs to be transferred for specific knowledge'. Both dimensions exert a strong influence on the ease of knowledge acquisition (Narteh, 2008).

A resource-based view of the firm can be used to demonstrate how innovation depends on the development and accumulation of specialised internal capabilities. To stimulate the development of internal capabilities the firm needs organisational integration: a set of relations that creates incentives for employees who participate in hierarchical and functional divisions of labour to apply their skills and efforts to the innovation process (Helper et al., 2000). To absorb knowledge from the external environment, firms need organisational integration in which employees function as interfaces with the environment. These employees have to possess the skills to screen, interpret and assimilate knowledge and transfer it through internal communication and diffusion on the work floor. At the same time, the acquisition of external R&D can be considered a knowledge-based transaction often characterised by complexity and contractual problems (Anand and Khanna, 2000).

Inspired by the OECD Frascati Manual (OECD, 2002) and Spithoven and Teirlinck (2010), the relation between R&D personnel and knowledge acquisition can be considered in terms of expertise and qualification; training; and management.

First, the role of experts should be seen in relation to the acquisition of complex and tacit knowledge which is closely related to absorptive capacity. Absorptive capacity refers to the ability of the recipient to utilise externally held knowledge by means of recognising and understanding potentially valuable new knowledge, assimilation of valuable new knowledge to transformative learning, and application of the acquired knowledge to create new knowledge and commercial outputs through exploitative learning (Cohen and Levinthal, 1990). If the external knowledge is actively used as a problem-solving capability it supports a skill (compared to experience) if it is tacit, and it becomes know-how (compared to information) if it is coded (Kogut and Zander, 1992). As such, a higher level of internal knowledge is helpful for firms to understand and acquire external knowledge. This external knowledge acquisition can help firms to accumulate relevant experiences and routines for knowledge sharing and interpretation, which in turn can promote the firm's absorptive capabilities (Eisenhardt and Martin, 2000). Veugelers (1997) used R&D departments with personnel holding a doctorate degree (as a measure for absorptive capacity) and found that their presence positively influences the effect of contracting on internal R&D. She also stresses that the complementarity between in-house R&D and external know-how depends on an optimal tuning to absorb effectively external know-how of in-house R&D groups. High qualified employees can be associated with higher R&D investment levels (Roach and Sauermann, 2010) and education and training are found crucial to innovation (Lam, 2005). High educational levels can be supposed facilitating the detection and management of relevant external knowledge flows (OECD, 2008), which are key ingredients in absorptive capacity (Roach and Sauermann, 2010). In particular in the case of doctorate degrees the body of research supporting this view is considerable (Stuart and Ding, 2006; Bercowitz and Feldman, 2008; Baba et al., 2010).

Second, training (and especially on-the-job-training) is considered an effective mechanism for transferring less-complex and

codified knowledge (Hansen, 1999). Moreover, it can be considered as an important element of a learning environment that constantly encourages employees to capture and use external knowledge, skills and expertise (Ajmal and Koskinen, 2008). It is a part of an organisational culture that motivates employees to act and behave in a particular manner (Alavi et al., 2005) and therefore has the potential to facilitate (e.g. Hamel, 1991; Simonin, 2004) or constrain (Gold et al., 2001) knowledge acquisition. People are the main conveyors of external knowledge and people with advanced professional skills can be supposed to learn more than people with poor working skills. Training programs can promote employees' professional skills (Minbaeva et al., 2003) and employees with higher professional skills will also be more likely to acquire external tacit knowledge. Since learning is a path-dependent process, employees with a good basic professional knowledge are more likely to observe and acquire external knowledge (Cohen and Levinthal, 1990). Lam (2000) finds that the narrower the interfaces to the external environment, the less knowledge and ideas are absorbed. The less internal employees learn about external ideas, the smaller the chance that they will succeed in their innovative efforts. Apart from a learning aspect related to skills which can be partly developed or learned at the working place, also skills obtained through education can exert an important influence on external networking (Lam, 2005).

Third, with regard to management, the increasing challenges and uncertainties in the business environment drive organisations to pay more attention to the productivity of knowledge assets. Good knowledge management can accelerate the information flow and enhances integration of knowledge, innovation and creativity in the organisation. To achieve this ideal, a well-developed knowledge management system should not only take advantage of the IT solutions but also of cultural change, rewards and an execution team (Malhotra, 2003), and pays considerable attention to knowledge exchange by means of patents and licensing (cf. Katz and Ordover, 1990). The importance of the availability of research managers both for research cooperation and for R&D outsourcing can be linked to the tacit nature of innovation and the potential loss of technological competitiveness requiring management skills for an appropriate knowledge protection and increased attention to the productivity of knowledge assets (Katz and Ordover, 1990). This is especially relevant in the case of SMEs (van de Vrande et al., 2009).

How can we relate knowledge acquisition and differences in R&D personnel requirements to R&D outsourcing and research cooperation? The basic assumption is that there are differences in the complexity and tacitness of the knowledge involved in research cooperation versus R&D outsourcing. In general, knowledge involved in research cooperation is supposed to be more tacit and complex, whereas – based on von Hippel's theory (1994) on the allocation of information and problem-solving capabilities along the innovation process – knowledge involved in R&D outsourcing tends to be less complex and more codified.

First, with regard to R&D outsourcing, this reasoning is supported both by views from a transaction cost and a technology sourcing perspective. According to transaction cost economics outsourcing occurs under conditions of low transaction costs. This is the case when asset specificity, the frequency of transactions, and uncertainty are low (Williamson, 1985; Walker and Weber, 1984). However, in the case of technological knowledge the uncertainty of the outcome and the information differentials between buyer and supplier (subcontractor) can create serious monitoring problems and external R&D expenditure will fall prey to moral hazard as the subcontractor may be tempted to sell the knowledge concerned to others. Therefore, technology transactions should be confined to standardised technologies (Milgrom and Roberts, 1987).

According to the views on technology sourcing the outsourcing of non-core activities allows firms to increase managerial attention and resource allocation to those tasks they do best (Narula, 2001). Also from the perspective of firm capabilities, the firm will outsource non-core activities in which it is not particularly specialised, but may still be important as support (Kogut and Zander, 1992). As such, technology outsourcing should concern relatively standardised technological knowledge which is non-core to the firm's activities. However, R&D outsourcing of more core-related activities facilitates the access of fresh knowledge and new technology. This helps to benefit from complementary capabilities. Though, this only occurs in the case of sufficient appropriation of the results of outsourced R&D (Teece, 1996; Chesbrough, 2003). Davidson and McFetridge (1985) found the probability of outsourcing to be lower, the more radical the technology and the larger the R&D department of the firm. Other studies indicate that, in general, outsourcing is more frequent the more codifiable and less complex the technology is (Wilson, 1977; Kogut and Zander, 1992). Veugelers (1997) emphasises that especially in the case of R&D outsourcing where the firm only gets the codified results and not the accumulated person-embodied skills there is a need to maintain a minimum level of in-house capacity in order to utilise these results. This can be related to the internal and external training of R&D personnel. According to Tidd and Trewhella (1997), in general, firms show a preference to outsource applied research and product development to public research organisations and universities because of the fear of giving away their technology to a (potential) competitor.

Second, research cooperation may give access to intangible tacit knowledge and know-how, which does not spill over and cannot easily be contracted through market transactions (Katsoulakos and Ulph, 1998). It allows exploiting economies of scale and scope in both research and development, hereby reducing innovation costs. And in the same vein, it helps to share risks (Röller et al., 1997) and facilitates tacit knowledge sharing and transformation by means of people-to-people interactions (Gold et al., 2001). Just like innovative activity within the firm, close R&D collaboration with others limits transaction costs. Moreover, it has the advantage to allow to access specialist knowledge that is present in research partners. Information sharing in co-operative agreements favours to internalise incoming knowledge spillovers more efficiently (d'Aspremont and Jacquemin, 1988; Kamien et al., 1992). However, within research cooperation the existence of imperfect appropriability increases the incentive of firms to free ride on their partners' R&D investments and fosters free riding by outsiders to the cooperative partnership (Kesteloot and Veugelers, 1995).

According to Narula (2001), alliances in particular (compared to outsourcing) require considerable managerial resources. This because of the collaborative aspect and because cooperation tends to be used in the case knowledge is tacit. Collaborative technologies encourage and facilitate employees to share and acquire new knowledge (Alavi et al., 2005). They allow organisations to communicate effectively, transfer and acquire knowledge from their partners, eliminating structural and geographical impediments that may have previously prevented such interaction (Gold et al., 2001).

Relational capital represents an important element in co-operation. It represents the long-term interaction between two partners in an alliance based on mutual trust, respect, and friendship (Kale et al., 2000). In such circumstances it can be related to intensive communications which lead to a high level of knowledge acquisition (e.g. Gupta and Govindaragjan, 2000). Srivardhana and Pawlowski (2007) found that social integration can lower the barriers to knowledge sharing and increases the efficiency and effectiveness of transformation and exploitation capabilities. Moreover, insufficient background about each other

and lack of common languages limits the ability to communicate and transfer knowledge across organisational boundaries (Lin et al., 2005). Chesbrough et al. (2006) emphasise that informal ties with employees of other organisations are crucial for understanding the creation and commercialisation of new products. Innovation by the individual employee – even beyond the organisational boundaries (Van Dijk and Van den Ende, 2002) – is a mean to foster organisational success (Van de Ven, 1986). Moreover, capitalising on the initiatives and knowledge of current employees stimulates to benefit from internal knowledge.

An important difference between research cooperation and R&D outsourcing is that the distinct type of knowledge provided generates different knowledge exposure and imposes different learning requirements (Lucena, 2011). R&D outsourcing tends to generate an interaction mode in terms of codified information about technical problems. Technological solutions are provided in the form of blueprints, manuals or technological packages. By contrast, research cooperation is a rather interactive form of learning involving knowledge generation based on a conjoint participation in research activities. Lane and Lubatkin (1998) highlight the main implications of this distinction. In case of R&D outsourcing, the firm's learning process related to the knowledge exchange needs to be seen in terms of problem-solving capabilities embedded in the production of the proper technological expertise. In case of research cooperation tacit sources of knowledge are provided allowing the firm to obtain not only standard forms of knowledge but also knowledge hardly definable outside the cooperation context. The latter implies that learning from cooperation is more demanding since more complex knowledge is provided. This requires more attention to managing capabilities in terms of research cooperation (Lane and Lubatkin, 1998). At the same time it helps to prevent the emergence of lock-out effects (Tidd and Trewhella, 1997).

2.2. SMEs

Empirical testing of research cooperation and R&D outsourcing has mainly focused on large (multinational) enterprises (Gassmann et al., 2010). Only more recently, in the open innovation literature attention is being paid to the implementation of external networking in SMEs. The relatively low attention to SMEs is somewhat surprising since there is considerable evidence (see e.g. Audretsch and Vivarelli, 1996; Laursen and Salter, 2004) that SMEs tend to have a higher R&D productivity compared to large firms which is largely due to the ability to innovate by exploiting more efficiently knowledge created outside the firm. This flexibility, adaptability and efficient internal communication process of smaller companies allow for a quicker response to external opportunities and threats (Veugelers, 1997). However, SMEs are disadvantaged due to their absolute size limitations which may be enhanced by tendencies towards multiple technological competences and cross-border competition (Narula, 2004). Pavitt (1998) refers to the cognitive limits on what firms can and cannot do by emphasising a minimum threshold size of a research group within any area, and this represents a constraint to SMEs. Narula (2004) argues that alliances in particular require some threshold level in terms of physical resources which are often too high for SMEs. Moreover, limited human resources in SMEs imply limitation to the absolute size of personnel that can be devoted to managing alliances. Also Rothwell and Dodgson (1991), when tackling the specific problems of SMEs in establishing external linkages, stress that the in-house employment of qualified technical specialists, scientists and engineers condition the ability of SMEs to access external know-how.

In a context of open innovation, SMEs increasingly have to devote resources to other aspects of the value chain in order to market the internally developed and externally sourced knowledge. Using a sample of 605 Dutch SMEs, van de Vrande et al. (2009) found that open innovation practices (in- and out-licensing of proprietary technologies, external networking, R&D outsourcing) have been increasingly adopted by SMEs in the period 1999–2005. They also found that medium-sized firms, on average, are more heavily involved in open innovation than their smaller counterparts and associate this with (compared to small firms) the larger disposal of the required scale and resources to organise a broader range of innovation activities. Also, many SMEs attempt to benefit from the initiatives and knowledge of their workers for technology exploitation. van de Vrande et al. (2009) reveal that the main barrier to open innovation in SMEs is related to organisational and cultural issues which arise when SMEs start to interact and collaborate with external partners. However, a major hampering factor for SMEs to innovate is the recruitment of specialized workers (Acs and Audretsch, 1990; Vossen, 1998; Rothwell and Dodgson, 1991). This forces SMEs to draw more heavily on their networks to find missing innovation resources.

Interesting views about SMEs growth are provided in the change management model developed by Greiner (1972). Greiner emphasises that for small (and young) firms creativity is the main driver. As SMEs grow they increasingly develop and apply formal structures, also marketed by recruiting specialized workers and introducing managerial layers, rules and procedures. This means that formal management becomes meaningful. This finding is important with regard to the size of the firm. Lucena (2011) argues that the more complex form of knowledge provision in research cooperation is positively related to increased use of innovation management practices and the presence of technological opportunities. Anand and Khanna (2000) add to this that research cooperation is positively associated to a higher learning potential. Small firms lack formal R&D management and a broad range of technological opportunities which may discourage them to engage in research cooperation. Anand and Khanna (2000) relate value creation in alliances – to be seen as incomplete contracts – both to the firm's experience in managing alliances and to the existence of persistent firm-specific differences in the (in)ability to create value. This can be linked to the costly process of the firm's learning dynamics in terms of the ability to acquire and assimilate information needed in order to specify and react to contingencies in research cooperation in terms of e.g. unanticipated changes in the environment; intangible attributes affecting the ongoing relationships between firms … (Anand and Khanna, 2000). Kogut (1989) (implicitly) highlights the difficulty to (develop the ability to) manage alliances. A main issue is related to firm specific effects in managing capability and in learning to manage research (Henderson and Cockburn, 1994) and for alliances (Anand and Khanna, 2000).

SMEs tend to be concerned about the possible loss of technical knowledge due to outsourcing and especially strategic cooperation because, more often, they are in a vulnerable position to maintain a sufficiently high level of internal competences in only a few (or even a single) technological areas (Narula, 2004). The smaller technological portfolio also creates fewer opportunities for SMEs to engage in research cooperation and may orient SMEs to R&D outsourcing. Knowledge intensive small firms are found to be less likely involved in external knowledge relations because they often rely on the exploitation of new ideas. Given the danger they face from leakage of their ideas, they limit the nature and scope of their external interaction (Laursen and Salter, 2006). However, other studies document the emergence of dedicated-small firms in high-tech industries, which tend to form R&D alliances with external agents as a way to bring their discoveries from the early research stages to the markets (see e.g. Bagchi-Sen and Lawton Smith, 2008 for insights in small biotech companies).

2.3. Hypotheses development

2.3.1. Relation between internal R&D resources and research cooperation and R&D outsourcing

Based on the insights provided by the literature regarding specificities in terms of more complex forms of knowledge provision in research cooperation compared to R&D outsourcing, different R&D personnel requirements can be expected along the type of external knowledge interaction for SMEs. The following research hypotheses are formulated:

Research hypothesis 1a. A higher internal availability in SMEs of research managers, R&D experts as well as their higher levels of qualification and involvement in training should be related to an environment favourable to external knowledge relations by means of research cooperation.

Research hypothesis 1b. A lower internal availability in SMEs of research managers, R&D experts as well as their lower levels of qualification and involvement in training should be related to an environment favourable to external knowledge relations by means of R&D outsourcing.

Based on the literature review differences between research collaboration and R&D outsourcing, as well as particularities for SMEs, can be expected in terms of internal personnel and training requirements due to differences in terms of R&D and innovation management capabilities (Lane and Lubatkin, 1998), learning potential (Lucena, 2011), training and recruitment of specialized workers (Acs and Audretsch, 1990), problem-solving capabilities (von Hippel, 1994) and complexity and contractual issues (Anand and Khanna, 2000).

2.3.2. Differences with regard to the size of SMEs

Little is known about small firms and their external networking capabilities and, as referred to by Anand and Khanna (2000), there is a need to explore possible unobserved differences. Inspired by the views by Greiner (1972) that, as SMEs grow they increasingly develop and apply formal structures, including recruiting specialized workers and introducing managerial layers, rules and procedures we elaborate upon the size effect of the SME. As will become clear in the empirical analysis a distinction will be made between very small, small-sized, and medium-sized firms in order to formulate the following research hypotheses:

Research hypothesis 2a. Requirements in terms of R&D experts for the engagement in external knowledge relations by means of research cooperation decrease with the size of the SME.

Research hypothesis 2b. Requirements in terms of research managers for the engagement in external knowledge relations by means of R&D outsourcing increase with the size of the SME.

Based on the scarce insights available in the economic literature, related to the less complex nature of knowledge provision and the limited internal technology portfolio and management capabilities, we expect R&D outsourcing to be more popular for smaller firms and research cooperation in these firms being more likely to be informal (Anand and Khanna, 2000). Therefore, the PhD expert, holding tied linkages with a university or public research organisation, can be expected to be a main driver for collaboration especially in small-sized firms. On the other hand, in R&D outsourcing a firm mainly gets the codified results and not the accumulated person-embodied skills. Therefore, there is a need to maintain a minimum level of in-house capacity. We can expect that medium-sized firms have more means to manage this process and pay more attention to train internal R&D personnel to implement the incoming technology. At the same time, as suggested by Greiner (1972) and Anand and Khanna (2000), for research cooperation in medium-sized firms we expect management and formal cooperation to be more standard. In between the limitations for very small firms and the more developed management capabilities in medium-sized firms (also in relation to more formal structures with regard to employment once firms reach 50 employees), small firms combine technology expertise with flexibility. This yields to the assumptions presented in Table 1 with regard to firm size of the SMEs and the internal R&D employment and training.

3. Data description

3.1. Survey and representativeness

Use is made of firm-level data from the bi-annual OECD business R&D survey for Belgium. This postal survey collects data regarding R&D (employment, cooperation, outsourcing …). Firms are defined at the level of the smallest legal entity: i.e. those having a VAT number. The survey is based on an inventory of (quasi-) permanent R&D active firms. This inventory is updated when a new survey is launched, taking into account both firms known from the past to be R&D active, and a monitoring of firms declaring to be R&D active (e.g. by means of press releases, demands for R&D grants, and regularly organised random and stratified samples among the population of firms).

This paper makes use of the R&D survey of 2006, offering results for the years 2004 and 2005. It was not possible to rely on more recent data because more recent surveys do not distinguish research managers among the R&D personnel. The target population consists of (quasi-) permanent R&D active SMEs with 10 employees or more. The threshold level of 10 employees was set because the collection of information of so called 'micro-enterprises' (i.e. SMEs with less than 10 employees) does not take place in a systematic way leading to biased results.

Table 1
SME size and strengths and hampering factors with regard to management, expertise and training for research cooperation and R&D outsourcing.

	VERY SMALL FIRM	SMALL FIRM	MEDIUM-SIZED FIRM
RESEARCH COOPERATION	Lack of critical mass to absorb full results and rather informal (personnel and trust based) relations due to limited managerial capabilities	Critical level of internal expertise reached and structure beneficial to both formal and informal networking	Critical mass both in terms of research and managerial capabilities. But relatively less room for informal initiatives
R&D OUTSOURCING	Possibility to compensate for limited internal R&D portfolio and critical mass but limited resources for internal training to implement external technology and knowledge protection	Sufficient critical mass to implement external technology and knowledge protection	Sufficient resources for internal training to implement external technology. However, broader portfolio and more internal critical mass could weaken the need to outsource

Table 2
R&D personnel and external knowledge exchange activities in SMEs, by firm size ($N=140$), mean (standard deviation).

	VERY SMALL FIRMS	SMALL FIRMS	MEDIUM-SIZED FIRMS	TOTAL
Variable acronym and description				
Background firm characteristics				
Firm size: Number of employees in 2005 – in full time equivalents	13.6 (3.0)	33.6 (9.3)	104.8 (51.6)	49.7 (46.9)
Firm age: Age of the firm in years in 2005	16.4 (11.6)	25.9 (21.2)	31.7 (20.9)	25.2 (19.8)
Dependent variables				
RESEARCH COOPERATION=1 if the firm is engaged in research cooperation in the period 2004–2005; 0 otherwise	0.24 (0.43)	0.41 (0.50)	0.33 (0.47)	0.34 (0.48)
R&D OUTSOURCING=1 if the firm is engaged in outsourcing of R&D activities in the period 2004–2005; 0 otherwise	0.49 (0.51)	0.52 (0.50)	0.26 (0.45)	0.44 (0.50)
Independent variables – research managers and R&D experts				
RESEARCH_MANAGERS: Total number of research managers in FTE, 2005	0.71 (0.98)	0.75 (0.81)	0.79 (0.87)	0.75 (0.87)
R&D_EXPERTS: Total number of R&D experts in FTE, 2005	1.98 (2.75)	2.90 (4.64)	1.56 (2.44)	2.25 (3.65)
PHD_HOLDERS: Share of research managers and R&D experts holding a PhD, 2005	0.11 (0.23)	0.09 (0.21)	0.10 (0.21)	0.10 (0.22)
R&D_TRAINING=1 if the firm invested in internal/external training of the internal R&D personnel to increase internal R&D knowledge in the period 2004–2005; 0 otherwise	0.62 (0.49)	0.67 (0.47)	0.62 (0.49)	0.64 (0.48)
Independent variables – general R&D characteristics				
R&D_PERS_INT: Share of R&D personnel in total firm personnel (in FTE), 2005	0.29 (0.29)	0.19 (0.24)	0.05 (0.05)	0.17 (0.24)
RESEARCH: Share of research expenditures in internal R&D expenditures, 2005	0.52 (0.36)	0.40 (0.37)	0.40 (0.34)	0.43 (0.36)
INNOPROD=1 if the firm introduced a new product on the market in the period 2004–2005; 0 otherwise	0.89 (0.31)	0.84 (0.37)	0.86 (0.35)	0.86 (0.35)
Independent variables – sector activity				
Information Intensive Services: computer and related activities; telecommunications; research and development; technical engineering	0.35 (0.48)	0.26 (0.44)	0.14 (0.35)	0.25 (0.43)
Science based Manufacturing: Primary sector (biotech); computers, office machinery; scientific instruments; pharmaceuticals; aerospace	0.16 (0.37)	0.08 (0.28)	0.09 (0.30)	0.11 (0.31)
Labour Intensive Manufacturing: textile and clothing; wood and furniture; non-metallic mineral products; recycling; construction; other manufacturing	0.14 (0.35)	0.26 (0.44)	0.26 (0.45)	0.23 (0.42)
Resource Intensive Manufacturing: food, beverages and tobacco; gas, water, electricity; non-ferrous metals; fabricated metal products; petroleum refining	0.00 (0.00)	0.08 (0.28)	0.07 (0.26)	0.06 (0.23)
Scale Intensive Manufacturing: other transport equipment; rubber and plastic products; chemicals; motor vehicles; ferrous metals; shipbuilding; paper printing	0.11 (0.31)	0.10 (0.30)	0.26 (0.45)	0.15 (0.35)
Specialised Suppliers Manufacturing: non-electrical machinery; electronics; communications; electrical machinery	0.19 (0.40)	0.14 (0.36)	0.12 (0.33)	0.15 (0.36)
Specialised Suppliers Services: financial intermediation; logistic services; business services; wholesale; posts	0.05 (0.23)	0.07 (0.25)	0.05 (0.22)	0.06 (0.23)
Number of observations	37	61	42	140

Note: The sector classificaton is derived from Pavitt (1984) and Tidd et al. (1997).

An SME is defined as a firm with less than 250 employees; not being controlled for more than 25% by firms that are not SMEs; having an annual turnover of less than 50 million euro and/or a balance total inferior to 43 million euro (EU definition of an SME – Article 2 of the Annex of Recommendation 2003/361/EC). The target population consists of 368 private SMEs. Due to both unit and item non-response in the R&D survey only 140 of these enterprises revealed detailed information on R&D personnel, research cooperation and R&D outsourcing agreements. As to the representativeness of the sample of 140 SMEs, a comparison has been made with the 228 SMEs excluded from the analysis. An independent samples *t* test to compare between both groups the means in terms of internal R&D expenditures, total R&D personnel, the share of R&D personnel in total employment, and the probability of engagement in R&D outsourcing revealed no significant differences between the firms included in the analysis and those excluded because of incomplete data. Guided by the differences in terms of open innovation behaviour and management according to the SMEs size class as highlighted by van de Vrande et al. (2009), the dataset has been divided in three subgroups. A first group is composed of very small firms (firms with 10 or more and less than 20 employees). A second and third group respectively have 20 or more and less than 50 employees (small firms) and 50 or more and less than 250 employees (medium-sized firms). The classification of SMEs by these size classes is based on the internationally accepted OECD Frascati Manual guidelines (OECD, 2002). Size generally affects the extent and nature of the R&D programs of entities in the business enterprise sector and employment is less ambiguous and therefore preferable measure for firm size. The proposed size classes for SMEs classification have been chosen in particular based on differences in R&D behaviour and for their ability to conform to the size classification adopted by the European Commission for small and medium-sized enterprises (which, however, also includes a turnover or balance sheet threshold) which in turn is related to policy making for SMEs in the business enterprise sector. This enhances the relevance of the analysis for policy making.

Compared to the classification used by van de Vrande et al. (2009) who, for the Netherlands, distinguish between two categories (10–99 employees and 100–499 employees) this classification is more detailed and takes into account the EC guidelines for distinguishing between small and medium-sized firms. In terms of SME size class (very small, small, medium-sized) and sector (extended Pavitt classification, see further), based on a chi-square test at 5% significance level, no significant differences in the distribution between the group of firms included in the analysis and those excluded could be found.

A comparison of the above mentioned variables at the level of the three size categories (very small, small, and medium-sized enterprises) as well revealed no significant differences between

the firms included in the analysis and those excluded because of unit or item non-response.

3.2. Data variables

Table 2 provides insights in the variables of relevance with regard to the research focus on associations between external network forms (research cooperation and R&D outsourcing) and the availability, qualification and training of research managers and R&D experts within SMEs.

Research cooperation and R&D outsourcing are measured as binary variables which take the value of 1 if a firm is engaged in this kind of activity. For research cooperation, in line with the arguments provided in the literature review, both formal and informal cooperation agreements are taken into account. With regard to R&D personnel a classification according to function and formal qualification is used (OECD, 2002). From a functional perspective a distinction can be made between researchers and R&D managers; technicians; and other supporting staff (OECD, 2002). This paper focuses on the first category. 'Researchers and R&D managers' are involved in the conception and generation of new knowledge, products, processes, methods and systems. Also the management of the R&D projects falls under this heading. For formal qualification, following Lam (2000), the share of PhD holders among the research managers and R&D experts is considered. In addition to formal qualification, also internal and external training of the internal R&D personnel has been highlighted as an important determinant for learning about external ideas (Lam, 2005). Within the survey PhD holder levels refer to research managers and R&D experts together and R&D training cannot be refined by qualification or occupation of the R&D personnel.

A first set of control variables relate to characteristics of the R&D activities and includes R&D intensity, and research and product innovation orientation of the R&D expenditures. These variables are supposed to be linked to the nature of knowledge within the firm (see e.g. OECD, 2002). However, the internal R&D focus is not necessarily related to the nature of knowledge exchanged in research cooperation or R&D outsourcing. Connected to the views connecting firm size and R&D productivity to different technological regimes (Revilla and Fernandez, 2012), sector of activity is added as a control variable. The sector activity refers to the main R&D activity and does not necessarily correspond to the main economic activity (e.g. a brewery with main activity of wholesales but R&D mainly in brewing is classified in the brewing industry and not in wholesales). Many classifications exist to account for the sector. In this paper, account is taken of an extended Pavitt sector classification including services (Pavitt, 1984; Tidd et al., 1997; Laursen and Salter, 2006). The approach can be justified since this classification both allows to verify the idea that 'open innovation' mainly started in the high-tech sector but there is a trend for the low-tech sector to exploit the potentials of opening up the innovation process (Spithoven et al., 2010), and the necessity to learn more about (particularities of) the service sector (Gassmann et al., 2010). However, since only (quasi-) permanent R&D active firms are included, the sector could be expected less important to determine the R&D characteristics (see e.g. Teirlinck et al., 2010 for a study on R&D outsourcing).

A main objective is to study the differences in R&D personnel requirements for cooperation and outsourcing behaviour according to the size of the SME. Therefore, the descriptive statistics are presented separately for very small (10 or more and less than 20 employees), small (20 or more and less than 50 employees) and medium-sized (50 or more and less than 250 employees) firms. With regard to the distribution of firms over the size categories, the average firm size of a medium-sized firm amounts to 105 employees. For small and very small firms this is, respectively, 34 and 14. The evolution in terms of employment during the three years before and the three years after the reference year was relatively stable (growth rates in interquartiles respectively between −15% and +8.3% and between −20% and +4.8%). This is not surprising since the focus in this paper is on quasi-permanent R&D active firms. The average size of firms increases with firm age. Since no firm age effect per size category could be identified, for reasons of parsimony, the age variable is not reported in the analysis in Section 4).

More than two out of five R&D active SMEs are involved in R&D outsourcing compared to one third involved in research cooperation. Research cooperation occurs (significantly) less in very small firms, whereas R&D outsourcing is (significantly) less probable in medium-sized firms (based on a two-way analysis of variance −5% significance level). The finding by van de Vrande et al. (2009) – who distinguish between medium-sized and small enterprises – that medium-sized firms are more likely to engage in external network activities could not be confirmed. However, this could be related to the different size classes taken into account by van de Vrande et al. (2009). They consider firms sized 10–99 as small and firms sized 100–499 employees as medium-sized. Our analysis shows that these classifications might be too broad since they potentially hide important within-class differences. A similar remark can be made for differences in the findings for cooperation compared to Lichtenhaler (2008) who concluded that firm size did not have a major impact on the degree of technology exploration.

For R&D personnel, and in line with the literature review, attention is paid to the presence of research managers and R&D experts, as well as their formal qualification and R&D training. On average, an SME employs 0.75 full time equivalent research managers. This represents about one fifth of the total R&D personnel and 3% of total firm employment. For each research manager, there are on average three R&D experts. 10% of the research managers and R&D experts hold a PhD and close to two thirds of the R&D active SMEs engage in internal or external R&D training of the internal R&D personnel. The presence of research managers is constant over the size-classes, whereas the availability of R&D experts tends to be inversed U-shaped in the sense that small firms are characterised by a higher intensity compared to the very small and medium-sized ones. However, the results based on the correlation matrix in Table 3 reveal no significant differences in terms of these variables in relation to the three size classes.

With regard to the 'general' R&D characteristics, an average R&D active SME employs five full time equivalent R&D persons, which represent 17% of the total firm personnel. The R&D personnel has an R&D budget of over five hundred thousand euro of which 43% is spend for research (versus development) activities. Over 85% of the SMEs are engaged in product innovation (versus process or other types of innovation), which on average accounts for 58% of the total R&D budget. According to differences related to firm size, a significant decrease with firm size in terms of the share of R&D personnel in total firm personnel can be witnessed (see also Table 3).

The descriptive information in Tables 2 and 3, guided by the differences found by van de Vrande et al. (2009), tend to justify the classification of SMEs into different size categories. As can be seen in the correlation matrix in Table 3, research cooperation and R&D outsourcing are not mutually exclusive and a positive correlation exists between them. This finding is supported by the views of Tidd and Trewhella (1997) and Narula (2001), who – taking into account the idea of absorptive capacity put forward by Cohen and Levinthal (1990) – highlight the distribution of (research and innovation) competences at firm level between research cooperation, R&D outsourcing, and in-house R&D.

Table 3
Correlation between variables of interest, SMEs, 2005, $N=140$.

	R&D OUTSOURCING	R&D_PERS_INT	RESEARCH_MANAGERS	R&D_EXPERTS	PhD_HOLDERS	INNO_PROD	RESEARCH
RESEARCH COOPERATION	0.18*		0.19*	0.31***	0.29***		
RESEARCH_MANAGERS		0.44***				0.24**	
R&D_EXPERTS		0.63***	0.31***			0.20*	
PhD_HOLDERS		0.34***	0.33***	0.25**			
R&D_TRAINING		0.18*		0.17*			
INNOPROD		0.21*					
INFORMATION INTENSIVE SERVICES	−0.21*		0.18*	0.19**			
SCIENCE BASED MANUFACTURING		0.36***	0.18*	0.25**	0.26**		
LABOUR INTENSIVE MANUFACTURING		−0.21*	−0.18*	−0.18*		−0.21*	−0.26**
SCALE INTENSIVE MANUFACTURING		−0.19*					
VERY SMALL FIRM		0.29***					
SMALL FIRM							
MEDIUM-SIZED FIRM	−0.23**	−0.34***					

Note: Only significant correlations are presented.

* Denote significance at 5% level.
** Denote significance at 1% level.
*** Denote significance at 0.1% level.

4. Empirics

The empirical analysis focuses on the research question whether or not differences in the size of the SME necessitate different requirements for research cooperation and R&D outsourcing in terms of research managers and R&D experts as well as their formal qualification and training. The descriptive statistics in Tables 2 and 3 revealed that R&D outsourcing and research cooperation are not mutually exclusive. Therefore, bivariate probit models are estimated for each size class linking the probability of engagement in both forms of external networking and the R&D personnel related variables:

$$\text{RESEARCH COOPERATION} = ß_1 X + ß_2\ \text{RESEARCH\_ MANAGERS} + ß_3\ R\&D\text{\_ EXPERTS} + ß_4\ \text{PhD\_ HOLDERS} + ß_5\ R\&D\text{\_ TRAINING} + \varepsilon_1$$

$$R\&D\ \text{OUTSOURCING} = ß_6 X + ß_7\ \text{RESEARCH\_ MANAGERS} + ß_8\ R\&D\text{\_ EXPERTS} + ß_9\ \text{PhD\_ HOLDERS} + ß_{10}\ R\&D\text{\_ TRAINING} + \varepsilon_2$$

where: X denotes the vector of the industry classification variable and the research related set of explanatory variables as presented in Table 2. Note: an alternative model has been considered including managers' and researchers' intensities (as a percentage of total personnel and as a percentage of R&D personnel). These intensities revealed to be not significant indicating that rather the absolute size instead of the intensity matters. This in line with Pavitt (1998) and van de Vrande et al. (2009) emphasising the threshold size for research and innovation.

In order to ensure a robust analysis only four industry categories are included in the analysis. The reason being the low number of observations (see Table 2) in one or more size categories for specialised supplier services (which was merged with specialised supplier manufacturing industries), and for scale and resource intensive manufacturing industries. Firms in the latter industries have been merged with SMEs in labour intensive industries and constitute a broad group of rather 'traditional' manufacturing activities. This category serves as reference category.

Table 4 presents the results of the three bivariate probit analyses by size class as well as the effects at the level of all size classes taken together. Important differences according to firm size exist in terms of the determinants for research cooperation and R&D outsourcing. First, an industry effect in science based manufacturing and information intensive service activities is witnessed. SMEs that are R&D active in information intensive services are significantly less involved in R&D outsourcing than the reference category. This effect is present in all size categories and at the overall level of SMEs. However, and compared to the reference category, the amplitude and significance of it tends to increase with the size of the SME. The finding that R&D outsourcing is less likely to occur in information intensive service firms is in line with the results by Laursen and Salter (2006) and van de Vrande et al. (2009). Laursen and Salter (2006) explain this by the fact that firms active in this sector often rely on the exploitation of new ideas and given the danger they face from leakage of their ideas, they limit the nature and scope of their external interaction (Laursen and Salter, 2006). However, this finding is not reflected in a significant lower engagement in research cooperation. In the science based manufacturing industry, very small firms significantly more rely on R&D outsourcing, whereas medium-sized firms seem to engage significantly less both in research cooperation and in R&D outsourcing. This could be related to the argument that once a certain level of critical mass is reached science based manufacturing firms perform their research significantly more internally.

These industry differences are somewhat unexpected since only permanent R&D active firms are included and earlier studies on R&D outsourcing revealed that the sector is less important to determine the R&D outsourcing behaviour (see e.g. Teirlinck et al., 2010). The extent to which these differences can be explained by the focus on (different size categories in) SMEs needs to be further explored.

The variables on research and product innovation barely influence the propensity to engage in research cooperation and R&D outsourcing. Also, hardly any differentiation exists according to firm size. A notable exception is the internal R&D personnel intensity (R&D personnel as a share of total personnel). In the case of small firms, the higher this intensity, the lower the propensity to engage in research cooperation and in R&D outsourcing. However, these results tend to change according to the inclusion of variables related to the occupation (managers and experts) and qualification (PhD holders) of the R&D personnel (see the results of a model without inclusion of more detailed characteristics regarding qualification and occupation – Appendix A1). We will interpret the results in more detail when discussing the outcomes of these variables.

With regard to the variables on R&D personnel, research managers and R&D experts, it turns out that their absolute presence and the formal qualification in terms of PhD holders and R&D training are associated with research cooperation and

Table 4
Bivariate probit model relating R&D personnel characteristics to research cooperation and R&D outsourcing in SMEs, by size class ($N=140$).

	VERY SMALL FIRMS		SMALL FIRMS		MEDIUM-SIZED FIRMS		TOTAL SMEs	
	RESEARCH COOPERATION	R&D OUT-SOURCING	RESEARCH COOPERATION	R&D OUT-SOURCING	RESEARCH COOPERATION	R&D OUT-SOURCING	RESEARCH COOPERATION	R&D OUT-SOURCING
Dependent variables								
SCIENCE BASED MANUFACTURING	−0.70 (−1.00)	7.28 (12.87)***	1.11 (1.29)	−0.29 (−0.47)	−7.30 (−11.07)***	−8.33 (−7.57)***	−0.22 (−0.47)	−0.12(−0.26)
INFORMATION INTENSIVE SERVICES	−0.66 (−1.00)	−1.73 (−2.05)*	0.14 (0.29)	−1.86 (−3.69)***	0.45 (0.77)	−7.79 (−6.31)***	0.09 (0.28)	−0.97 (−3.19)**
SPECIALISED SUPPLIERS	0.12 (0.12)	−0.38 (−0.49)	−0.24 (−0.51)	−0.91 (−1.87)	0.73 (1.25)	1.41 (1.90)	0.14 (0.47)	−0.03 (−0.12)
R&D_PERS_INT	0.85 (0.43)	0.56 (0.44)	−3.22 (−2.19)*	−2.81 (−2.12)*	−11.40 (−1.47)	3.15 (0.24)	−1.12 (−1.53)	0.74 (0.97)
RESEARCH	0.01 (1.02)	0.00 (.14)	−0.00 (−0.03)	−0.01 (−1.24)	−0.01 (−0.91)	0.00 (0.14)	−0.00 (−0.60)	−0.00 (−1.20)
INNOPROD	−1.47 (−1.23)	−1.24 (−1.50)	−0.31 (−0.67)	0.07 (0.13)	−0.73 (−0.95)	0.12 (0.12)	−0.32 (−0.95)	−0.14 (−0.42)
RESEARCH_MANAGERS	−0.90–1.79)	0.08 (0.19)	0.32 (0.96)	0.87 (2.50)*	0.70 (2.08)*	0.51 (1.19)	0.18 (1.11)	.20 (1.30)
R&D_EXPERTS	0.29 (1.93)	0.14 (0.99)	0.17 (2.39)*	0.14 (2.46)*	0.29 (2.18)*	−0.13 (−0.98)	0.14 (2.84)**	0.03 (0.68)
PhD_HOLDERS	7.23 (2.65)**	2.53 (1.02)	1.68 (2.08)*	−0.75 (−0.89)	1.23 (1.16)	3.02 (2.31)*	1.67 (3.07)**	0.23 (0.42)
R&D_TRAINING	−1.30 (−2.03)*	0.62 (0.81)	−0.20 (−0.52)	0.27 (0.65)	0.49 (0.95)	1.47 (2.12)*	−0.05 (−0.20)	0.33 (1.35)
CONSTANT	−0.03 (−0.03)	0.53 (0.77)	−0.18 (−0.37)	0.36 (0.66)	−0.53 (−0.77)	−2.66 (−3.03)**	−0.50 (−1.44)	−0.21 (−0.66)
Rho (significance Wald χ^2)	0.43 (0.16)		0.26 (0.29)		0.13 (0.70)		0.27 (0.07)	
Wald χ^2 model test	1794.26 (0.0000)		51.17 (0.0002)		2723.38 (0.0000)		48.70 (0.0003)	
Number of observations	37		61		42		140	

Notes: Reference sector: scale, labour and resource intensive manufacturing industry. The z-values appear between brackets (two-tailed tests).
The bivariate probit regression has been conducted robust to misspecification of error distribution. In order to highlight the robustness of the outcomes of the analysis, the results of an analysis only including the sector variable and the general research related variables are presented in Appendix A1.

* Denote the significance at 5%.
** Denote the significance at 1%.
*** Denote the significance at 0.1%.

R&D outsourcing. The fact that the absolute presence of research managers and R&D experts is more important than the relative share in the total firm or total R&D personnel is in line with Pavitt's (1998) recognition of the cognitive limits on what firms can and cannot do by emphasising that – besides the firm size independent challenge to consistently innovate at the technological frontier within the dominant paradigm – there is a minimum threshold size of a research group within any area, representing in particular a constraint to SMEs. As suggested by the literature review, marked differences exist between research cooperation and R&D outsourcing.

At the overall SME level research cooperation is significantly associated with research expertise (reflected by R&D experts and PhD holders), whereas R&D outsourcing seems to be independent from R&D personnel qualification. This finding is in line with the distinct type of knowledge provided in research cooperation versus R&D outsourcing: R&D outsourcing generates an interaction mode in terms of codified information about technical problems whereas research cooperation is more interactive involving knowledge generation based on a conjoint participation in research activities. The more complex and tacit knowledge involved in research cooperation demands for a larger absorptive capacity (Cohen and Levinthal, 1990) and can be linked to the presence of R&D experts and particularly PhD holders (e.g. Baba et al., 2010). Also at the overall level, no significant effects of management and training could be identified. This is somewhat surprising given the arguments – for differences between research cooperation and R&D outsourcing – by Lane and Lubatkin (1998) and Anand and Khanna (2000) concerning the need for management capabilities; von Hippel (1994) concerning problem-solving capabilities; and Lucena (2011) with regard to learning requirements.

However, these findings cannot be seen independently from the size of the SME. In terms of our first dependent variable, research cooperation, for very small and small firms, no significant association with a higher availability of research managers is found. In contrast, both the presence of R&D experts (significance level for very small firms is close to 0.05) and PhD holders among the researcher managers and R&D experts does significantly influence in a positive way the propensity to engage – within these size classes – in research cooperation. The importance of highly qualified R&D experts mainly refers to the need for internal research capacity and absorptive capacity (Cohen and Levinthal, 1990) for knowledge generation in research cooperation and also matters for medium-sized firms. However, for the latter group of firms, it is also the presence of research managers rather than the high education level that determines cooperation.

The differences according to SME size could be related to the view that high educational levels, and in particular PhDs, can be seen as facilitating the detection and management of relevant external knowledge flows (OECD, 2008), which are also key ingredients in absorptive capacity (Roach and Sauermann, 2010; Stuart and Ding, 2006; Bercowitz and Feldman, 2008; Baba et al., 2010). These findings suggest that, for smaller firms, the involvement in research cooperation could be part of the role of the researcher PhD holder, whereas in medium-sized firms formal R&D management takes a more decisive role for the engagement

in research cooperation. The fact that over half of the very small and small firms are engaged in research cooperation with universities or public research organisations supports this hypothesis (Tidd and Trewhella, 1997). The idea behind this is that PhD holders maintain formal or informal relationships with these organisations. This idea is corroborated by the negative relation between engagement in research cooperation and R&D training of internal R&D personnel. Additional information provided by the R&D survey reveals a strong concentration of cooperation within the proper region for very small firms. However, more detailed evidence is needed to highlight the differences (related to variation in the size of the SME) in the role of the research manager and the PhD holder for the engagement in research cooperation.

The second dependent variable, R&D outsourcing, shows important variations by firm size. A significant positive relationship with the availability of research managers and R&D experts exists for small firms. For very small and medium-sized firms, in contrast with research cooperation, there is no significant relationship with R&D experts. The difference with small firms could be related to the finding that small firms – on average – employ significantly more R&D experts than very small and medium-sized firms. The importance of an absolute – compared to relative – number of experts and or research managers is even more pronounced if the outcomes are linked to the previously found changing and negative influence of the R&D personnel intensity. In medium-sized firms, the lack of critical mass seems to be compensated for by a high education level (PhD holders) of the R&D experts and with significantly more internal and external R&D training for the internal R&D personnel. This could imply that the need to maintain a minimum level of in-house capacity (Veugelers, 1997) can at least partly be compensated for by properly managed training of internal R&D personnel.

The effects with regard to differences in firm size confirm the view by Greiner (1972) that, as SMEs grow, they increasingly develop and apply formal structures, including recruiting specialized workers and introducing managerial layers, rules and procedures. The presented evidence confirms that the more complex form of knowledge provision in research cooperation is related to a higher extent to the use of innovation management practices and the presence of technological opportunities (as highlighted by Lucena, 2011) and shows this to be more difficult in smaller firms. Similarly, with regard to learning potential, in line with Anand and Khanna (2000), especially small firms turn out to be discouraged and the research cooperation process is more informal and depending on the initiatives taken by individual highly qualified research experts in the absence of formal procedures (Greiner, 1972). These views are in line with Anand and Khanna (2000) who relate value creation in alliances to the firm's experience in managing alliances and to the existence of persistent firm-specific differences in the (in)ability to create value. These factors, in turn, are related to a firm's learning dynamics in terms of the ability to acquire and assimilate information needed. The argument by Kogut (1989) with regard to the difficulty to – develop the ability to – manage alliances is confirmed and positively linked to the size of the SME. This is in line with the views expressed by Greiner (1972). The importance of management for R&D outsourcing in the category 'small firms' relates size specific effects in managing capability and in learning to this type of research interaction (Henderson and Cockburn, 1994) for these firms. The findings confirm the existence of size to explain unobserved differences at the overall SME level (Anand and Khanna, 2000). A final remark tackles the high intensity in terms of PhD holders in very small firms. This intensity can be positively associated with research cooperation but not with R&D outsourcing. In medium-sized firms (which on average were found to be significantly less involved in R&D outsourcing – Table 2) this is exactly the opposite: PhD holders and R&D training can be positively associated with R&D outsourcing. However, in the latter case they are accompanied by formal R&D management support.

5. Conclusions

The open innovation literature argues that the management and organisation of innovation becomes more complex since it is extended towards activities other than traditional R&D department related ones. Especially small and medium-sized enterprises face challenges for the sourcing of external knowledge (Gassmann et al., 2010), and this not at least because of their absolute (R&D) size limitations. Research cooperation and R&D outsourcing may help to overcome this problem. However, related to the necessity to acquire and use external knowledge, these activities should be complemented by internal capacity in terms of R&D management and research expertise. Taking differences in the complexity and tacitness of the knowledge acquired as a starting point, the paper examined variations in requirements in terms of the availability of research managers and R&D experts as well as their qualification and training when it comes to research cooperation and R&D outsourcing. Moreover, based on empirical work by van de Vrande et al. (2009) the paper started from the assumption that these differences vary according to SME size.

An empirical analysis at firm level has been performed on the basis of a representative sample of 140 (quasi-) permanent R&D active SMEs in Belgium. Based on the EU definition of an SME a distinction is made between very small (10–19 employees), small (20–49 employees) and medium-sized (50–249 employees) firms. The empirical results confirmed the views by Pavitt (1998) and van de Vrande et al. (2009) that a threshold level of R&D personnel is needed, both in terms of research managers and R&D experts. Though, in line with the expectations from the theoretical literature there are marked differences in terms of required availability of research managers and R&D experts not only between research cooperation and R&D outsourcing (as highlighted by Narula, 2004; Veugelers, 1997) but also by the size of the SME.

Corroborating the theoretical expectations, the analysis revealed research cooperation to occur less in very small firms; whereas R&D outsourcing is less probable in medium-sized firms. The presence (in full time equivalents) of research managers is constant over the size-classes, whereas the availability of R&D experts tends to be inversed U-shaped in the sense that small firms are characterised by a higher level compared to the very small and medium-sized ones. The presence of a relatively high internal R&D expertise (absorptive) capacity within the small sized firms can explain the higher propensity to engage both in research cooperation and R&D outsourcing.

In very small and small firms, the presence of R&D experts and the share of PhD holders among research managers and R&D experts are positively associated with the propensity to engage in research cooperation. For medium-sized firms, it is the presence of research managers rather than PhD holders that promotes research cooperation. For smaller firms, involvement in research cooperation turns out to be part of the role of the researcher holding a PhD; whereas in medium-sized firms formal R&D management takes a more decisive role for the engagement in research cooperation. This turned out to be related to a strong engagement in cooperation with universities and public research organisations and cooperation within the proper region.

Also with regard to R&D outsourcing important variations are noted in accordance with firm size. For small firms a positive relationship with the availability of research managers and R&D experts exists. In contrast with cooperation activities, no such

Table A1
Bivariate probit model relating general firm and R&D characteristics to research cooperation and R&D outsourcing in SMEs, by size class ($N=140$).

	VERY SMALL FIRMS		SMALL FIRMS		MEDIUM-SIZED FIRMS	
	RESEARCH COOPERATION	R&D OUT-SOURCING	RESEARCH COOPERATION	R&D OUT-SOURCING	RESEARCH COOPERATION	R&D OUT-SOURCING
Independent variables						
SCIENCE BASED MANUFACTING	0.04 (0.05)	7.16 (15.97)***	0.56 (0.72)	−0.55 (−0.73)	−6.90 (−8.58)***	−7.69 (−6.57)***
INFORMATION INTENSIVE SERVICES	−0.95 (−1.66)	−1.03 (−1.41)	0.57 (1.34)	−1.05 (−2.54)*	−0.06 (−0.10)	−7.81 (−6.97)***
SPECIALISED SUPPLIERS	0.25 (0.30)	0.01 (0.02)	−0.07 (−0.14))	−0.64 (−1.37)	0.25 (0.43)	1.03 (1.64)
R&D_PERS_INT	2.86 (2.87)**	1.46 (1.13)	0.39 (0.45)	0.68 (0.88)	2.58 (046)	9.84 (1.23)
RESEARCH	−0.00 (−0.22)	0.00 (0.14)	0.00 (0.26)	−0.01 (−1.39)	−0.00 (−0.18)	0.00 (0.67)
INNOPROD	−0.86 (−0.95)	−0.93 (−1.19)	−0.25 (−0.54)	0.25 (0.49)	−0.02 (−0.04)	0.14 (0.18)
CONSTANT	−0.52 (−0.64)	0.51 (0.75)	−0.34 (−0.76)	0.45 (0.95)	−0.43 (−0.69)	−1.39 (−2.12)*
Rho (significance)	0.49 (0.11)		0.33 (0.13)		0.09 (0.76)	
Wald χ^2 test	2.53		2.34		0.10	
No. of observations	37		61		42	

Notes: reference sector: scale, labour and resource intensive manufacturing industry. The z-values appear between brackets (two-tailed tests).
The bivariate probit regression has been conducted robust to misspecification of error distribution.

* Denote the significance at 5%.
** Denote the significance at 1%.
*** Denote the significance at 0.1%.

association could be identified for very small and medium-sized firms. The difference with small firms lies in the fact that small firms – on average – employ significantly more R&D experts than very small and medium-sized firms. This creates a higher potential in terms of critical mass to absorb the results of R&D outsourcing. In contrast with very small firms, for medium-sized firms (which on average were found to be significantly less involved in R&D outsourcing) this seems to be compensated for by the relatively higher presence of PhD holders and R&D training which can be positively associated with R&D outsourcing. This seems to indicate that medium-sized firms are more able to use R&D training to internally use the results of outsourced R&D.

In summary, the findings in this paper clearly indicate that the propensity for a firm to engage in research cooperation or R&D outsourcing should be seen in relation to the internal R&D personnel potential to assimilate and manage external ideas and is linked to the size of the SME. The results obtained for R&D personnel requirements to a high extent are in line with the change management model developed by Greiner (1972) that emphasises creativity as the main driver for small firms and more importance of formal management as the firm becomes larger. Supporting Greiner (1972) and Anand and Khanna (2000) the results provide evidence that the size of the SME is an important determinant to account for differences in external knowledge interactions by means of research cooperation and R&D outsourcing. These differences can be related to different capabilities in terms of R&D and innovation management (Lane and Lubatkin, 1998), learning potential (Lucena, 2011), training and recruitment of specialized workers (Acs and Audretsch, 1990), and problem-solving (von Hippel, 1994) and complexity and contractual issues (Anand and Khanna, 2000).

Areas for further research include a more detailed view on research collaboration and R&D outsourcing partners (Teirlinck et al., 2010). In particular the role of universities and public research organisations deserve further attention since because of the fear of giving away their technology to a competitor or potential competitor, both large and small firms show a preference to outsource applied research and product development to public research institutes and universities (Tidd and Trewhella, 1997). Further research on the formal or informal characteristics of collaboration agreements and the role of the individual researcher in the SME is also needed. As this paper revealed, when studying these topics, it is necessary to take account of the size of the SME. Addressing the latter topic from a longitudinal firm-based perspective would reveal interesting information with regard to change management.

Appendix A1

See Table A1 above.

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