What drives the delegation of innovation decisions?
The roles of firm innovation strategy and the nature of external knowledge

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THE ROLES OF FIRM INNOVATION STRATEGY AND
THE NATURE OF EXTERNAL KNOWLEDGE

Abstract

We study what determines delegation of authority over innovation decisions in firms. Extant research that addresses this topic in an open innovation context, suggests that firms that engage in open innovation tend to delegate authority over innovation decisions. We provide a more nuanced argument that considers important contingencies. Thus, we argue that the extent of delegation depends upon the combined effect of the relative importance of innovation decisions to the firm's strategy and, when a firm engages in open innovation, on the nature of the external knowledge (*scientific* vs. *practical*) that it seeks to absorb from the external environment. We test our hypotheses on data from a double-respondent survey of Danish firms that we link to Community Innovation Survey data and to the Danish Integrated Database for Labor Market Research. We provide econometric results that support our hypotheses.

1. Introduction

Since Schumpeter's (1942) seminal work, it has been generally accepted that innovation is crucial for successful long-run firm performance and economic growth. However, how firms should organize their innovation activities is more contentious. In this article, we address an important aspect of this issue by focusing on decision systems, a key component of firms' organizational design (e.g., Galbraith, 1974; Colombo and Delmastro, 2008). We address the following research question: what makes firms delegate authority over innovation decisions (e.g., decisions relating to such aspects as entry into new technological fields, launch or termination of R&D projects, and development of new products or services) to R&D personnel (i.e. scientists, engineers and R&D middle managers) rather than centralize this authority in the hands of the CEO and other top managers? While several studies have examined the delegation of decision authority within firms (e.g. Acemoglu et al., 2007; Dobrajska et al., 2015; Graham et al., 2015), the delegation of authority over innovation decision remains an under-researched topic, in spite of its obvious importance.

An influential view, which builds on the absorptive capacity (e.g., Cohen & Levinthal, 1989, 1990; Zahra and George, 2002) and open innovation (e.g., Chesbrough, 2003; Fey and Birkinshaw, 2005; Laursen and Salter, 2006) literatures, emphasizes the merits of substantial delegation of authority over innovation decisions, combined with some formalization of procedures, and intense vertical and lateral communication (e.g. Jansen et al., 2005; Foss et al., 2011; Colombo et al., 2013; Foss et al. 2013; Arora et al., 2014). In this view, substantial delegation of decision authority allows employees to leverage their personal information and social links to identify sources of relevant external knowledge and to insource this knowledge. Broad communication channels inside the firm allow this knowledge to be disseminated inside the firm and deployed in the context of innovation. This "one size fits all" approach neglects the possibility that important contingencies can influence which organizational design is best for supporting the firm's innovation strategy.

We argue that firms choose the optimal extent of delegation of authority over innovation decisions depending upon contingencies relating to their innovation strategy. We first argue that the level of delegation relates negatively to firms' R&D intensity. A higher R&D intensity indicates greater strategic importance of innovation decisions, which is a force pushing towards less delegation of authority over innovation decisions to R&D personnel. This argument applies to firms adopting a closed innovation strategy, which conceives "the innovation process as typically carried out within the confines of a given firm, starting with firms investing in R&D to (internally) generate inventions" (Arora et al., 2016: 1116).[2] However, under an open innovation strategy when firms absorb external knowledge as an important input to their innovation activities, the nature of the knowledge they seek to absorb moderates the relationship between R&D intensity and the delegation of authority over innovation decisions. Following Hayek (1945), we distinguish between scientific knowledge and practical knowledge, where the former is knowledge generated by universities and other research organizations, and the latter is knowledge that is created by other firms (i.e., customers, suppliers, competitors, and other firms) and relates to the use of end-products, production equipment, or materials. We argue that when the absorption of scientific knowledge plays a key role in firms' open innovation strategy, the negative association between firms' R&D intensity and delegation is weakened, whereas the reverse holds true for the absorption of practical knowledge.

The logic behind these hypotheses is as follows. Scientific knowledge is more complex and less targeted to firms' specific needs than is practical knowledge, and therefore more difficult to absorb (Cohen & Levinthal, 1989: 582).[3] In a context where external scientific knowledge is a crucial input to firms' innovation and innovation decisions have great strategic importance, granting firms' R&D personnel extensive decision authority over those decisions has great benefits because

[3] This point also relates to the distinction in Cohen and Levinthal (1990) between "eleven basic and applied fields of science" and "five extra-industry sources of knowledge" (1990: 143-144).

these individuals are better able than firms' top managers to absorb external *scientific* knowledge, that is, detect, insource, assimilate and use it. This negatively influences the firms' inclination to centralize authority over innovation decisions at the top of the hierarchy the more important these decisions are for the firms. Conversely, in a context where external *practical* knowledge is fundamental, the information advantage of R&D personnel over top managers (and employees and middle managers in other functions) concerning the absorption of this practical knowledge is limited. This reinforces firms' inclination to centralize authority over innovation decisions at the top of the hierarchy.

To test our hypotheses, we combine several data sources. The first data source comes from a large-scale survey of 3,409 Danish firms in 2009. The survey comprises two questionnaires, one addressed to each firm's CEO and the other addressed to the most senior HR manager. The second data source was obtained from the official Danish statistics agency, Statistics Denmark. This panel database, known as the IDA database, contains detailed individual-level information on all members of the Danish labor market. We used this database to identify employees and link them to firms. Finally, we used data from the Danish implementation of the Community Innovation Survey. The results of the econometric models, including several robustness tests, confirm our predictions.

2. Theoretical background and hypotheses

2.1. Organizational design and absorption of external knowledge

The notion that access to knowledge held by external parties can result in successful innovation is central to both the absorptive capacity (Cohen and Levinthal, 1989; see Volberda, Foss and Lyles, 2010, for a review) and the open innovation literatures (Chesbrough, 2003, 2006; see Dahlander and Gann, 2010, for a review). Recently, research has started to examine the links between firms' organizational designs and external knowledge absorption (e.g., Volberda et al., 2010). For example, Jansen et al. (2005) find that cross-functional teams, job rotation, and subordinates' participation in decision-making positively influence firms' potential absorptive capacity (i.e., the ability to identify, acquire, and assimilate external knowledge), whereas realized absorptive capacity (i.e., the ability to transform and exploit this knowledge; Zahra and George, 2002:189), is related to organizational mechanisms that foster connectedness and socialization. Foss et al. (2013) show that the absorption of external knowledge in the context of opportunity exploitation is facilitated by formalization and delegation of decision authority. Arora et al. (2014) use the share of patents assigned by firms to their affiliates (i.e., their wholly owned subsidiaries) rather than to corporate parents to measure the level of delegation in R&D, and find that this share is positively associated with the share of acquired patents relative to total patents, which serves as a proxy of firms' reliance on acquisitions for technology insourcing.

A few studies focus on the organizational requirements of absorbing knowledge from *specific* external sources. For example, Bercovitz and Feldman (2007) examine on how explorative R&D conducted in collaboration with universities relates to the organization of internal R&D operations, and find that firms that have a highly concentrated R&D structure with most R&D operations conducted in a few labs also have higher levels of involvement with university-based exploratory R&D. Foss et al. (2011) consider knowledge absorption from customers and examine how "new organizational practices" such as a high degree of delegation of decision authority, a high level of vertical and lateral communication, and incentives for knowledge sharing stimulate the absorption of customer knowledge and its subsequent deployment in the context of innovation. Colombo et al. (2013) examine firms' collaboration with communities of practice. They show that software firms are more inclined to delegate authority over knowledge absorption from the open-source community to employees if they lack firm-level potential absorptive capacity and must therefore rely on the individual absorption abilities of their personnel.

Although such studies break new ground, they suffer from two shortcomings. First, in these studies the level of delegation of authority is usually measured at the firm level without considering the types of decisions and tasks to which the relevant decision rights refer. This means that, for example, delegation of decision authority over internal accounting is implicitly seen as relevant for understanding how firms organize to absorb innovation-related knowledge.[4] Second, these studies broadly assert that a high degree of delegation of decision authority is beneficial for accessing external knowledge. However, knowledge held by external parties might differ in terms of, for example, applicability, complexity, tacitness, and context dependence. As we shall argue later, different knowledge contingencies likely influence how the firm's organizational design supports the process of knowledge absorption.[5]

2.2. Benefits and costs of delegating decision authority

Our key dependent variable is the level of delegation of authority over innovation decisions, here defined as decisions about the internal development of new products and services, the launch of new R&D projects, and the management of R&D personnel. To the extent that firms adopt an open innovation strategy, innovation decisions also relate to recognizing relevant external knowledge, evaluating this knowledge, establishing contacts with external knowledge sources, transferring knowledge across the boundaries of the firm, transferring knowledge to relevant organizational units, combining the transferred knowledge with other internal knowledge, and deploying knowledge in the context of innovation.

[4] The few studies that do focus on R&D, innovation, and absorption of technical knowledge use proxies that only indirectly and imperfectly reflect delegation of decision authority over innovation decisions (e.g., Colombo et al., 2013; Arora et al., 2014).

[5] Only Bercovitz and Feldman (2007) raise this point to some extent, as their distinction between exploratory and exploitative efforts in the context of firms' collaborations with universities (which they link to the structural organization of R&D and the level of decision autonomy granted to R&D laboratories) might somehow capture different underlying knowledge characteristics.

Organizational theory (e.g., Galbraith, 1974) and organizational economics (e.g., Colombo & Delmastro, 2008) research helps to identify the determinants of the benefits and costs of delegation of decision authority that jointly shape its optimal level. On the benefit side, delegating authority over a focal decision downward the corporate hierarchy makes sense when top managers face high opportunity costs of getting involved in the decision (i.e., ineffective use of their time; Harris and Raviv, 2002), when middle managers and employees hold valuable knowledge and transferring this knowledge to their corporate superior is costly (Hayek, 1945; Jensen and Meckling, 1992; Dessein, 2002), when holding decision authority motivate employees (Aghion and Tirole, 1997; Benabou and Tirole, 2003), and when it is important to speed up the decision-making process, as occurs in highly dynamic environments (Radner, 1993). On the cost side delegation of decision authority can cause agency costs when the objectives pursued by middle managers and employees are less aligned with firm's objectives than those of the CEO and other top managers. These agency costs are greater when decisions potentially have a greater effect on firm performance. With delegation of decision authority, there are two additional sources of costs. The benefits of double-checking decisions to avoid costly mistakes are lost (Sah and Stiglitz, 1986), and there are concerns about potential coordination failures when decisions in one domain (e.g. marketing) generate externalities in other domains (e.g. production) (Bolton and Farrell, 1990; Alonso et al., 2008). In the following, we apply these arguments to the specific domain of innovation decisions.

3. Hypotheses

3.1. Delegation of authority over innovation decisions and firms' R&D intensity

Our first hypothesis is that the level of delegation of authority over innovation decisions decreases with firms' R&D intensity. As we explain in the following, in more R&D-intensive firms, innovation decisions have a strategic nature and are crucial drivers of firms' competitive advantages. Therefore, we expect these decisions to be more centralized at the top of the corporate hierarchy. Conversely, the strategic importance of innovation decisions is more limited in firms characterized by lower R&D intensity, and, accordingly, we expect that authority over these decisions is more likely to be delegated to R&D personnel. Several arguments support this contention.

First, optimal organizational design implies that top executives should make decisions concerning the highest-value activities (e.g., Harris and Raviv, 2002), which in R&D-intensive firms means centralizing innovation decisions at the top of the corporate hierarchy. Second, in more R&D-intensive firms, making the wrong innovation decisions has a stronger negative effect on firm performance; therefore, the greater benefits of double-checking innovation decisions lead to greater centralization of decision authority (i.e., less delegation). Although this organizational arrangement can slow down the decision-making process, it reduces the likelihood of costly mistakes. Third, in more R&D-intensive firms, the delegation of decision authority over innovation decisions to R&D personnel generates greater costs because loss-of-control problems have more severe consequence. In fact, the unpredictability of the results of R&D leaves room for opportunistic behaviors (e.g., pursuit of "pet" R&D projects) and, at the same time, makes it difficult to use high-powered incentives to realign the objectives of R&D personnel with the firm's objectives (Zenger, 1994; Lerner and Wulf, 2007). Finally, more R&D-intensive firms are more likely than are other firms to invest in basic, long-term, non-specific research projects that shape their future competitive position. These projects have the potential to generate positive spillovers across several business units, but their returns closely depend upon coordinated changes in other functions outside the R&D labs.[6] The centralization of decision authority over these projects allows for internalization of the

[6] A telling example is offered by X, the R&D facility created by Google to run futuristic projects ("moonshots") such as the self-driving car, Wing (product delivery across a city through flying vehicles) and Loon (high-altitude Wi-Fi

intra-firm spillovers they generate and leads to better coordination across functions (Argyres and Silverman, 2004).

Based on the above reasoning, we offer the following hypothesis:

H1: *More R&D-intensive firms have a lower level of delegation of authority over innovation decisions.*

3.2. Delegation of authority over innovation decisions in an open innovation context: the moderating role of the type of external knowledge

Although innovation openness has several dimensions, the absorption of external knowledge as a key input to firms' innovation activities is a dimension that has attracted considerable interest from open innovation scholars (Dahlander & Gann, 2010). Because this knowledge is generated by different sources, it has different characteristics that influence whether and how it can be effectively absorbed by firms. As indicated earlier, we make a distinction between scientific knowledge, produced by universities and other research organizations, and practical knowledge, produced by other firms (i.e., customers, suppliers, competitors and other firms).

Scientific knowledge potentially is a valuable input to firms' innovation activity, but it is typically complex and is generated with little consideration for its direct commercial exploitation (e.g., Stephan, 2012).[7] Universities and other research organizations produce science-related knowledge that is the output of fundamental research in basic sciences such as mathematics and physics and potentially can generate radically new technologies. They also possess state-of-the-art technical knowledge that is generated by applied research programs, and has a broad spectrum of application in different technological domains (Klevorick et al., 1995, pp. 189-190).

balloons) projects. Work at X is managed by Astro Teller (www.astroteller.net) and overseen by Sergey Brin, a Google co-founder.

[7] Consistent with this view, Walsh et al. (2016) show that patents generated by collaborations between firms and universities are of higher technical quality than are those arising from vertical collaborations (i.e., with suppliers or customers). However, given technical quality, they are less likely to be commercialized.

Firms can use scientific knowledge to both generate novel innovative ideas and launch new R&D projects (Cohen et al., 2002)—for example, as an input to explorative innovation activities—and to fix technical bottlenecks through innovative solutions that complete existing R&D projects—that is, as an input to exploitative innovation activities (Berkovitz and Feldman, 2007). However, scientific knowledge is generally not targeted to the needs and concerns of the firms that are absorbing it, as academic scientists are responsive to the incentives defined by the community of their peers (i.e., publications, citations) rather than the potential commercial value of research results (Stephan, 2012). Although academic scientists likely have intrinsic motivations to produce academic work because of their "taste for science" (Roach & Sauermann, 2010), they are unlikely to have intrinsic motivations to produce knowledge that is ready to use for firms, because "what is a challenging problem for a firm might not be interesting for academic scientists and engineers" (Tether and Tajar, 2008, p. 1082). Firms can induce academic scientists to commit effort to knowledge transfer activity by offering them adequate pay for their consultant services (Perkmann and Walsh, 2008), but for most academic scientists, technology transfer is an ancillary activity (Perkmann et al., 2013).

Consequently, although scientific knowledge consists of declarative knowledge and is disseminated through publications, the costs firms incur in identifying, insourcing, assimilating and using this type of knowledge can be significant because firms generally struggle to judge its quality and understand how it can add value to their operations. (Cockburn and Henderson, 1998; Gittelman and Kogut, 2003; Cassiman et al., 2018).[8] Firms' R&D personnel hold a significant information advantage over higher-level managers in performing these tasks because of their human

[8] Work on the biotech industry, in which scientific knowledge clearly is a key input to firms' innovation activities, supports our view. In fact, previous studies have long emphasized that to absorb scientific knowledge, firms must establish close collaborative ties with prestigious universities and star scientists. For this reason, they often co-locate their research activities with those of partner universities (Zucker et al., 1998; Audretsch and Stephan, 1996).

and social capital. Thus, firms' R&D personnel usually have backgrounds and mindsets similar to those of researchers, because many have PhDs and have been trained in the production of scientific knowledge. R&D personnel can rely on the proximity to science of their prior knowledge and their mastering of the language of science to effectively absorb scientific knowledge. In addition, firms' R&D personnel have often spent time as "insiders" in academia during their PhD or working as university professors before obtaining a job in industry. They attend scientific and technical conferences, and occasionally co-publish and co-patent with academic scientists. This social capital is fundamental to identifying academic scientists whose scientific knowledge is potentially valuable to the focal firm. It also helps to create effective communication channels with them and to induce them to commit the effort required to make their non-targeted knowledge more easily usable for commercial purposes (Van Dierdonck et al., 1990; Jensen and Thursby, 2001; Cohen et al., 2002). In accordance with this view, Tether and Tajar (2008) show that firms with a higher share of university graduates in science and engineering, who allegedly have more widespread social links with scientists in universities and other research organizations, are more likely to insource relevant innovation-related knowledge from these organizations.

As explained earlier, we predict a negative association between firms' R&D intensity and the delegation of authority over innovation decisions to R&D personnel. However, in a context in which external scientific knowledge is an important input to firms' innovation activities, this association is weakened. This is so for the following reasons. First, in this context, R&D managers and employees have an information advantage over higher-level managers. Transmission of this knowledge is ineffective as it likely generates communication leaks (e.g., Keren and Lehvari, 1989) and delays (e.g., Radner, 1993), leading to sub-optimal decisions. Note that in this situation centralization of decision authority would not eliminate agency costs. Indeed, R&D managers and employees can purposefully and safely distort the transmitted information, with the aim of inducing their corporate superiors to make decisions that are consistent with their personal objectives, despite these objectives are detrimental to the firm (Dessein, 2002). Second, the social capital that R&D personnel leverage to absorb scientific knowledge is a “sticky” resource, which cannot be used by firms’ top managers (Inkpen and Tsang, 2005). Third, delegation of decision authority over innovation decisions may generate intrinsic incentives for R&D personnel to commit effort and attention to the absorption of scientific knowledge (Benabou and Tirole, 2003).

In sum, in this context, the delegation of authority over innovation decisions generates benefits that do not materialize when the contribution of scientific knowledge insourcing to firm’s innovation is negligible. In turn, these benefits will clearly be larger for more-R&D-intensive firms, because for these firms, innovation decisions are more strategic. Accordingly, we expect that R&D-intensive firms that adopt an open innovation strategy based on the absorption of scientific knowledge, are more inclined to delegate authority over innovation decisions than are their counterparts for which absorbing scientific knowledge plays a negligible role. These ideas motivate the following hypothesis:

H2: *The negative relationship between firms’ R&D intensity and the level of delegation of authority over innovation decisions is weaker if scientific knowledge absorbed from universities and other research organizations is a key input to the focal firm’s innovation activities.*

Conversely, the negative relationship between firms’ R&D intensity and the level of delegation of authority over innovation decisions is stronger when, in an open innovation context, external practical knowledge generated by suppliers, customers, competitors and other firms is a fundamental input for the focal firm’s innovation activities.

Loss-of-information problems associated with centralization of decision authority over innovation decisions are not a serious concern for firms absorbing practical knowledge. Indeed, the characteristics of this knowledge, which differ markedly from those of scientific knowledge, confer at best a limited information advantage to R&D personnel. Whilst external scientific knowledge is distant from commercial applications, external practical knowledge has an applied nature, closely relates to the internal knowledge of the absorbing firm, and is targeted to its specific needs and concerns. Moreover, firms producing this external practical knowledge (e.g., suppliers of production equipment) clearly have incentives to convey it effectively to the absorbing firm because its effective insourcing, assimilation, and use by the absorbing firm generate greater profits for the knowledge-producing firms (Cohen and Levinthal, 1989; 1990). Therefore, in addition to R&D employees, within the focal firm, there likely are several employees and middle managers, in functions as different as purchasing, production, and sales & marketing, who are familiar with this external practical knowledge and can easily evaluate its value, insource, and assimilate it. Similarly, in the case of absorption of practical knowledge, R&D personnel enjoy a limited information advantage with respect to top managers. Indeed, firms' CEOs and other top managers have a general understanding of the technical knowledge and capabilities possessed by their competitors, suppliers, and customers.[9] Such an understanding is mandatory to make sense of the product-markets in which their firms operate, formulate effective (innovation) strategies, and, more generally, lead their firms.

Conversely, firms that adopt an open innovation strategy based on the absorption of practical knowledge from customers suppliers, and competitors (and to a lesser extent from other firms) can face substantial loss-of-control problems because of the appropriability hazards inherent in inter-firm collaborations (Williamson, 1991; Oxley, 1997). These loss-of-control problems are likely greater than are those experienced by firms that adopt a closed innovation strategy.

[9] This notion resembles the concept of *top management team absorptive capacity*, which Kor and Mesko (2013: 237) define "as the collective capacity of managers to absorb new knowledge and combine their existing knowledge repositories with new insights, assumptions, and knowledge systems".

Firms engaging in inter-firm collaborations expose their internal knowledge to the risk of misappropriation by partners. Knowledge misappropriation and its detrimental effects are commonly mentioned among the drawbacks of open innovation (Almirall and Casadesus-Masanell, 2010) and have been extensively analyzed by studies on coopetition (e.g., Gnyawal and Park, 2009; 2011), technological alliances (e.g., Diestre and Rajagopalam, 2012; Colombo and Piva, 2019), and corporate venture capital (e.g., Dushnitsky and Shaver, 2009; Colombo and Shafi, 2016). These studies indicate that unintended leakages of knowledge to partners and partners' subsequent misuse of the appropriated knowledge can considerably damage the focal firm's competitive position.[10] A focal firm's technical collaboration with a competitor aimed at absorbing its knowledge is case in point. Competitors are very dangerous partners. Because they serve the same customers, satisfy similar customer needs, and offer similar products and services, it is easy for them to absorb the focal firm's knowledge. In addition, they have great incentives to misuse the absorbed knowledge to the detriment of the focal firm. In fact, being active in the same product-market as the focal firm from which they have absorbed knowledge, competitors likely possess technological, productive and commercial resources, which are complementary to this knowledge. Hence, they can use the absorbed knowledge in combination with these complementary resources to improve their competitive position to the detriment of the focal firm (Colombo and Piva, 2019). Similar reasoning applies when the focal firm absorbs practical knowledge by collaborating with suppliers and customers. Suppliers of equipment or components likely have both the capabilities and incentives to absorb the knowledge of the focal customer firm, use it to improve their own products, and sell these improved products to the customer firm's competitors, thus damaging its competitive position

[10] Firms adopting an open innovation strategy based on the absorption of scientific knowledge are much less concerned about the risks of misappropriation of their knowledge by universities and other public research organizations. Education and research are the primary mission of these organizations, whereas making profits is a secondary objective. Moreover, although they often have third mission activities, they lack the complementary assets to exploit commercially the knowledge of partner firms' and compete directly in the market arena (e.g. Bercovitz and Feldman, 2007).

in its end product-markets. Likewise, a customer collaborating with a focal firm (for instance in the co-design of a product) can absorb the focal firm's knowledge and transfer it to a competitor, which then can commit to develop the same product and sell it at a lower price. The risk of knowledge misappropriation by partners from which a focal firm is absorbing practical knowledge and its detrimental effects are greater the more valuable and unique is the firm's knowledge. Therefore, appropriability hazards are greater for more-R&D-intensive firms that may possess more valuable technical knowledge.[11]

Because of the aforementioned appropriability hazards, R&D-intensive firms that adopt an open innovation strategy based on absorption of practical knowledge are less inclined to delegate authority over innovation decisions than similarly R&D-intensive firms for which absorption of practical knowledge is of negligible importance. Indeed, centralization of decision authority in the hands of CEOs and other top managers allows to closely monitor knowledge flows across firms' boundaries, to double-check which knowledge can be shared, and, ultimately, to limit dangerous leakages of valuable internal knowledge and the associated risk of knowledge misappropriation. Clearly, the intensity of this effect favoring centralization of authority over innovation decisions is weaker for less R&D-intensive firms because the loss-of-control problems generated by appropriability hazards are smaller for these firms. Hypothesis H3 follows:

> **H3:** *The negative relationship between firms' R&D intensity and the level of delegation of authority over innovation decisions is stronger if practical knowledge absorbed from other firms is a key input to the focal firm's innovation activities.*

4. Data and methods

4.1. Data and sampling frame

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[11] One might expect the extent of these appropriability hazards to differ across firms. For example, they might be greater for smaller and younger R&D-intensive firms, which lack the financial and legal resources to protect their internal knowledge (Lanjouw and Shankermann, 2004). The investigation of this interesting topic lies beyond the scope of the present work.

To test the above hypotheses, we used data from three sources. The first source is a large, paired-respondent survey of Danish firms that covers decision-making structures and firm strategies and was performed in 2009. The official statistical agency of Denmark (Statistics Denmark, http://www.DST.dk) administered the survey, which was sent to all Danish companies with more than 40 employees. The survey consisted of two separate questionnaires—one sent to each firm's executive top manager (e.g., CEO or president) and one sent to each firm's most senior HR manager. The questionnaire addressed to the HR manager contained questions concerning the firm's organizational setup, including its decision-making structure. The questionnaire addressed to the CEO focused on the firm's entrepreneurial and innovation activities.

Prior to sending out the questionnaires, Statistics Denmark tested it with several executives and senior HR managers. Because the pre-tests did not indicate comprehension issues, no substantial changes were made to the questionnaires. Statistics Denmark mailed the questionnaires directly to the relevant respondents. Specifically, each potential respondent received a personalized email containing a short description of the research aim of the survey and an individual password to the online survey. To facilitate a high response rate, non-respondents received up to two email reminders before being telephoned and requested to complete the survey. Of the 3,392 questionnaires sent out, we received double responses from 654 firms (19.2%).

The second data source was the Danish Integrated Database for Labor Market Research (IDA). The IDA database is a composite registry of information on all participants in the Danish labor market with a minimum age of 15. By relying on matched identification numbers, we were able to collect information on employees and top managers employed in each firm. To reduce bias caused by missing individual observations, a cutoff was employed. Specifically, list-wise deletion was used in the case of missing individual observations. When deletion resulted in more than 5% of the firm's employees being eliminated, the firm was removed in its entirety.

Finally, we integrated answers from the Danish implementation of the Community Innovation Survey (CIS). The CIS relies on stratified random sampling. Yet, chance overlap with our survey sample resulted in a final sample consisting of 235 firms.

Because this final sample combines different data sources, evaluating its representativeness is not straightforward. First, to probe whether our dependent variable was affected by our sampling, we compared the 235 firms in the final sample with all responses from the HR survey (n=1,234). Indeed, the items used to construct the average composite measure of delegation of decision authority over innovation decisions all came from the HR survey. Thus, by excluding matching with the CEO questionnaire, we maximize the comparison sample. We did not find any significant difference (at conventional confidence levels) across the two samples in the levels of delegation of authority over innovation decisions. Second, to evaluate possible biases relating to our main independent variable, that is, firms' R&D intensity measured by the share of R&D personnel out of the total workforce (see infra), we compared our sample with the full CIS sample (n=4,545). We found that firms in our final sample were not significantly different (at conventional confidence levels) from the full CIS sample in terms of R&D intensity. Finally, we compared our sample with the full sample of Danish firms with at least 40 employees in 2009 that were the target of the survey administered by Statistics Denmark. The samples were compared in the dimensions of firm age, size (measured by number of employees), and sales. The final sample was significantly different in terms of sales and age ($p < 0.05$). However, we were unable to detect a significant size difference. These differences in sales and age might call generalizability into question. However, we note that these variables are unlikely to be directly related to both delegation of authority over innovation decisions and R&D intensity, given also our inclusion in the model specification of firm size as a control. Thus, the results are likely not biased by the sampling strategy.

Common method variance concerns (Podsakoff et al., 2003) were addressed in several ways. First, information on various aspects of each firm's organizational design and operations was collected from different respondents based on each respondent's main area of responsibility. Second, the use of two additional (register) data sources mitigates concerns that unobserved factors caused biased estimates.

4.2.Variables

Dependent variable. Decision authority over innovation decisions can be centralized at CEO level or delegated to individuals at lower hierarchical levels. Moreover, authority can be differently delegated or centralized depending on the type of decision. For example, the authority to start an innovation project might not necessarily be coupled with the authority to shut down an existing project. To account for this dispersion of authority, we measured the delegation of authority over innovation decisions based on five questionnaire items. Specifically, respondents were asked "what is the lowest level that has the authority to make the following decisions:" 1) "develop new products or services"; 2) "introduce major innovations in marketing activities"; 3) "decide which new projects to pursue"; 4) "make significant changes to products and services" and 5) "discontinue a major existing product or service". Respondents were presented with a generically worded scale covering four different hierarchical levels as the relevant decision-making loci and asked to place each of the above-mentioned tasks on one of these levels. The scale ranged from the lowest (1: top management; e.g., executive director or deputy director) to the highest (4: lower-level management; e.g., head of department or first-line manager) level of delegation of decision authority. The other two scores represented intermediate situations in which decision authority over innovation decisions is placed in the hand of middle managers who are relatively closer to the top or the bottom of the corporate hierarchy, respectively. We used standardized items to construct an average measure of delegation (Bloom, Sadun & Van Reenen, 2007). The constructed average composite measure

(*Delegation)* showed acceptable internal reliability as a measure of delegation of decision authority over innovation decisions (alpha = .73). The use of an average composite measure was further supported by the high correlations among the five individual delegation items, presented in Table 1.

[Insert Table 1 Here]

Independent variables. We used information collected through the Community Innovation Survey (CIS) to construct the independent variables for firms' R&D intensity and type of knowledge sources. More precisely, *R&D intensity* was constructed using information from the CIS and IDA databases. From the CIS, we collected information on the number of research personnel employed by the firm. Based on information obtained through IDA, we normalized this count by the firm's total number of employees. The ratio of R&D employees to the total workforce is a typical indicator of firms' innovative effort. For instance, Cohen and Levin (1989, p. 1064) note: "most commonly, innovative effort is measured by expenditures on R&D or by *personnel engaged in R&D*" (italics added), although extant research on knowledge absorption predominantly employs measures based on total R&D expenditures relative to sales. This last measure might be less appropriate in the context of this study. First, measures of R&D intensity that rely on measures of R&D expenditures and sales can fluctuate based on market conditions. Therefore, in cross-sectional samples, these measures are likely to be confounded by market variations. Conversely, the measure we employ is more stable over time because it varies with deliberate decisions to increase or reduce the employment of research personnel and does not vary with fluctuations in sales or investments in R&D assets, which can be quite erratic over time. Second, our sample includes several small and medium-sized firms. These firms often do not report R&D expenditures, because they do not have formal R&D activities. For these firms, data on personnel involved in R&D are a more reliable indicator of R&D intensity in comparison with R&D expenditures.

Scientific knowledge is a dummy variable equal to one if the firm indicated that it had collaborated on innovation projects[12] with one or more sources of scientific knowledge. Four of the knowledge sources included in the CIS were coded as scientific sources: 1) universities or other higher-education institutions, 2) public R&D institutions, 3) members of the Danish Advanced Technology Group,[13] and 4) private R&D institutions (e.g., innovation consultants and private laboratories). Similarly, *Practical knowledge* equals one if the firm engaged in collaborative innovative projects with sources of practical knowledge: 1) suppliers (e.g., of equipment, materials, or software), 2) customers/clients, 3) competitors or other firms in the same industry, and 4) firms in other industries (excluding customers and suppliers). In both cases, we use the existence of collaborative relationships with external sources of either scientific or practical knowledge as an indication of the importance of the corresponding type of knowledge for innovation activities in the focal firms.

Given that the two aforementioned knowledge variables measure external collaboration as a binary action (yes/no), we constructed two additional more fine-grained measures that also consider the importance of external knowledge sources to the focal firm's innovation activity. These two measures are used in the auxiliary main model. Respondents indicated whether each source of external knowledge has a "large," "some," or "small" effect on their innovation activities or whether it is considered "irrelevant." We use the perceived effect of scientific and practical sources to construct proxies for the importance of external scientific and practical knowledge sourcing. Inspired by Tether and Tajar (2008), we created variables measuring *Scientific knowledge intensity*

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[12] The CIS survey defines innovation collaboration as follows: "Innovation co-operation means active participation in joint innovation projects (including R&D) with other organizations. It does not necessarily imply that either partner derives immediate commercial benefit from the venture. Pure contracting out of work, where there is no active collaboration, is not defined as co-operation in this survey."

[13] The group is made up of nine independent research and technology organizations (http://en.gts-net.dk/). External knowledge sourcing is largely a domestic phenomenon. However, given the minimal knowledge insourcing from non-Danish organizations, these sources were included in our measure of knowledge sources.

and *Practical knowledge intensity*. *Scientific knowledge intensity* was given the maximum value (equal to 5) if the firm indicated that it had collaborated for innovation with scientific knowledge sources (indicated by the binary measure). For firms that did not indicate explicit collaboration with scientific sources, *Scientific knowledge intensity* was coded using the (perceived) impact of external scientific knowledge on the firm's innovation activities. The impact scale measures the perceived impact of external scientific sources (i.e., universities and other higher education institutions) for a focal firm's innovation activity using a 4-point scale (from not relevant = 1 to large = 4). *Scientific knowledge intensity* was given a value equal to 4 if the firm indicated that scientific sources had a large impact, a score equal to 3 in case of some impact, 2 in case of little impact, and 1 if scientific knowledge was irrelevant in terms of the firm's innovation activities. We defined *Practical knowledge intensity* similarly, based on the perceived impact of knowledge insourced from other firms. Thus, in comparison to the binary variables, the two augmented measures allow us to investigate whether our results are sensitive to the intensity of the impact on innovation of external knowledge sources of either scientific or practical knowledge perceived by firms that did not collaborate for innovation projects with those knowledge sources.

Controls. To mitigate concerns regarding confounding influences from contextual variables, our models included a large number of controls.

The first control variable directly addresses a potential shortcoming of capturing R&D intensity by means of the proportion of R&D personnel out of total workforce. A key concern relates to the presence of supporting staff. R&D likely necessitates that an array of non-research activities is carried out in support of the innovation activities. Thus, capturing the firm's R&D intensity only by means of its employment of research personnel may be misleading. To mitigate this concern, we control for the number of employees tasked with supporting R&D activities, but not directly engaged in this activity (*Support staff*). Support staff may include laboratory assistants, programmers, administrative personnel, machine operators, and so on. Second, certain characteristics of the firm's human capital may affect managers' disposition to delegate decision authority. The average educational level of senior managers was included as a control in all models. The educational level of senior managers has been linked to their behavior (Hambrick, Cho, & Chen, 1996). More educated senior managers may be more prone to delegating decision-making authority, e.g. because of their better monitoring abilities. However, they may also find it easier to comprehend R&D activities and thus be less likely to delegate authority over innovation activities. To control for the (ambiguous) influence of managers' educational level on delegation of innovation decisions, we included in the model the control variable *Manager education*. This variable was coded according to the International Standard Classification of Education (ISCED). The educational background of each manager was categorized based on eight education levels (e.g., primary school, high-school diploma, bachelor's degree, master's degree). The variable, ranging from 1- 8, was then aggregated to the firm-level through averaging.

The inclusion of other firm-level controls was largely based on factors highlighted in previous studies among the antecedents of the level of delegation of decision authority (see e.g. Colombo & Delmastro, 2008: Chapter 2). *Firm size* was measured as the natural logarithm of the number of employees. Previous studies generally show a positive association between firm size and the delegation of decision authority. *Firm age* can influence the likelihood that the firm will delegate decision authority, as older firms may have routines and standards that make it difficult to deviate from the established authoritative norm. We measure firm age as the number of years from firm formation to 2009.

Several other controls account for characteristics of firms' organization that may be associated with more (or less) delegation of decision authority. *Hierarchical levels* controls for the number of hierarchical levels within the firm (i.e., vertical depth). Specifically, we asked respondents to report the number of levels between the most senior manager and the non-managerial employees (both levels included). To restrict the influence of variance in firm size, we capped the measure at ten levels. The firms' vertical depth likely influences delegation of decision authority in at least two ways. First, a firm may be more inclined to delegate decision authority to lower levels in the corporate hierarchy just because they have created more vertical levels. The second reason for controlling for the hierarchical setup of the firm relates to the way in which we measure of our dependent variable. Despite the use of generically worded levels, firms may systematically vary in how decentralized they perceive authority depending on the number of hierarchical levels. For example, in a firm with relative few hierarchical levels, delegating decision authority from top to middle management may be viewed as considerable decentralization. In a firm with many hierarchical levels, the same degree of delegation may be perceived as negligible. Thus, controlling for hierarchical levels alleviates problems of respondents unintentionally misreporting the true level at which decision authority is vested.

All models also include a broad measure of the characteristics of the firms' organizational design (*Organizational design*), based on whether the organizational design is organic or mechanistic. In particular, we chose to measure the extent to which the firm is characterized by an organic structure. Organic structures have previously been associated with firms' rate of innovation and their strategic learning capabilities (Aiken and Hage, 1971; Anderson et al., 2009). Our measure of organicity includes five items covering the firm's preference for: 1) "getting things done, even if this means disregarding formal procedures," 2) "opening channels of communication with easy access to important information," 3) "managerial styles that are allowed to range from the very formal to the very informal," 4) "letting the expert in a given situation have the final say in a decision-making, even if this means temporarily bypassing formal lines of authority," and 5) "adapting to changing circumstances without too much concern for past practice" (cf. Khandwalla, 1977). Based on Likert-scale responses (from 1 = “never or to a very low degree” to 7 = “to a very high degree”), an average composite measure was constructed (Cronbach’s alpha = 0.71).

We also control for the structure of R&D activities. *R&D department* is a dummy variable that equals 1 if the firm indicated that it has an internal R&D department. Firms with an R&D department generally employ more R&D personnel on a full-time basis and thus our measure of R&D intensity is more accurate for these firms. Conversely, firms which do not have a R&D department are likely to underestimate the share of R&D personnel out of the total workforce, as R&D activities are less formalized and often performed by employees on a part time basis. Omission of this control may lead to a downward bias in our estimates of the relation between *R&D intensity* and *Delegation*.

The hierarchical level at which the authority to engage in knowledge sourcing is vested may directly influence the delegation of authority over innovation activities. To control for this effect, we inlcude in the model an average composite measure of delegation of authority over collaborative activity (*Delegation of collaborative activity*, alpha = 0.75). The measure is constructed using two items from the questionnaire with the same scoring as the dependent variable, that is, the extent to which authority over decisions relating to 1) collaboration with other units in the firm and 2) collaboration with external firms or organizations are delegated. The measure includes internal knowledge sourcing given the substitution effect between internal and external knowledge sourcing. Moreover, the levels of delegation of decision authority over internal and external knowledge sourcing are likely to substantially overlap.

A control was included to capture purchase of external R&D. Although we focus on internal R&D intensity, firms may also engage in external R&D activities through arm’s-length arrangements. Purchases of R&D activities may simply substitute for R&D activities which would otherwise be carried out by internal personnel. Alternatively, purchases of R&D activities (e.g.

laboratory tests) may be a complement of internal R&D activities. In either case, the omission of this variable may generate a bias in the estimated coefficient of the *R&D intensity* variable. Thus, we include a control for external R&D activities purchased by the firm. Specifically, *External R&D activity* measures the firm's reported expenses (in millions) on purchased R&D activities.

Finally, we control for industry effects through a set of dummy variables based on the Pavitt-Miozzo-Soete (PMS) classification as benchmark. The combined Pavitt (1984) and Miozzo and Soete (2001) (PMS) classification clusters firms into eight industry categories based on their innovation patterns and the required knowledge input (e.g., Bonaccorsi et al., 2013). The PMS patterns and the observed knowledge input in the sample generally corroborate the precision of our knowledge measures. Thus, this control guards against systematical variations across industries' underlying innovation patterns.

5. Results

5.1. Main results

Descriptive statistics and pair-wise correlations for all the variables are presented in Table 2. The correlation matrix does not suggest that collinearity issues are an actionable concern. Calculated independent and average variance inflation factors (VIF) also indicate a lack of collinearity issues, because the values are below conventional cutoff levels.

[Insert Table 2 Here]

An inspection of Table 2 reveals that, on average, approximately 3% of the employees of the sampled firms are R&D personnel. However, there is substantial variation ($\sigma = 0.09$) in this respect. Although the variance can indicate that relatively few firms make up the lion's share of R&D employment, the proportions of R&D personnel in the sample cover most of the spectrum. The fact that only 36% of firms report they have an R&D department illustrates that firms do not necessarily set up a formal organizational structure before engaging in R&D activities. Moreover, firms can entrust employees with innovative tasks in addition to their ordinary activities. Many sample firms engage in collaborations with firms and universities (and other research organizations) as a source of external knowledge. Notably, approximately 40 percent of the sampled firms engage with sources of practical knowledge, whereas 29 percent of the sample firms absorb scientific knowledge.[14] The mean for unstandardized *Delegation* ($\mu = 1.98$) indicates that decisions relating to innovative tasks are more frequently located at the upper hierarchical levels of the firm. However, inspection of the standard deviation ($\sigma = 0.7$) again reveals substantial variation among the sampled firms.

Table 2 also presents several interesting correlations. As might be expected, *Delegation* positively correlates with the extent to which the firm employs a more organic organization ($\beta = 0.20$, $p < 0.01$) and delegates authority over collaborative activities ($\beta = 0.43$, $p < 0.001$). The magnitude of the correlations supports the importance of holding firms' broader organizational design constant when examining innovation decision structures. The highest correlations in Table 1 are that between *External R&D activities* and *Support staff* ($\beta = 0.85$) and those between *Scientific knowledge and Practical knowledge* ($\beta = 0.65$) and between *Scientific knowledge intensity* and *Practical knowledge intensity* ($\beta = 0.63$). The first correlation indicates an interesting complementarity between R&D and support staff. It appears that the more R&D activities are performed outside the firm boundaries, the more support staff is needed for the practical facilitation of innovation. However, we caution that such interpretation is only based on pairwise correlation, not multivariate analysis. The second and third correlations might indicate that firms adopting an open innovation model based on external knowledge sourcing tend to absorb knowledge from various sources (i.e. to absorb *both* scientific and practical knowledge). Nevertheless, out of the

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External knowledge sourcing is largely a domestic phenomenon. However, given the minimal knowledge insourcing from non-Danish organizations, these sources were included in our measure of knowledge sources.

sample firms that adopt an open innovation model, a non-negligible number (43%) absorb either practical or scientific knowledge (but not both types of knowledge).

[Insert Table 3 Here]

Given our measure of delegation, we use an ordinary least squares regression model, with robust standard errors, to test the hypotheses. Model 1 contains all control variables. As expected, firms with more organic organizational structures also engage more in delegating authority over innovation decisions ($p < 0.05$). *Delegation of collaborative activity* has also a positive and highly significant ($p < 0.001$) coefficient. Thus, in addition to the influence of the overall organizational design, at which hierarchical level the authority to collaborate with other parties and insource knowledge is vested also is closely associated with the delegation of innovation decision-making. Combined, the two significant controls emphasize the importance of accounting for the organizational context surrounding innovative activities and the allocation of decision authority over such activities. Interestingly, the coefficient for *Support staff* is positively and significantly ($p < 0.05$) associated with *Delegation*. Conversely, the variable *External R&D activity* has a negative coefficient, significant at conventional confidence levels. Thus, the results illustrate that exclusively capturing R&D intensity based on R&D activities might produce biased estimates. None of the other controls is significant at conventional confidence levels. In Model 2a, we insert in the model specification the independent variable *R&D intensity* and the binary variables *Scientific knowledge* and *Practical knowledge*. Model 2b includes the two variables based on intensity of scientific/practical external knowledge sourcing.

In support of Hypothesis 1, the coefficient for *R&D intensity* is negative in both model 2a ($p < 0.05$) and model 2b ($p < 0.05$). Thus, on average, a higher R&D intensity is associated with less delegation of decision authority over innovation decisions. Increasing *R&D intensity* by one standard deviation is associated with a decrease in *Delegation* by approximately 1/10 of a standard deviation. Thus, the practical effect of the direct relationship is relatively small. However, given the hypothesized moderating effects of engaging with different types of external knowledge sources, this result is not surprising, because it should be interpreted as a baseline effect.

None of the measures of scientific and practical knowledge have generalizable associations with the delegation of authority over innovation decisions.[15] Hence, adoption by firms of an open innovation model does not appear to be associated with a higher (or lower) level of delegation of decision authority over innovation decisions than would occur with a closed innovation model.

In Model 3a/b, we include the interaction terms between *R&D intensity* and the two sets of variables capturing insourcing of scientific and practical knowledge (*Scientific knowledge X R&D intensity* and *Practical knowledge X R&D intensity*, and *Scientific knowledge intensity X R&D intensity* and *Practical knowledge intensity X R&D intensity*, respectively). The values of the F-tests ($p < 0.05$) indicate that the null hypothesis that the coefficients of the two interaction terms in Models 3a/b are jointly equal to 0 can be rejected. An inspection of the two knowledge sources' interaction terms reveals that the contextual nature of the external knowledge insourced by firms determines the directionality of the association between *R&D intensity* and *delegation.*

Hypothesis 2 is supported by the positive interaction term between *R&D intensity* and both the binary ($p < 0.01$) and continuous ($p < 0.001$) measure of *scientific knowledge*. Figure 1 illustrates the association between the *R&D intensity* and the predicted value of *Delegation* when *Scientific knowledge* is set at 0 or 1 and the firm is fixed to not engage with external practical knowledge sources.[16] Interestingly, our results indicate that the moderating effect of this variable is sufficiently strong to reverse the direct negative effect of *R&D intensity* on *Delegation*, thereby leading to an overall positive association between the R&D intensity of firms involved in scientific

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[15] The lack of a direct association between *delegation* and *external scientific knowledge* mimics the lack of association between decision autonomy and the extent of exploratory university research found by Bercovitz and Feldman (2007).
[16] Because the results are similar between the two models, we exclude the graphical illustration of Model 3b.

knowledge absorption (but not in practical knowledge absorption) and the extent to which these firms delegate authority over innovation decisions. Given sourcing of external scientific knowledge, a one standard deviation increase in *R&D intensity* is, on average, associated with approximately 0.6 of a standard deviation increase in the predicted level of delegation. Similarly, estimates based on the continuous measure, indicate that when *Scientific knowledge intensity* is set at one standard deviation above the mean value (and *Practical knowledge intensity* is set at the minimum) a one standard deviation increase of *R&D intensity* results in 0.3 of a standard deviation increase of the level of delegation.

[Insert Figure 1 here]

Our estimates reveal a different scenario for firms that absorb practical knowledge. The negative ($p < 0.05$) interaction term between *Practical knowledge* and *R&D intensity* lends support to Hypothesis 3. Figure 2 illustrates this relationship holding *Scientific knowledge* constant at 0. Thus, the negative association between *R&D intensity* and the predicted value of *Delegation* is stronger if firms collaborate with suppliers, customers, competitors or other firms (i.e., *Practical knowledge* equals 1). Given engagement with practical knowledge sources, a one standard deviation increase in *R&D intensity* leads to approximately ¾ of a standard deviation reduction in the predicted value of *Delegation*. In terms of the continuous measure of practical knowledge sourcing, when *Practical knowledge intensity* is set at one standard deviation above the mean value (and *Scientific knowledge intensity* is set at the minimum) increasing *R&D intensity* by one standard deviation is associated with approximately one standard deviation decrease in *Delegation*, given a high level (1 sd above the mean) of *Practical knowledge intensity* and keeping *Scientific knowledge intensity* at the minimum level.

[Insert Figure 2 here]

Given the results illustrated above, a check of the combined moderating effect of insourcing both practical and scientific knowledge on the association between *R&D intensity* and *Delegation* is interesting. To this end, we calculate the average marginal effect of *R&D intensity* after setting both *Scientific knowledge* and *Practical knowledge* equal to 1 in Model 3a (to mean + 1sd in Model 3b). The average marginal effect is insignificant in Models 3a and 3b, meaning that higher R&D intensity is not associated with changes in the level of delegation of authority over innovation decisions. In other words, when firms insource both practical and scientific knowledge, the positive moderating effect of insourcing scientific knowledge is sufficiently strong to cancel out both the direct negative effect of increased R&D intensity and the negative moderating effect of insourcing practical knowledge.

Above we interpret the combined effect of insourcing both practical and scientific knowledge based on the additive effect of the two interaction coefficients. However, to guard against the potential of an unobserved effect related to the joint engagement of firms with scientific and practical knowledge sources, Model 4 includes the three-way interaction between *R&D intensity*, *Scientific knowledge* and *Practical knowledge*. In total 26% of the sampled firms reported to concurrently engage with both scientific and practical external knowledge sources. Inspection of the intermediate model with all two-way interactions, omitted for brevity, reveals that the two interactions between external sources and R&D intensity remains significant while the direct interaction between scientific and practical knowledge sources in not significant. The absence of an interactive relationship between scientific and practical knowledge sources is further corroborated in the full three-way model. The three-way interaction is only significant ($p<0.01$) in the model using binary coding of scientific and practical knowledge, model 4a. However, graphical inspection of the three-way interaction shows that including an interactive relationship between the two types of knowledge sources produces relationships very similar to the independent interactions. In particular, similar to the evidence from Model 3a, changes in R&D intensity does not affect the level of delegation of decision authority when firms collaborate with *both* scientific and practical knowledge sources concurrently.

5.2.Robustness checks

To assess the sensitivity of the estimated associations between the delegation of decision authority over innovation decisions and our focal independent variables, we conduct several robustness tests.

We first probe the robustness of the average measure of delegation. Although we proffer theoretical mechanisms that are associated with the general level of delegation of decision-authority over innovation decisions, individual decisions may be suspected to unduly drive the results. Thus, using iterative deletion of one decision item, we construct five new average measures of delegation. Each average measure is based on four items only. All the new measures show acceptable internal reliability, alpha ranging from 0.62 to 0.73. The results of the new models are qualitatively similar to our main model. However, we note that *R&D intensity* in one model, excluding delegation of "which new project to pursue within the department", is not directly associated with delegation of innovation decisions ($p < 0.23$). However, as we do not have theoretical grounds to speculate about this difference and the interactions with external knowledge sources are comparable with those using the full average delegation measure, we do not consider this to be an actionable concern.

Although the models based on iterative deletion of single decision items helps mitigate concerns about single decision items biasing our findings, concerns may arise due to the treatment of ordinal responses as an average, continuous measure. Thus, we estimate a random effect ordinal logistic model at the decision level, including fixed effects for the five decisions under consideration and clustering errors at the firm level (Colombo and Delmastro 2004). Table 4 displays the results. Akin to our main findings, *R&D intensity* is negatively ($p < 0.09$) associated with delegation of decision-authority (see Model 2). Similarly, we find that engagement with external scientific/practical knowledge positively/negatively moderates this relationship ($p < 0.05$), see Model 3). Including the interaction terms also significantly ($p < 0.05$) increase the explanatory power of the model as indicated by a LR(Chi-square) test. We display the average marginal effect of *R&D intensity* while setting *Scientific knowledge* and *Practical knowledge* alternatively at 0 and 1, based on the estimate of Model 4. When firms do not insource scientific knowledge (i.e., *Scientific knowledge* equals zero), an increase of R&D intensity makes it more likely to vest authority over innovation decisions with firms' CEO. These effects are even more apparent when firms insource practical knowledge (i.e., *Practical knowledge* equals one). Conversely, when firms insource scientific knowledge and do not insource practical knowledge (i.e., *Scientific knowledge* equals one and *Practical knowledge* equals zero), an increase of R&D intensity makes it more likely to delegate authority over innovation decisions near the bottom of managerial hierarchy and less likely to centralize decision authority in the hands of the firms' CEO. Overall, these results further corroborate our theoretical hypotheses.

Another robustness re-specification is motivated by the distinctiveness of the individual knowledge sources within each type of knowledge. The construction of the binary measures of scientific and practical knowledge restricts individual variance between items. Thus, concerns may be raised that the constructs effectively force the items into the two predefined types of knowledge. In particular, two items may seem different from the type of knowledge category they are grouped in, namely 1) private R&D organizations (for the scientific knowledge category) and 2) the firm's competitors or other firms in the same industry (for the practical knowledge category). To ensure that these items do not unduly influence the results, we reran the model excluding these items from the respective knowledge type measure. The model produces similar results and thus mitigates concerns that these items are ill-fitted to their type of knowledge.[17] Although the test supports a categorization of external knowledge sources into two categories, individual sources, within these categories, may still provide distinct types of knowledge. This concern is particularly relevant in the case of practical knowledge sources, as these may lie at opposite ends of the firm's value chain. Thus, to ensure that the moderating effect of practical knowledge sourcing is not caused by one specific type of practical knowledge, we construct three new constructs for practical knowledge employing iterative exclusion of one practical knowledge item at a time. All the three new constructs produce results similar to the full practical knowledge construct. Although the exclusion of suppliers somehow reduces accuracy in the estimation of the interaction effect between *R&D intensity* and *Pratical knowledge* ($p < 0.15$). Taken together, the test does not indicate that the moderating effect of practical knowledge sourcing is driven by the distinctiveness of individual practical sources.

An additional robustness test sought to address a key underlying factor of our model, namely whether employees have the authority to engage in knowledge sourcing. The control for *Delegation of collaborative activity* mitigates concerns that who has control over external knowledge insourcing decisions bias the results. Furthermore, we examined whether *R&D intensity* drives engagement with external knowledge sources. For this purpose, we ran a re-specified model with *Delegation of collaborative activities* as the dependent variable. The estimates do not support that the *R&D intensity* is a significant predictor of *Delegation of collaborative activity*. We tested the re-specified model both with and without including *Delegation* (of authority over innovation decisions) as a predictor (results are not reported in the text and are available from the authors upon request).

6. Concluding discussion

[17] Results are available from the authors upon request.

Systematic relationships between internal (formal) organization and innovation outcomes have long been recognized (Schumpeter, 1942; Burns and Stalker, 1961; Burgelman, 1983; Burgelman and Sayles, 1986; Teece, 1992; Argyres and Silverman, 2004). We contribute to this stream by focusing on a specific, important aspect of organization design, namely the delegation of authority over innovation decisions. We show that, in a closed innovation context, more R&D-intensive firms have a lower level of delegation of authority over innovation decisions. This result echoes the descriptive univariate evidence provided by Bercovitz and Feldman (2007), which is based on a smaller sample of firms with large R&D budgets and generalizes that evidence to a more heterogeneous sample of (large and small) firms in a multivariate setting. However, we go a step further by showing that in, an open innovation context, the type of external knowledge that is a key input to firms' innovation activities—either scientific knowledge produced by universities and other research organizations or practical knowledge produced by customers, suppliers, competitors, and other firms—is an important moderator of the relationship under investigation.

Specifically, the negative association between R&D intensity and delegation of authority over innovation decisions is reinforced if firms absorb practical knowledge. Conversely, in case absorption of scientific knowledge is a key input to firms' innovation activities, its moderating effect is so strong that the negative association between R&D intensity and the level of delegation of authority over innovation decisions disappears, if firms contextually absorb also practical knowledge. If they do not, the association becomes (weakly) positive (i.e. the level of delegation is slightly greater for more-R&D-intensive firms).

Our work adds novel contingencies to the literature on innovation and internal organization. In particular, despite the increasing importance of open innovation, the study of organizational design in an open innovation context is in its infancy. Existing research proffers a "one size fits all approach", which does not do justice to the complexity of the theme. Thus, extant contributions predict that open innovation is generally associated with a high level of delegation. Instead, we have theoretically discussed and empirically documented that the level of delegation depends upon both the importance of R&D to the firm and the type of absorbed knowledge.

We hope our findings inspire future research on the role of formal organization in innovation in general and open innovation in particular. However, one should consider them in the light of the study's limitations. In addition to concerns of generalizability beyond the Danish context, which served as the site of our research, future research should address several issues.

First, our use of cross-sectional data raises endogeneity concerns. However, the large set of controls in the model specification accounts for several observable confounding factors that might lead to spurious correlations between our dependent and independent variables. Note also that our work considers differences among types of external knowledge. If unobserved factors correlated with both delegation of authority over innovation decisions and absorption of external knowledge, the moderating effects of absorbing different types of knowledge would be biased in the same direction. We find that absorbing scientific and practical knowledge differently influences the association between R&D intensity and delegation of authority over innovation decisions. These diverging moderating effects are unlikely to be purely the result of unobserved heterogeneity. Finally, we model the two types of external knowledge as moderators. Therefore, endogeneity concerns, although relevant, might be somewhat less potent in the light of these observations.

However, we remain unable to econometrically rule out the possibility that, for example, the recruitment of R&D personnel and the delegation of authority over innovation decisions are driven by unobserved common factors related to the firm's innovation activities. If longitudinal data on firms' organization were available and one were able to identify valid and strong instruments for firms' recruitment of R&D personnel and the absorption of scientific and practical knowledge, one could test more rigorously the causal relationships underlying our hypotheses. Nonetheless, the collection of longitudinal data on firm organization poses serious challenges that have been rarely taken up by previous studies (see Colombo and Delmastro, 2002, for an exception), and we are unaware of studies on the evolution over time of firms' decision systems.

Second, we use relatively crude proxies for the characteristics of external knowledge, that is, knowledge that firms absorb from different sources. It would be desirable to include relevant knowledge characteristics (e.g., tacitness and complexity; Winter, 1987) rather than inferring them from the nature of the source. Third, future research might want to include more organizational design variables than those used here, such as variables capturing incentives and coordination mechanisms. Indeed, extant research suggests that the extent to which decisions are delegated might depend upon the extent to which incentives can be provided to the firm's personnel (Jensen and Meckling, 1992). The idea is that delegation creates a latent agency problem that can be controlled if delegation is combined with (monetary and/or intrinsic) incentives. Similar reasoning applies to the existence of efficient mechanisms to address the coordination problems generated by delegation of decision authority (Alonso et al., 2008).

Finally, our work is silent about the effects of delegation of authority over innovation decisions on firms' innovative and economic performance. As is usual in the organizational design literature, we assume in this study that firms choose the "optimal" (i.e., profit maximizing) level of delegation, and we predict the ensuing association between firms' R&D intensity, their absorption of practical and scientific knowledge, and the level of delegation of decision authority over innovation decisions. Do R&D-intensive firms obtain more patents and/or higher profits if they centralize more the authority over innovation decisions? Do the innovative and economic performances of these firms depend upon the combination of the characteristics of their decision systems and the adoption of a closed or open innovation strategy? In this latter case, do they depend upon the type of knowledge—either scientific or practical, that they absorb as a key input to their innovation activities? Works that answer these questions would valuably complement our study.

Despite these limitations, if one makes the assumption, current in the economics literature, that the observed level of delegation is close enough to the one "optimal" for the focal firm, our work offers interesting managerial implications. Thus, top managers of R&D-intensive firms, for which R&D is of high strategic importance should think twice before delegating authority over innovation decisions to R&D personnel, as losing control over a strategically crucial function could have severely negative implications. If their firms adopt a closed innovation strategy, these negative effects are likely to more than compensate for the drawbacks of not (fully) leveraging the individual, specific knowledge of R&D personnel, as would occur with delegation of decision authority. Managers of R&D-intensive firms should be even more careful in delegating decision authority over innovation decisions to R&D personnel if they adopt an open innovation strategy and collaborations with customers, suppliers and most notably competitors aimed at absorbing their practical knowledge is a key aspect of this strategy. In this situation, the risk of misappropriation of their firm's innovative knowledge by the partners of these collaborations argues in favor of exerting tighter control over innovation activities than in a closed innovation context and makes centralization of decision authority over innovation decisions almost mandatory. Instead, top managers of R&D-intensive firms may want to consider delegating authority over innovation decisions to R&D personnel when absorbing scientific knowledge is a key component of their firms' open innovation strategies. In this case, given the non-profit mission of universities and other public research organizations, the risk of misappropriation of their firms' knowledge is minimal. Conversely, because of the nature of scientific knowledge, firms' R&D personnel enjoy a considerable advantage over their corporate superiors in detecting, insourcing and assimilating this knowledge. Delegation of decision authority over innovation decisions to R&D middle managers, scientists and engineers serves the purpose of leveraging their individual abilities of absorbing scientific knowledge.

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TABLE 1: *Descriptive statistics and correlation matrix of delegation items*

	Delegation item	Mean	SD	(1)	(2)	(3)	(4)	(5)
(1)	Developing new products/services	0	1	1.00				
(2)	Introduce major changes in marketing activities	0	1	0.35***	1.00			
(3)	Deciding which new projects to pursue within the department	0	1	0.16*	0.26***	1.00		
(4)	Making significant changes in products and services	0	1	0.39***	0.45***	0.32***	1.00	
(5)	Discontinuing a major existing product or service	0	1	0.36***	0.42***	0.22***	0.63***	1.00

t = p < .10; * = p < .05; ** = p < .01; *** = p < .001

TABLE 2: *Descriptive statistics and correlation matrix*

	Variables	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1)	Delegation	0.00	.7	1.00														
(2)	R&D intensity	0.03	0.09	-0.05	1.00													
(3)	Scientific knowledge	0.29	0.45	0.05	0.11	1.00												
(4)	Practical knowledge	0.4	0.49	0.05	0.04	0.65*	1.00											
(5)	Scientific knowledge intensity	2.50	1.71	0.07	0.24*	0.92*	0.57*	1.00										
(6)	Practical knowledge intensity	3.07	1.71	0.12	0.11	0.61*	0.92*	0.63*	1.00									
(7)	Support staff	7.66	36.91	0.10	0.24*	0.18*	0.19*	0.18*	0.19*	1.00								
(8)	Hierarchical levels	4.3	1.45	0.07	0.02	0.1	0.07	0.1	0.04	0.20*	1.00							
(9)	Firm age	26.59	25.32	-0.04	-0.01	0.01	0.05	0.004	0.01	0.09	0.12	1.00						
(10)	Firm size	5.21	0.98	0.05	-0.08	0.18*	0.22*	0.17*	0.19*	0.30*	0.51*	0.18*	1.00					
(11)	R&D department	0.36	0.48	0.08	0.23*	0.31*	0.22*	0.39*	0.29*	0.24*	0.17*	0.03	0.16*	1.00				
(12)	Manager education	4.98	0.97	-0.01	0.24*	0.22*	0.18*	0.24*	0.17*	0.18*	-0.09	0.05	-0.02	0.21*	1.00			
(13)	Organizational design	5.10	1.02	0.20*	0.09	0.01	0.01	0.01	0.01	-0.01	-0.01	-0.11	-0.07	0.05	0.21*	1.00		
(14)	Delegation of collaborative activity	2.76	0.76	0.43*	-0.004	0.18*	0.17*	0.22*	0.2*	0.08	0.20*	-0.12	0.27*	0.11	0.11	0.15*	1.00	
(15)	External R&D activities	9.45	97.38	0.01	0.18*	0.10	0.1	0.1	0.09	0.85*	0.12	0.08	0.19*	0.12	0.11	-0.02	-0.01	1.00

n = 235; * = p <0.05

TABLE 3: Estimates: OLS models

DV: Delegation	Model 1	Model 2a	Model 2b	Model 3a	Model 3b	Model 4a
R&D intensity		-0.84* (0.40)	-0.8* (0.40)	-1.08* (0.44)	-3.37*** (0.88)	-1.06* (0.44)
Scientific knowledge		-0.02 (0.13)		0.005 (0.13)		-0.2 (0.25)
Practical knowledge		-0.02 (0.12)		-0.06 (0.11)		-0.21t (0.12)
Scientific knowledge intensity			-0.03 (0.03)		-0.002 (0.03)	
Practical knowledge intensity			0.03 (0.03)		0.03 (0.03)	
Scientific knowledge X R&D intensity				5.40* (2.23)		2.78 (2.11)
Practical knowledge X R&D intensity				-4.51* (2.22)		-10.33*** (2.57)
Scientific knowledge X Practical knowledge						0.35 (0.28)
Scientific knowledge X Practical knowledge X R&D intensity						8.56** (3.3)
Scientific intensity X R&D intensity					2.16*** (0.64)	
Practical intensity X R&D intensity					-0.88t (0.46)	
Support staff	0.005* (0.002)	0.01* (0.002)	0.005* (0.002)	0.01** (0.002)	0.01** (0.002)	0.01*** (0.002)
Hierarchical levels	-0.003 (0.04)	-0.001 (0.04)	0.004 (0.04)	-0.01 (0.04)	-0.004 (0.04)	-0.01 (0.04)
Firm age	0.001 (0.001)	0.002 (0.001)	0.002 (0.001)	0.001 (0.001)	0.001 (0.001)	0.002 (0.001)
Firm size	-0.08 (0.06)	-0.09 (0.06)	-0.10t (0.06)	-0.11t (0.06)	-0.11t (0.06)	-0.11t (0.06)
R&D department	0.11 (0.10)	0.14 (0.11)	0.13 (0.11)	0.16 (0.11)	0.19t (0.11)	0.21t (0.11)
Organizational design	0.11* (0.04)	0.11* (0.04)	0.11* (0.04)	0.12** (0.04)	0.12** (0.04)	0.12** (0.05)
Manager education	-0.1* (0.05)	-0.09t (0.05)	-0.09t (0.05)	-0.11* (0.05)	-0.12* (0.05)	-0.12* (0.05)
Delegation of collaborative activity	0.39*** (0.07)	0.39*** (0.06)	0.39*** (0.06)	0.39*** (0.06)	0.39*** (0.06)	0.39*** (0.06)
External R&D activities	-0.001* (0.001)	-0.001* (0.001)	-0.001t (0.001)	-0.001** (0.001)	-0.002** (0.001)	-0.002** (0.001)
Constant	0.7t (0.41)	-0.66 (0.41)	-0.6 (0.42)	-0.73t (0.42)	-0.65 (0.43)	-0.66 (0.42)
F-test	5.08*** (16, 218)	4.40*** (19, 125)	4.41*** (19, 125)	4.65*** (21, 213)	6.44*** (21,213)	4.39*** (23, 211)
Adjusted R-squared	0.19***	0.19***	0.19***	0.20***	0.21***	0.21***

n = 235; t = p < .10; * = p < .05; ** = p < .01; *** = p < .001; robust standard errors in parentheses;
F-test displays degrees of freedom in parentheses; all models include industry controls.

TABLE 4: Estimates: Ordinal Logit Models

DV: Delegation	Model 1	Model 2	Model 3	Model 4
R&D intensity		-2.64t (1.55)	-3.50t (1.88)	-3.39t (1.84)
Scientific knowledge		-0.01 (0.33)	0.05 (0.32)	-0.41 (0.64)
Practical knowledge		-0.01 (0.30)	-0.12 (0.29)	-0.52t (0.31)
Scientific knowledge X R&D intensity			14.87* (5.81)	7.73 (5.51)
Practical knowledge X R&D intensity			-11.93* (5.79)	-27.43*** (7.59)
Scientific knowledge X Practical knowledge				0.83 (0.72)
Scientific knowledge X Practical knowledge X R&D intensity				22.91* (9.18)
Support staff	0.01* (0.005)	0.01* (0.01)	0.02** (0.01)	0.02*** (0.01)
Hierarchical levels	-0.02 (0.10)	-0.01 (0.10)	-0.03 (0.10)	-0.05 (0.10)
Firm age	0.01 (0.004)	0.01 (0.004)	0.01 (0.003)	0.01 (0.003)
Firm size	-0.24 (0.15)	-0.28t (0.15)	-0.31* (0.15)	-0.31* (0.15)
R&D department	0.31 (0.27)	0.41 (0.29)	0.46 (0.28)	0.58* (0.29)
Organizational design	0.32* (0.13)	0.34** (0.13)	0.36** (0.13)	0.38** (0.13)
Manager education	-0.27* (0.12)	-0.25* (0.13)	-0.29* (0.12)	-0.33** (0.12)
Delegation of collaborative activity	1.08*** (0.18)	1.08*** (0.18)	1.07*** (0.18)	1.07*** (0.18)
External R&D activities	-0.003* (0.001)	-0.003t (0.002)	-0.004** (0.001)	-0.005** (0.002)
Wald Chi-square	259.65*** (20)	265.85*** (23)	270.07*** (25)	270.89*** (27)

n = 1175, 235 clusters; t = p < .10; * = p < .05; ** = p < .01; *** = p < .001; robust standard errors in parentheses; Wald Chi^2 displays degrees of freedom in parentheses; all models include industry and decision item controls.

TABLE 4: Average marginal effects of R&D intensity

DV: Decision level	Scientific = 0 Practical = 0	Scientific = 0 Practical = 1	Scientific = 1 Practical = 0	Scientific = 1 Practical = 1
1	0.46t (0.24)	2.39** (0.79)	-1.84* (0.40)	0.09 (0.26)
2	-0.11t (0.26)	-0.61 (0.39)	0.58 (0.55)	-0.01 (0.03)
3	-0.22t (0.12)	-1.15** (0.41)	0.76*** (0.22)	-0.05 (0.14)
4	-0.12t (0.07)	-0.63* (0.25)	0.49* (0.25)	-0.03 (0.09)

n = 1175, 235 clusters; t = p < .10; * = p < .05; ** = p < .01; *** = p < .001; robust standard errors in parentheses; all models include industry and decision item controls.

FIGURE 1: ***Moderating effect of scientific knowledge***

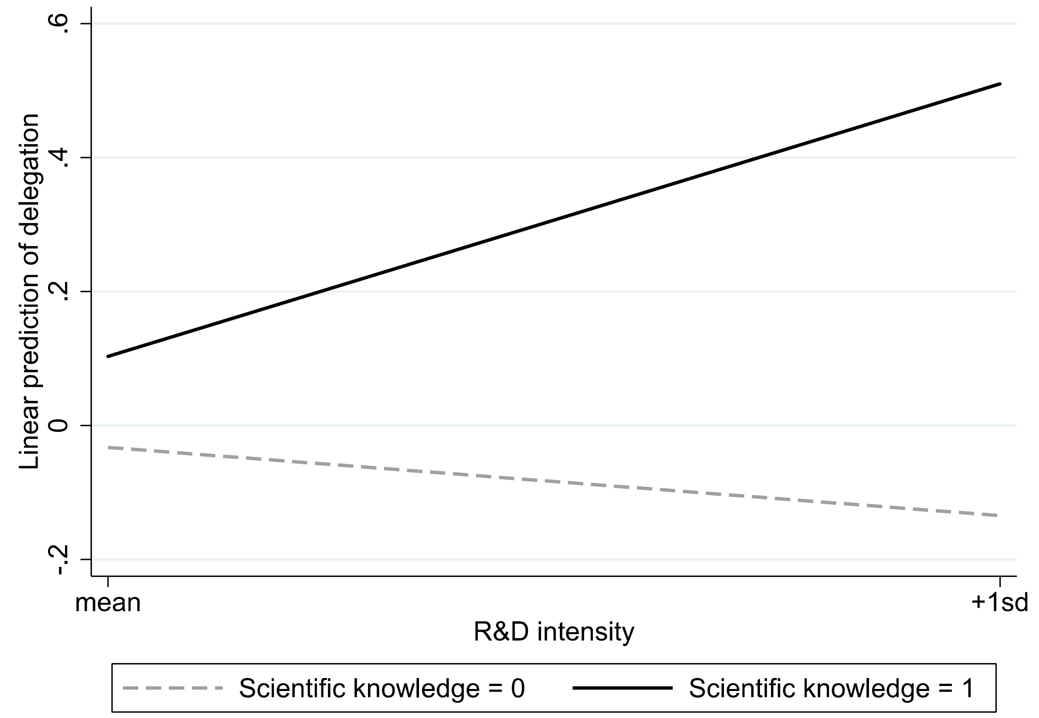

FIGURE 2: ***Moderating effect of practical knowledge***