Abandoning Innovation Activities and Performance: The moderating role of openness

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ABSTRACT

Firms are encouraged to continually initiate innovation activities as part of their new product development processes and to be open to the use of external knowledge sources. Yet, many are abandoned. Openness to external knowledge sources and the experience of abandoning innovation activities are, therefore, becoming a part of an organization's reality and innovation strategy. In this paper, we aim to explore how the experience of having abandoned an innovation activity can affect innovation performance and the role two key dimensions of openness, external search breadth and formal innovation collaboration breadth, play. Using data from the UK Innovation Survey, we find that the experience of having abandoned an innovation activity leads to improved innovation performance and that this is negatively moderated by the two dimensions of openness. When external search breadth is high, i.e. when an organization engages with a higher number of different types of knowledge sources, the link between abandoning innovation activities and innovation performance weakens. Similarly, when formal innovation collaboration breadth is high, i.e. the breadth of a firm's formal collaboration relationships is high, the link between abandoning innovation activities and innovation performance also weakens. We conclude by discussing the theoretical and practical implications of our findings.

Keywords: Abandoning innovation activities, openness, technology management, innovation performance.

Introduction

Innovation activities aim at bringing ideas for new (tangible or intangible) products to market. Yet, they are often abandoned (Leoncini, 2016). An indication of the size of this phenomenon comes from the pharmaceutical sector, where, on average, 80.3% of the compounds tested as potential drugs have been abandoned, significantly increasing the cost of development (Grabowski and Hansen, 2014). As it is successful conclusion that drives future revenues and competitiveness, organizations are more likely to succeed if they pursue innovation strategies that help them react more effectively to the experience of abandoning an innovation activity. Therefore, a better understanding of how these strategies help deduce and apply the right lessons can have a significant effect on the management of their new product development processes and, ultimately, their innovation performance.

Recent evidence in the innovation literature explains that a key innovation strategy that determines an organization's effectiveness in managing its new product development processes is its openness to different types of knowledge sources (Gambardella and Panico, 2014; Laursen and Salter, 2014; Robertson et al., 2012). Openness relates to the extent to which an organization engages in inbound and outbound exchange of knowledge with different types of external sources (Chesbrough, 2003). This exchange is a combination of external search breadth (i.e. the number of different types of knowledge sources it is exposed to) and formal innovation collaboration breadth (i.e. the breadth of a firm's formal collaboration relationships) (Laursen and Salter, 2014). It can increase access to new ideas on the one hand (Bogers et al., 2018; West et al., 2014) but requires significant managerial effort on the other (Laursen and Salter, 2006; Laursen and Salter, 2014). Openness to different types of knowledge sources and the experience of abandoning an innovation activity are, therefore, parts of an organization's

innovation strategy, which has a significant effect on learning and, subsequently, innovation performance.

A profound example of how the experience of abandoning an innovation activity can affect innovation performance is the shutting down of *Project Tango* by Google after 3 years of development. Tango was one of Google's earliest efforts to venture into augmented reality, which should have allowed the development of camera-based apps. Google, who pursues a strategy of open innovation (jartese, 2014) engaged formally and informally with several external knowledge sources, including phone manufacturers, other developers and retailers such as Walgreens and Target in the US. However, its success was dependent upon the integration of a complex camera in new phones, a prospect that made the manufacturing of the phones very expensive. As a result, Google decided to abandon it. Google was able to learn from the experience and to then develop other newer products (e.g. ARCore). Project Tango is one among many that Google abandoned in recent years (Mercer, 2018) and illustrates how organizations can learn from the experience of abandoning an innovation activity. However, and given that it happened while pursuing an open innovation strategy, it also raises questions about the effects the experience can have on this learning process.

An organization's openness to different types of external knowledge sources can affect how it learns (Love et al., 2016). It can increase the number of reference points against which it can compare its performance and expose it to different ideas and thinking (Rass et al., 2013). Therefore, when an innovation activity has been abandoned, openness can improve how an organization manages its new product development process. Yet, an open innovation strategy may require the management of intense collaborations (Laursen and Salter, 2006), which involve formal agreements that outline the way collaborators will work together and how they will share any benefits. It thus generates network inertia (Tai-Young et al., 2006), which can lead to structural rigidities (Tomlinson, 2010; Vestal and Danneels, 2018). As a result, when

an innovation activity is abandoned, openness may also have negative implications on how the new product development process is managed. Although previous studies have explored aspects of these relationships, they have either done so by looking at individual cases (Chesbrough, 2010), or by focusing on openness's direct impact on innovation performance (Leoncini, 2016), overlooking its moderating effects. As a result, research on abandoning innovation activities on the one hand and the effect of openness on the other remains limited. Unanswered questions about both the impact of the experience of abandoning an innovation activity on innovation performance and the moderating role of openness prompt us to pose the following research questions:

- How does the experience of having abandoned an innovation activity affect an organization's innovation performance?
- How does openness affect the relationship between the experience of having abandoned an innovation activity and innovation performance?

We contribute to the literature on innovation management first by explaining theoretically and empirically how the experience of having abandoned at least one innovation activity can be a positive antecedent for developing new products. We, thus, address recent calls in the literature to investigate the impact of such experiences on an organization's innovation projects (Khanna et al., 2016; Leoncini, 2016). Second, we explain that the impact of abandoning an innovation activity is contingent upon the forms of openness (i.e., external search breadth and formal innovation collaboration breadth) that is being employed. More specifically, we explain how the two forms openness moderate the relationship between the experience of abandoning an innovation activity and innovation performance. Our work contributes to the literature of open innovation by offering a model which explains theoretically and empirically how openness affects a situation – the abandoning of innovation activities – which is a frequent occurrence in modern organizations' life (Kester et al., 2011)

In the next section we review the literature and hypothesize that the experience of having abandoned an innovation activity, supports the firm's ability to develop new products and hence its innovation performance. We also hypothesize that this relationship is likely to be moderated by two dimensions of openness: external search breadth and formal innovation collaboration breadth. Next, we explain the data and methods adopted to test the hypotheses and proceed to discuss the results and implications. We conclude by discussing the managerial implications, limitations, and directions for future research.

Theoretical Background

Despite the impact that the experience of abandoning an innovation activity may have on business life, the literature exploring its implications is relatively limited (Khanna et al., 2016; Leoncini, 2016). One body of literature that has developed theoretical concepts that could help explain how an organization reacts to such experiences is the one that focuses on the response to failure. Studies in this stream focus on catastrophic or operational failures (Haunschild and Rhee, 2004; Madsen and Desai, 2010) and have explored how they trigger organizational responses.

Failures are unwelcome events and occur because of flaws between the interaction of individuals with the system within which they operate (Shrivastava, 1994). When they occur, individuals and organizations deduce lessons, which may help explain why the failure happened and potentially how it could have been avoided. A failure can reveal rich information about an organization's systems and how they respond to certain events. It can initiate formal and informal learning processes which, can lead to suggestions about updates in procedures and, subsequently, improvements in performance (Ramanujam and Goodman, 2003). Therefore, when failures lead to the right lessons which are then applied (Baumard and

Starbuck, 2005), e.g. via a change in the way a process is managed, they can lead to improvements in organizational performance (Deichmann and Ende, 2014; Edmondson, 2011).

Although catastrophic and operational failures and the abandoning of innovation activities are different, in that the latter is part of experimentation and thus a part of the new product development process (Khanna et al., 2016), they also share at least two similarities. Both are unwelcome events and both can be the result of errors on the interaction between a part of the system (e.g. the innovation manager and team), and the wider context within which it operates (e.g. the organization or the market). Therefore, as with the experience of a failure, the experience of having abandoned an innovation activity could encourage an organization to learn by reflecting on its processes and assumptions. It could encourage managers to steer away from the path they may be following (Deichmann and Ende, 2014); it could highlight some of the incorrect assumptions and mistakes made about the interaction of the innovation activity and its environment (Desai, 2015); and it could reveal information about how the system (e.g. the innovation manager and their team) interacts with its environment. Therefore, the experience of having abandoned an innovation activity should also affect performance.

The effectiveness of learning depends on the innovation strategy it is pursuing including the approach to openness to external knowledge. If the innovation strategy is not supportive then organizations may be unable or unwilling to apply the lessons they deduced, or even, may learn nothing from the experience (Madsen and Desai, 2010). However, if it is supportive, learning from failure can lead to a bigger positive impact than learning from successes (Madsen and Desai, 2010). We view and, subsequently, measure openness in terms of the external linkages an organization is engaging with during its new product development process (Laursen and Salter, 2006; Love et al., 2014). More specifically, we focus on two forms of openness, external search breadth and formal innovation collaboration breadth (Laursen and Salter, 2014). External search breadth relates to the number of different types of knowledge sources an

organization is exposed to during its new product development processes. Formal innovation collaboration breadth relates to the breadth of a firm's formal collaboration relationships for innovation (Laursen and Salter, 2014).

External search breadth focuses on the communication with a number of different types of knowledge sources for the acquisition of codified knowledge, e.g. knowledge held in a partner's databases, manuals and reports. As explained by Laursen and Salter (2014 p. 868), it "can be seen as a form of 'soft' openness, typically involving drawing knowledge from external parties without entering into legally binding agreements". When an innovation activity is abandoned, it enables managers and innovation teams to compare their experience with multiple reference points (Ahn et al., 2017). Therefore, it should make it more likely to deduce the right lessons (Khanna et al., 2016; Leoncini, 2016) and have a positive impact on performance (Bianchi et al., 2015; Cheng and Huizingh, 2014; Tsinopoulos et al., 2018).

Formal innovation collaboration breadth, on the other hand, focuses on the management of intense relationships, with potentially many different partners (Carey et al., 2011; Laursen and Salter, 2006), for the transfer of context specific knowledge (Alavi and Leidner, 2001). It can therefore be seen as a 'hard' form of openness where the firm and the external partner "adhere to an agreed structure for the exchange" (Laursen and Salter, 2014 p. 868). In this case, organizations have to develop agreements with each one, e.g. for the co-development of products (Aggeri and Segrestin, 2007) or the sharing of proprietary knowledge (Henkel et al., 2014), which may be too complex to communicate in standardized format. These are undertakings that can lead to higher transaction costs, because they require the management of relationship specific socialization mechanisms (Cousins and Menguc, 2006) and thus absorb time and attention (Ocasio, 1997). As a result, organizations may have less time and fewer resources to allocate to the identification of new, potentially more capable, external knowledge sources (Villena et al., 2011). In addition, formal agreements may lock organizations into long

term partnerships (Koufteros et al., 2007). Although this could help reduce some of the transaction costs associated with managing the partnership, e.g. by standardizing and automating shared processes, it risks reducing the partners' capacity to think creatively (Alavi and Leidner, 2001; Villena et al., 2011). The combination of high transaction costs, the management of intense relationships and the lack of identification of new sources, can deter attention from identifying new ideas (Laursen and Salter, 2006) and reinforce the paths managers may be following (Deichmann and Ende, 2014), thereby constraining the application of lessons. Therefore, high collaboration innovation breadth may also have a negative contribution on how an organization applies learning (Dahlander and Piezunka, 2014; Henkel et al., 2014; Laursen and Salter, 2006; Love et al., 2014) and this may affect how it manages its new product development process.

In the following section we develop a set of hypotheses to explain the relationship between the experience of having abandoned an innovation activity and innovation performance and the role of openness in terms of *external search breadth* and *formal innovation collaboration breadth* (Laursen and Salter, 2014). Finally, it is important to pay attention to the issue of potential endogeneity in the relationships we predict. It is likely that there exist unobserved factors that could affect an organization's innovation performance. These may include its structure, the technical capability and educational background of its employees, and its innovation strategy (Chen et al., 2016). Furthermore, it is also possible that the effect of experiencing the abandoning of innovation activities on innovation performance may run the opposite way, i.e. that an innovation-active organization with better innovation performance will be more likely to experience the abandoning of innovation activities than its innovation-non-active counterparts. In econometric terms, this means that there may be an endogeneity problem, which, if not accounted for could affect the interpretation of our results. In the method section we explain the empirical strategies we followed to ensure the effect was minimized.

Research hypotheses

The experience of abandoning innovation an activity and innovation performance

Organizations initiate innovation activities, because they have expectations about what can be achieved (Cooper, 2001). When an activity does not meet these expectations and the decision is made for it to be abandoned, its objectives are compared with its outcomes (Lant and Mezias, 1992), and any discrepancies trigger formal and informal learning processes (Greve and Seidel, 2015; Tsinopoulos et al., 2014). Formal processes, such as "lessons learnt" exercises that aim to systematically collect information about the activity from everyone, are included and documented in management systems (Sanghera, 2010). When these are implemented, the reasons that led to the decision to abandon the activity are identified and actions are taken to learn from them, thereby increasing the organization's absorptive capacity (Love et al., 2016), which supports new product development processes.

Informal processes are associated with the way routines were actually implemented (Kim et al., 2009) e.g. a manager or a team member's personal reflection of whether a process or an idea worked or not. Such *post-hoc* reviews of outcomes and expectations would lead to a process of confirmation or rejection of previous actions perceived to have contributed to the activity's progress (Gioia and Sims, 1986). They, therefore, contribute to organizational awareness about what does and does not work.

When an organization has not experienced the abandoning of innovation activities, it is more likely to perceive them as unwelcome failures and thus the result of incompetence and negligence (Desai, 2015). Yet, these events also reveal information about how the system interacts with its wider environment. In addition, in a new product development context, many new product ideas will not work as intended (George and Jing, 2007). When organizations

experience the abandoning of innovation activities they learn how to manage their aftermath and understand its consequences. Experiencing "failures" is, thus, part of normal experimentation and can lead to learning (Dietfried and Søren, 2015; Khanna et al., 2016). Consequently, organizations that have experienced the abandoning of an innovation activity and have been able to build a higher 'tolerance for failure' are likely to be more innovative (Manso, 2011; Tian and Wang, 2014). As a result we hypothesize:

Hypothesis 1: A firm that has experienced the abandoning of innovation activities is more likely to demonstrate higher levels of innovation performance.

The moderating effect of openness

The way an organization is engaging with openness may intensify or weaken the effect of the experience of abandoning an innovation activity on innovation performance. This is because managers' perceptions about the lessons they can deduce from it and their ability to apply them, are affected by their interaction with the environment within which they operate (Denrell, 2003; Madsen and Desai, 2018). Furthermore, the different types of openness are likely to facilitate different types of knowledge (Alavi and Leidner, 2001). More specifically, we predict that the two forms of openness (external search breadth and formal innovation collaboration breadth) have opposite effects. For instance, when they engage with a number of different stakeholders, e.g. suppliers and Universities, they will be exposed to a higher variety of types of knowledge sources and will be able to easily acquire standardized knowledge. This will provide more opportunities to learn and to compare their experiences with those of others. However, when they collaborate formally with their knowledge sources, the organization's attention will be more focused on managing the relationship thereby potentially constraining the application of lessons learnt. When this form of openness is pursued the knowledge acquired is more likely

to be protected or too complex to communicate in a standardized format. In the remainder of this section we explain in more detail how these two forms of openness (external search breadth and formal innovation collaboration breadth (Laursen and Salter, 2014)) affect the relationship between the experience of abandoning an innovation activity and innovation performance.

The effect of external search breadth

External search breadth relates to the number of different types of knowledge sources an organization is exposed to during its new product development processes. This form of openness implies that the organization engages in knowledge exchanges without any formal collaborations (Laursen and Salter, 2014). It is more likely to be pursued when the knowledge in question has been codified and thus is relatively easy to transfer (Alavi and Leidner, 2001). For instance, it may inform the development of certain technologies or research, e.g. attending a University presentation or a trade fair where suppliers display their solutions, without working formally with them. The mechanisms that it is employing to transfer knowledge from these sources may include communication of relatively standardized content, e.g. knowledge articulated in manuals, reports and other documents (Hass and Hansen, 2007), or other, relatively passive activities (Laursen and Salter, 2006), which aim at informing an organization about any new or relevant knowledge which is out there. The higher the external search breadth the higher the number of types of knowledge sources that are being used.

When external search breadth is higher, the formal and informal learning processes that take place when an innovation activity has been abandoned would occur in a relatively more open and outward-looking environment. Using a higher number of different types of external knowledge sources can increase the number of ideas on the one hand and the number of opportunities of comparing the knowledge an organization holds with that of others' (Ahn et

al., 2017). This is especially so because any acquired knowledge is likely to be codified and hence relatively easy to compare with any internal knowledge assets. Openness, helps to access knowledge that facilitates commercialization of a new technology (Hult et al., 2003), and exposes it to different ways of working (Ju and Zhao, 2009). Such knowledge could act as a push on an organization's overall R&D productivity (Ceccagnoli et al., 2010) and thus can increase the awareness of what can and cannot work. It would also help to identify some of the errors which may have led to abandoning the innovation activities and help to correct them by developing new methods and ideas which would help learning once they understand failure (Maslach, 2016).

As a result, for organizations that have experienced the abandoning of an innovation activity, a higher level of external search breadth will expand the scope of learning thereby strengthening the new product development process. It will thus leverage the positive effect of abandoning an innovation activity on innovation performance. We therefore hypothesize:

Hypothesis 2: The positive effect of abandoning an innovation activity on innovation performance is a) weaker with low levels of search breadth and b) stronger with high levels of search breadth.

The effect of formal innovation collaboration breadth

Formal innovation collaboration breadth relates to the breadth of a firm's formal relationships, and is often manifested via the signing of an agreement for the development of a specific product or the undertaking of a specific task (Laursen and Salter, 2014). Such agreements aim at improving the communication between partners, which subsequently increases the chances of knowledge transfer (Szulanski et al., 2016). Therefore, formal innovation collaboration

breadth is more likely to be deployed in situations where knowledge that needs to be acquired or co-developed is either protected or too complex to be communicated in standardized format.

Formal collaborations include vertical collaborations, i.e. with customers and suppliers, and horizontal ones, i.e. with competitors. Such collaborations could play a positive role because they facilitate the sharing of knowledge (Tsai, 2009). However, they also require the sharing of investment, processes, and the cooperation in the testing of new ideas (Petersen et al., 2005), all of which bring about higher levels of inertia and structural rigidities (Schreyögg and Sydow, 2011). Thus, the higher the degree of formal innovation collaboration, the higher the integration between the focal company and its collaborators and the higher the inertial forces (Tai-Young et al., 2006). We argue that these forces will constrain organizations that have experienced the abandoning of innovation activities from applying any lessons they may have learnt to generate new product sales, i.e. that formal innovation collaboration breadth will have a negative moderating effect on how such experience affects innovation performance.

Converting knowledge acquired through formal collaborations which is protected or complicated requires the deployment of several complex processes (Szulanski, 1996; von Hippel, 1994). It requires the focal organization and its collaborators to establish agreements about how they are going to operate (Chapman et al., 2018). Such agreements attract high transaction costs and tend to be more effective when they are based on trust and reciprocity (Vestal and Danneels, 2018). As a result, they need to account for the needs and idiosyncrasies of each organization, to articulate the key deliverables, and to explain how knowledge will be shared and who will own any intellectual property that emerges from it. Moreover, the complexity of these processes tends to increase in the case of horizontal collaborations, as sharing knowledge with competitors will be more difficult and dangerous (Laursen and Salter, 2014; Tomlinson, 2010). Agreements therefore tend to be unique to each collaboration, potentially complex, and costly.

When an innovation activity is abandoned, the collaborators would need to determine who can use what in the future. However, often it is not immediately apparent who owns any intellectual property that may have emerged from the activity (Buss and Peukert, 2015). Resolving this requires negotiations and can be difficult both in cases of horizontal (with competitors) and vertical (with customers and suppliers) collaborations. In the case of the former it would be more difficult to use this knowledge in any future innovation activities that would not involve that competitor. Therefore, it will be difficult to apply any lessons learnt, especially when these may lead to legal disputes (Belderbos et al., 2014). Similarly, in the case of the latter, there will be situations where the innovation activity has been focusing on one customer or a specific problem and as such any lessons learnt may not be of interest to others (Havila et al., 2013). Therefore, formal innovation collaboration breadth would inevitably constrain the application of any lessons deduced from the experience of abandoning the innovation activity.

In summary, formal collaborations strengthen interdependencies and structural rigidities, which generate inertial forces negatively constraining the processes needed to apply lessons learnt from the experience of having abandoned an innovation activity. As a result, we hypothesize:

Hypothesis 3: The positive effect of abandoning an innovation activity on innovation performance is a) stronger with low levels of collaboration breadth and b) weaker with high levels of collaboration breadth.

Methodology

Sample

To meet the aims of this research, we use data from the European Community Innovation Survey (CIS5, CIS6, CIS7, CIS8 and CIS9) administered by UK Office of National Statistics

(ONS). The purpose of this survey was to collect information about firm-level innovation capacities and innovation output. The sample was drawn from the ONS Inter-Departmental Business Register (IDBR). The survey was conducted every other year from 2004-2014 from the stratified random sample of IDBR. A mail survey was sent first and, when no response was received, it was followed by telephone call. It was typically answered by the R&D manager, the Chief Financial Officer or the Managing Director. The response rate is about 50%, which is high, given that the survey was voluntary. Each stratum was weighted back to the population using the inverse sampling proportion based on industry sectors as provided by CIS (more detail about the data and the sampling procedures can be found in the report of the UK's Department for Business Innovation & Skills (Robson and Achur, 2013). Therefore, the sampling process ensures representativeness of the populations of UK establishments.

Measures

Table 1 presents the list of variables we used. New Product Innovation (NPI) is our dependent variable and is used to measure innovation performance. It measures the logarithms of sales of products which are new to the market, and/or new to the firm, or significantly improved. This measure has frequently been used in prior innovation studies (e.g. Laursen and Salter, 2006; Tether and Tajar, 2008). It provides a direct assessment of the success of innovation commercialization, and as such it can be effective in measuring innovation performance (Grimpe and Kaiser, 2010). Our independent variable is INNOVABAN, a categorical variable that takes the value of 1 when a firm reports that it had abandoned innovation activities; and 0 when it does not.

The moderating variables are SEARCH and COLLAB. SEARCH measures the external search breadth, which is the number of different types of external knowledge types of sources from

which a firm draws ideas. We used six possible types of sources (suppliers, clients or customers, competitors, consultants and private R&D institutes, universities, and public research institutes). Following Laursen and Salter's (2014) procedure, our breadth variable is composed as follows. First, for each type of source we created a dummy variable which took the value of 1 when a firm indicated that it used this type of source and 0 when not. Then we created a new variable by calculating for each firm the sum of the dummies and then dividing it by 6 (the maximum number of types of knowledge sources). The resulting variable, which ranges from 0 to 1 has a high degree of internal consistency (Cronbach's alpha = 0.81). COLLAB measures the formal external collaboration breadth, which is the number of different types of external organizations with which a firm collaborates. Consistent with Laursen and Salter (2014), we used six types of organizations listed above. For each type of the collaborated organization we created a dummy variable which took the value of 1 when a firm indicated that they had collaborated on innovation activities with the type of the organization and 0 when not. Similar to SEARCH, the COLLAB variable was the sum of the dummy variables divided by the maximum number of types of collaborated organizations (6), thus it ranged from 0 to 1. Cronbach's alpha is 0.85, which suggests a high degree of internal consistency.

---Insert Table 1 about here---

Controls

Previous studies in new product development and innovation more generally have indicated that there are many factors that could influence innovation performance (Henard and Szymanski, 2001; Montoya-Weiss and Calantone, 1994) and as a result could provide different interpretation to our findings.

To make sure that these explanations do not affect our results we included several control variables. One is innovation effort. Higher levels of innovation effort would suggest that the organization is better able to deal with any issues arising at the aftermath of abandoning an innovation activity. This effort was measured as the natural logarithm of the internal R&D investment (INTKNOW). Internal R&D enables innovation and is closely linked to a firm's capability of absorbing external knowledge (Cohen and Levinthal, 1990) and thus affects the capability to initiate new innovation activities. A second measure of the innovation effort is external knowledge, which captures the extent to which an organization engages in investment with external parties. It was measured as the natural logarithm of external R&D investment (EXTKNOW). We included both, because in the aftermath of abandoning an innovation activity organizations may spend more on acquiring knowledge directly from external sources. Such an effect would lead to better innovation performance without necessarily improving the effectiveness of the new product development process. Joint development could indicate that the organization is better positioned to share the risk with other stakeholders and to recover from abandoning innovation activities (Spithoven et al., 2011). One additional variable that could impact on innovation performance is labor productivity. In the aftermath of abandoning an innovation activity, the relative productivity of the organizations will be reduced, i.e. there will be more resources available for relatively fewer activities. These additional resources could be used to accelerate the existing innovation activities, without necessarily improving their effectiveness. We measured labor productivity (LABOR) as the total annual turnover divided by the number of employees. Finally, we controlled for firm size, as larger organizations should be able to allocate more resources further affecting the new product

development process. Firm size was captured by the variable EMPLOYMENT that included the natural logarithms of employee numbers[1].

An additional factor that could influence our findings is the location of an organization as regional differences may affect innovation performance (Souder and Song, 1997) and the ability of organizations to learn. For instance, frequent interaction with Universities can increase an organization's absorptive capacity and hence its ability to learn (Bishop et al., 2011). Given that our sample is drawn from the UK only, international differences do not play a role. To make sure we capture any regional differences we controlled for location by including several UK region dummy variables using the regional classification made by ONS for CIS.

We also controlled for industry variance, as the propensity of some sectors to innovate is likely to be different (Pavitt, 1984). To do so, we included seven industry dummy variables composed by the three-digit SIC code. We included: manufacturing, mining, electricity and water supply, construction, hotel and hospitalities, transportation, and the remaining industries. Since standard industry coding varies across CIS datasets, we recoded all industry codes based on the Standard Industrial Classification in 2007 (ONS 2007) to prevent any measurement errors. Finally, we included time dummies to control for any survey period fixed effects. This eliminated any concerns about unobserved over-time differences (e.g. inflation or unemployment rate).

[1] EMPLOYMENT and SALES (the natural logarithms of the annual turnover) are highly correlated ($r=0.79$, $p<0.05$). We thus chose only one to control for the size effect. We use EMPLOYMENT instead of SALES, because EMPLOYMENT is not highly correlated with LABOR ($r=0.10$, $p<0.05$) but SALES is ($r=0.52$, $p<0.05$). Regression results of the model using EMPLOYMENT are highly consistent with those using SALES as a control variable.

Analysis

Model selection and descriptive analysis

In total, we have 41,877 observations, which formulate an unbalanced panel[2]. Our aim was to evaluate the effect of the experience of having abandoned an innovation activity, and the role of the two dimensions of openness, external search breadth and formal innovation collaboration breadth, on innovation performance. We therefore formed our estimator using a firm-year unit of analysis. Given that a) our measure of innovation performance captures the new product sales, and b) several organizations (about a third of respondents) report that they had no sales from new products, 66.81% of the dependent variable was zero. As such, NPI is a semi-continuous variable, i.e. *"a variable that combines a continuous distribution with point masses at one or more locations"* (Olsen and Schafer, 2001 p. 730). Given the nature of our dependent variable, generalized linear model with gamma distribution (Gamma GLM; (McCullagh and Nelder, 1989)) or generalized estimating equations (GEE; (Hardin and Hilbe, 2013)) are the more appropriate estimate techniques.

We used the lag inherent in CIS to test the relationship between abandoned innovation activities and innovation performance by relating the dependent variable (NPI) with the independent variables (INNOVABAN, SEARCH, and COLLAB). The NPI item asked respondents to report their product performance at the time of completion of the survey (e.g. 2012 in CIS8). The INNOVABAN one asked them to report whether they had experienced the abandoning of an innovation activity. The SEARCH (COLLAB) items asked them whether and the extent to which they had used a type of external knowledge sources (collaborated with a type of external organizations) during their innovation activities at any time during the previous three years (e.g. 2010-2012 in CIS8). Therefore, and in line with previous uses of this data (van Beers and

[2] In this unbalanced panel, 31,729 firms were observed once and 597 firms were observed five times.

Zand, 2014 p. 304) (e.g. Cassiman and Veugelers, 2002; Grimpe and Kaiser, 2010; Klingebiel and Rammer, 2014; Laursen and Salter, 2006), we used the built-in lag between the independent and dependent variables. We also tested for multicollinearity. Table 2 presents the descriptive statistics and correlations of the variables we used. We used variance inflation factors (VIFs) which are a concern when they are larger than 10 (Kutner et al., 2004). As shown in Table 2, the VIFs of the independent variables vary from 1.00 to 1.63, i.e. less than 10 and thus we conclude that there are no multicollinearity issues.

---Insert Table 2 about here---

Table 2 shows the summary statistics of the general estimating equation and Table 3 shows the estimated coefficients from the model. First, we specified and tested a set of tiered models. Model 1 includes the independent variable (INNOVABAN) and the control variables. Model 2 adds the linear term of the two dimensions of openness (SEARCH and COLLAB) and Model 3 adds the quadratic term of the two dimensions of openness ($SEARCH^2$ and $COLLAB^2$) to take the non-linear effects of SEARCH and COLLAB on innovation performance into account. Model 4 adds the linear interaction terms (INNOVABAN*SEARCH and INNOVABAN*COLLAB) and Model 5 adds the quadratic interaction terms (INNOVABAN*$SEARCH^2$ and INNOVABAN*$COLLAB^2$). Model 5 is our final model on which our analysis and discussion are based. Following Aiken and West (1991), SEARCH and COLLAB were standardized prior to calculating their squared term and the two-way linear/quadratic interaction terms. For models 1-5, the Wald Chi square were all significant at the 0.001 level. The computed statistical measures indicate that the independent and control variables included in the model affect innovation performance at the 0.001 level.

---Insert Table 3 about here---

Hypotheses testing

Hypothesis 1 predicted that a firm that has experienced the abandoning of an innovation activity is more likely to demonstrate higher levels of innovation performance. The coefficient *INNOVABAN* of models 1-5 in Table 3 indicates a positive and significant relationship ($\beta_{INNOVABAN\text{-}Model1}$=0.486, p<0.01; $\beta_{INNOVABAN\text{-}Model5}$=0.256, p<0.01). It indicates that the experience of abandoning an innovation activity is positively associated with the new product sales. Therefore, H_1 is supported. It is worth noting that the results in models 3-5 show a non-linear relationship between the moderator and the dependent variable, suggesting an inverted U-shaped relationship between SEARCH (COLLAB) and innovation performance ($\beta_{SEARCH\text{-}Model5}$=0.921, p<0.01; $\beta_{SEARCH^2\text{-}Model5}$= -0.524; $\beta_{COLLAB\text{-}Model5}$=0.484, p<0.01; $\beta_{COLLAB^2\text{-}Model5}$= -0.126). This finding was consistent with prior literature (Laursen and Salter, 2006).

Hypothesis 2 predicted that the positive effect of abandoning an innovation activity on innovation performance is weaker with low levels of external search breadth and stronger with high levels of such breadth. As seen in Model 5 of Table 3, results reveal significant linear and quadratic interactions for SEARCH. The linear interaction term of *INNOVABAN* and *SEARCH* is negative and significant at the 0.01 level ($\beta_{INNOVABAN*SEARCH\text{-}Model5}$= -0.326, p<0.01). The quadratic interaction term of *INNOVABAN* and *SEARCH* is positive and significant at the 0.01 level ($\beta_{INNOVABAN*SEARCH^2\text{-}Model5}$= 0.180, p<0.01). To facilitate the interpretation of the different interaction patterns, we visualized them using the procedure described by Aiken and West (1991). In Figure 1, as the square line shows, the pattern of the results suggests that when external search breadth is high (+1s.d.), the new product sales are higher for organizations that have experienced the abandoning of an innovation activity than those that have not. Moreover,

as the diamond line shows when external search breadth is low (-1s.d.), the new product sales are higher for organizations that have experienced the abandoning of an innovation activity. Furthermore, the slope of the diamond line is steeper than the square one. It shows that firms that have experienced the abandoning of an innovation activity show stronger new product sales by around 65% when their external search breadth is low. This indicates that the increases in number of types of external knowledge sources is associated with the decreases of the positive impact of experiencing the abandoning of an innovation activity on new product sales. The external search breadth thus negatively moderates the relationship between the experience of abandoning an innovation activity and new product sales. Therefore, H_2 is not supported.

Hypothesis 3 predicted that the positive effect of abandoning an innovation activity on innovation performance is stronger with low levels of collaboration breadth and weaker with high levels. Our results, shown in Model 5 of Table 3, reveal significant linear and quadratic interactions for COLLAB. The linear interaction term of *INNOVABAN* and *COLLAB* is negative and significant at the 0.01 level ($\beta_{INNOVABAN*COLLAB\text{-}Model5}$= -0.376, p<0.01). The quadratic interaction term of *INNOVABAN* and *COLLAB* is positive and significant at the 0.01 level ($\beta_{INNOVABAN*COLLAB^2\text{-}Model5}$= 0.093, p<0.01). In Figure 1, as the round line shows, when formal innovation collaboration breadth is high (+1s.d.), firms that have experienced the abandoning of an innovation activity underperform those with no such experience in terms of new product sales. Moreover, as the triangle line shows, when formal innovation collaboration breadth is low (-1s.d.), firms that have experienced the abandoning of an innovation activity also outperform those without such experience. The slope of the triangle line is steeper than the one of the round line. It shows that the experience of having abandoned an innovation activity has a stronger positive effect on new product sales when firms' formal innovation collaboration breadth is low. The increases in formal innovation collaboration breadth is associated with decreases of the positive effect between the experience of having abandoned

an innovation activity and new product sales. It indicates that as a firm collaborates with more types of external organizations, the positive impact of its experience on the new product sales is weakened. Therefore, H_3 is supported.

---Insert Figure 1 about here---

Robustness and Sensitivity

We tested the sensitivity of the results across different measures of innovativeness of new products by replacing our dependent variable (NPI) with NEWWORLD (log of sales from products new to the world, Model 6), NEWBUSI (log of sales from products new to the business, Model 7), and NEW (log of sales from products significantly improved, Model 8). As shown in Table 4, the sign and significance level of all coefficients are the same and the magnitude of all coefficients is highly comparable across models 7-9. More specifically, the experience of having abandoned an innovation activity has strongest positive effect on innovations which are new to the world ($\beta_{INNOVABAN\text{-}Model7}$=0.541, p<0.01; $\beta_{INNOVABAN\text{-}Model8}$=0.319, p<0.01; $\beta_{INNOVABAN\text{-}Model9}$=0.266, p<0.01).

We then reran our model by replacing the dependent variable with a NPI ratio (the percentage of new product sales, Model 9). Although the use of log values for the dependent variables in our models provides greater validity, ratio values can be more effective in reducing the influence of size (e.g., Laursen and Salter, 2006; Klingebiel and Rammer, 2014). The results are presented in Model 9 of Table 4 and are consistent with those of Model 5, suggesting that the effects of the experience of having abandoned an innovation abandoning experience and the forms of openness we used (SEARCH and COLLAB) are independent of size effects.

In addition, we composed an ordered categorical DV[3] (Ordered NPI, Model 10) to check if our results were consistent with the simulated coefficients (King et al., 2000). The ordered value of NPI was composed by segmenting the value of NPI into different levels, namely: 0, when a firm has no new product sales, 1-5, when the mean value of product sales is lower than 10%, 25%, 50%, 75%, 90%, and 6 when it is in the upper 10%. To perform the simulation, we took 10,000 times draws and used the Stata code based on King et al. (2000)[4]. The results using the ordered categorical values of NPI are presented in Model 10 of Table 4 and are consistent with the results of our main model (Model 5).

---Insert Table 4 about here---

Because CIS is a voluntary survey, the majority of the firms in the full sample only participated in the survey once. In order to check if our results were consistent across different samples, we composed a restricted sample of firms that participated in the survey for at least two waves, for which we repeated the estimation procedure. The results of the restricted NPI for which we had at least two observations are presented in Model 11 of Table 4. The results are similar to those of the full sample (Model 5).

To check if our results are independent of different estimation approaches, we used OLS (Model 12), GLM (Model 13), and random Tobit (Model 14)[5] estimations. The results of models 12-14 in Table 5 were highly comparable with those of Model 5. Therefore, the empirical findings are consistent across alternative estimation approaches.

---Insert Table 5 about here---

[3] This simulation method is applicable to models such as regression, logit, probit, ologit, oprobit, mlogit, poisson, nbreg, sureg and Weibull. Because our DV is a semi-continuous variable, the aforementioned models are not applicable. We used oprobit model on the ordered value of DV.
[4] The simulated coefficients of 99% upper and lower bond of confidence intervals are available upon request.
[5] To take the panel effect into account, we adopted the maximum likelihood estimation of a Tobit random-effect model.

We also examined the extent to which path dependency might bias our results. Following Klingebiel and Rammer (2014), we included the lagged dependent variable in Model 15 to recognize the likely effect of past innovation performance[6]. Past innovation performance was only recorded for a subset of firms and as a result, its inclusion left us with fewer observations. Nevertheless, the results, shown in Model 15, are consistent with those of Model 5 and thus provide us with further confidence of the robustness of our analysis.

Finally, there is a risk of endogeneity, which may arise from a confound effect of the experience of having abandoned an innovation activity and other firm-level characteristics. For example, firms that are innovation active (e.g. when a firm invests in internal and/or external R&D) may be more likely to experience the abandoning of innovation activity and more likely to perform well. If this were to be the case, the regression analyses could be biased by the selection of the "treatment condition" (having experienced the abandoning of an innovation) rather than the "control condition" (not having experienced the abandoning of an innovation). That is, being active in innovation could explain any observed association between the treatment (INNOVABAN) and the outcome variable (NPI).

To investigate whether endogeneity affects our results we undertook a further robustness check based on the propensity-score matching approach (Rosenbaum and Rubin, 1983). This approach mitigates any selectivity bias that could arise if any of the characteristics of firms that have experienced the abandoning of an innovation activity also lead to improved new product sales. There are 3,485 firm-year units in the "treatment condition" and the same number in the "control condition" giving us a sample size of 6,970. Firms in the "treatment condition" were similar to those in the "control condition" in terms of all observable characteristics (e.g., firm size, location, industry, internal/external R&D investment), except on whether they had

[6] Adding NPI_{t-1} introduces high correlation between the lagged variable and the error term, but it provides robustness check of our analysis.

experienced the abandoning of an innovation activity. The results from the matching approach (Model 16 in Table 5) are highly consistent with our main model (Model 5 in Table 3). Although the above provides further support to the robustness of our analysis[7] and, to a degree addresses the endogeneity issue, it does not completely eliminate it and thus is a potential limitation.

Discussion and Conclusions

In this paper we set out to explore the following two research questions:

- How does the experience of having abandoned an innovation activity affect an organization's innovation performance?
- How does openness affect the relationship between the experience of having abandoned an innovation activity and innovation performance?

Following our theoretical development and data analysis, we now revisit these questions and explain the contribution that our work makes.

First, we have explained and empirically validated how the experience of an event which may be unwelcome, but part of the new product development process (Khanna et al., 2016; Leoncini, 2016) – having abandoned an innovation activity - can positively affect an organization's innovation performance. Furthermore, we have made sure, to the degree possible, that the effect is not driven by factors external to the new product development process such as innovation activeness and firm size, providing further confidence about the positive effect. Second, our work explains how the interplay between the experience of having abandoned an innovation activity and the forms of openness (i.e. external search breadth and

[7] We nevertheless acknowledge that the interpretation of the results of our final model (Model 5) is contingent on the potential for endogeneity.

formal innovation collaboration breadth) affects the learning processes which is associated with improved innovation performance. Given the significant attention that openness has attracted both at the theoretical and the practical levels (Bogers et al., 2018; Dahlander and Piezunka, 2014; Henkel et al., 2014; Laursen and Salter, 2014), this work combines two concepts that are realities for many organizations (Kester et al., 2011). We explain the implications of each in turn.

We have built on the literature that explores the impact of failure on organizational performance. As with catastrophic and operational failures, which have been the main focus of this literature (Desai, 2015; Madsen and Desai, 2010), the experience of abandoning innovation activities is an unwelcome event (Khanna et al., 2016). They absorb organizational resources and individuals are likely to be emotionally and professionally attached to them. We find that when they are abandoned, they are likely to encourage the organization to learn and to improve its innovation performance. Furthermore, such an experience will likely increase an organization's tolerance to failure (Birkinshaw and Haas, 2016) and encourage it to experiment more in the future thereby improving further its innovation performance.

Our findings also show that the positive effect is contingent on the forms of openness an organization is utilizing. Our theoretical development suggested that external search breadth and formal innovation collaboration breadth will have positive and negative moderating effects respectively. Although our results supported the effect of formal innovation collaboration breadth, the one of external search breadth has been contrary to our predictions. Therefore, our results suggest that both dimensions of openness will negatively affect how organizations that have experienced the abandoning of an innovation activity manage their new product development processes. We discuss the implications of these findings in the remainder of this section.

External search breadth indicates the degree to which an organization engages with several types of knowledge sources during its innovation activities. Our results show that contrary to our hypothesis, engaging with a greater number of different types of external knowledge sources will have a negative effect on how an organization learns from the experience of abandoning an innovation activity. Our hypothesis was based on the premise that engaging with a greater number of types of external knowledge sources strengthens the learning opportunities during the new product development process more broadly.

This counterintuitive result can potentially be explained with the way organizations select which lessons are more relevant to their situation (Denrell, 2003) and the managerial attention needed to embed them into their processes (Grimpe and Kaiser, 2010). Engaging in informal knowledge exchange with higher number of different types of external sources can increase the population of external partners and hence the number of reference points an organization can learn from (Ahn et al., 2017). Yet, managerial time and attention is limited, which suggests that managers cannot learn from every member of the population, but from a sample. If the sample was selected to represent the population and managers had the time to analyze in detail whether or not and how the lessons learnt can be applied in their own case, the learning processes would be strengthened. However, the selection process is likely to be biased and based largely on cases that have been successful (Denrell, 2003). This is so either because managers select the successful cases or because external knowledge sources are less likely to showcase and discuss the failed ones. Thus, managers are more likely to try to learn by imitating practices that seem successful and not by understanding others' failures. This *under-sampling of failure* (Denrell, 2003 p. 227) can be misleading, especially when an organization is trying to learn from the abandoning of an own innovation activity. So, instead of learning lessons from external knowledge sources that may have also experienced the abandoning of

similar activities, managers ignore them and focus on those that they perceive as successful, limiting the opportunity to learn (Madsen and Desai, 2010).

Furthermore, integration of knowledge from external sources in situations where an organization is dealing with a larger number of different types of knowledge sources can be relatively shallow (Ahn et al., 2017) and focuses on knowledge which has been codified and thus easy to transfer. Although it encourages organizations to identify new ideas, in itself, it does not encourage the change of routines needed as a result of learning. When the number of types of sources of information is high, managerial attention is spread thinly (Grimpe and Kaiser, 2010; Laursen and Salter, 2006). As a result, it may lead to superficial knowledge exploitation (Cruz-González et al., 2015). In fact, the continuous, but not in-depth, engagement with a variety of types of knowledge sources which may be too different from the core business and functions of the focal organization, as can be the case when external search breadth is high, may make learning more difficult (Ahn et al., 2017).

When formal innovation collaboration breadth is considered, the effect is consistent with our hypothesized relationship. Formal innovation collaboration breadth is the breadth of a firm's formal collaboration relationships for innovation and means that the organization has developed relationships with its external sources to acquire and integrate knowledge. Our theoretical development and empirical validation suggest that it would weaken the new product development process in a way that organizations that have experienced the abandoning of an innovation activity would be less able to generate new product outputs. Although collaborations are generally seen as positive contributors to new product development processes (Petersen et al., 2003), they also generate inertial forces and internal rigidities which would limit the ability to learn from the decision to abandon innovation activities.

Our results also have some implications for the literature that has been focusing on an organization's response to failure (Desai, 2015; Khanna et al., 2016; Madsen and Desai, 2010) which argues that learning in such a context is a dynamic process (Maslach, 2016). Organizational search for knowledge in response to failure could challenge old assumptions and thus lead to the adoption of new and divergent ideas (Madsen and Desai, 2010). Although the experience of abandoning an innovation activity is not the same as that of catastrophic and operational failures that previous studies have explored, our findings suggest that learning in such a context will depend on the forms of openness the organization engages with.

Managerial and Policy Implications

Our work provides guidance to innovation managers and policy makers exploring the opportunities and challenges of engaging with new product development processes. Our results indicate that an organization which has experienced the abandoning of an innovation activity is likely to improve its innovation performance. However, we would not go as far as promoting the abandoning innovation activities just for the experience of it. Given that experience the abandoning of such activities is a normal part of the new product development process, it should not be viewed as detrimental by the organization. Instead the organization should promote an environment where experimentation is encouraged and failure is accepted. This type of environment would allow employees to be more willing to accept the risk of failure by testing new ideas that accompanies innovation and not be subject to blame and/or ridicule.

Our work also suggests that external search breadth and formal innovation collaboration breadth will weaken the positive effects associated with the experience of abandoning an innovation activity. We argued that this is because of the *under-sampling of failure* (Denrell, 2003 p. 227), and the inertial forces associated with the development of formal collaborative

relationships constrain organizations from learning from the experience. In the case of external search breadth, our recommendation is to focus on a lower number of different types of knowledge sources. For instance, project management methodologies advocate for the inclusion of specific stakeholders on their "lessons learnt" project review processes. Such processes could take into account these challenges and try to focus on identifying the causes that led to the decision to abandon the innovation activity by acknowledging that not all types of stakeholders will lead to learning. Furthermore, we would recommend that managers are more careful about who they learn the lesson from. Although trying to imitate successes is tempting and relatively easy, learning from failure can be more effective, but more difficult. This could mean that when reviewing the factors that led to the decision to abandon the activity with external knowledge sources, e.g. a supplier, innovation managers could try to explore any instances where they (the external knowledge sources) have experienced a similar decision. The potential learning from sharing such an experience would be significantly higher. Finally, focusing on a few key relationships is more appropriate.

Limitations and Directions for Future Research

Our work has some limitations within the context of which, our results and recommendations should be interpreted. The first relates to the difference between the time of experiencing the abandoning of an innovation activity and the measure of innovation performance. We used the three-year time period prior to the completion of the survey, i.e., the abandoning of the innovation activity might have happened at any time during the three-year period prior to the completion of the survey. Furthermore, in the methods section we explain the additional empirical strategy we used to reduce any endogeneity effects. Although this is a significant departure from many studies that do not use such lag effects, a greater gap or time period could

have been more desirable. For instance, the independent variable could have been in one survey wave and the dependent in the following one. Such an approach would have helped significantly reduce any risk, e.g. arising from the possibility that the causality may be in the opposite direction to the one we are predicting. In our case, applying this approach would have resulted to a significantly reduced sample size from which we would not have been able to deduce safe conclusions.

A second limitation relates to the potential for endogeneity. During our analysis we undertook several robustness tests to ensure that this does not affect our results. One additional test that would have completely eliminated any such risk would have been to use instrumental variable methods (IV). However, we were not able to identify good instruments from CIS because the questionnaire was designed for investigating firms' innovation activities and as a result all variables were associated with NPI one way or another. A future search for more informative firm characteristics is needed to explain innovation performance and identify good potential instruments. Nevertheless, and although we acknowledge that the interpretation of the results may be contingent upon the potential for endogeneity, the tests we have conducted significantly reduce the impact of this risk.

A third limitation relates to the geographical location where the data came from. The data came from the UK, which covers a wide spectrum of companies and innovation strategies. Yet, there may be some country specific effects that we cannot account for. For instance, attitudes to openness may vary, and different systems of innovation maybe less susceptible to learning (Niosi, 2002). We would, therefore, encourage future research to explore whether the same effects are present in other cultural and national contexts.

Finally, we should note that there may be a difference between horizontal (with a competitor) and vertical (with a supplier or a customer) collaborations. Our argument in the development

of the third hypothesis was that either of the two will increase network inertia and thus constrain an organization from applying its learning. Yet, collaborating with competitors can be more difficult than collaborating with customers or suppliers (Laursen and Salter, 2014). While we predict both (i.e., horizontal and vertical collaborations) to have a negative moderating impact, future work could focus on these differences and explore the degree to which they affect an organization's learning processes.

In addition to addressing some of the methodological limitations of this study, future work could explore aspects of failure and success, and how they can influence the subsequent introduction of new products and processes. Deichmann and Ende (2014), for example, argue that when employees take the initiative and fail, their threshold for taking the initiative again may decrease because of lower expectations. They also argue that in such contexts the motivation to take new initiatives will eventually reduce when many previous ones have failed, a proposition that has been examined in the entrepreneurship literature (Ucbasaran et al., 2009). Therefore, future studies could explore such thresholds by investigating how an increased number of activities that have been abandoned affect innovation performance. Such a study could provide more detail on the long-term impact abandoning innovation activities and offer some practical guidance on how much can actually be tolerated. It could also explore other internal factors that could moderate the relationship, e.g. R&D spending.

Furthermore, future studies could also explore how innovation performance is affected by the type of activity that is being abandoned. There is for instance evidence that feedback from abandoning process innovations may be richer than that of abandoning product innovations (Maslach, 2016). This is because the focus of the former is on intermediary steps and not on end outcomes (Piening and Salge, 2015).

We would also encourage future researchers to explore in more detail the effect of different types of knowledge. The knowledge management literature supports the notion that different types of knowledge are transferred better with different types of methods. In the development of the hypotheses we explain how the two forms of openness can help transfer codified and tacit knowledge. Exploring this in more detail could help explain how knowledge flows from different sources and types could help an organization learn from the abandoning of an innovation activity.

One final avenue for research relates to the reasons and situational factors that could precipitate abandoning an innovation activity. For instance, Behrens and Ernst (2014) argue that the determination of new product development managers to abandon an underperforming project is influenced by factors such as the advice from consultants and visual decision aids, e.g. colorful graphs. Therefore, both the reasons and the factors that lead to the decision could influence how learning occurs. Future studies could thus explore these factors by adding additional variables to our model.

Table 1: Model Variable Definitions in CIS dataset for 2004-2014

Equation 1: $NPI_{it}=\beta_{10} + \beta_{11}INNOVABAN_{it}+ \beta_{12}Control\ Variables + \varepsilon_{it}$

Equation 2: $NPI_{it}=\beta_{20} + \beta_{21}INNOVABAN_{it}+ \beta_{22}BREADTH_{it} + \beta_{23}COLLAB_{it} + \beta_{24}Control\ Variables + \varepsilon_{it}$

Equation 3: $NPI_{it}=\beta_{30} + \beta_{31}INNOVABAN_{it}+ \beta_{32}BREADTH_{it} + \beta_{33}COLLAB_{it} + \beta_{34}BREADTH^2_{it} + \beta_{35}COLLAB^2_{it} + \beta_{36}Control\ Variables + \varepsilon_{it}$

Equation 4: $NPI_{it}=\beta_{40} + \beta_{41}INNOVABAN_{it}+ \beta_{42}BREADTH_{it} + \beta_{43}COLLAB_{it} + \beta_{44}BREADTH^2_{it} + \beta_{45}COLLAB^2_{it} + \beta_{46}INNOVABAN_{it} * BREADTH_{it} + \beta_{47}INNOVABAN_{it} * COLLAB_{it} + \beta_{48}Control\ Variables + \varepsilon_{it}$

Equation 5: $NPI_{it}=\beta_{50} + \beta_{51}INNOVABAN_{it}+ \beta_{52}BREADTH_{it} + \beta_{53}COLLAB_{it} + \beta_{54}BREADTH^2_{it} + \beta_{55}COLLAB^2_{it} + \beta_{56}INNOVABAN_{it} * BREADTH_{it} + \beta_{57}INNOVABAN_{it} * COLLAB_{it} + \beta_{58}INNOVABAN_{it} * BREADTH^2_{it} + \beta_{59}INNOVABAN_{it} * COLLAB^2_{it} + \beta_{510}Control\ Variables + \varepsilon_{it}$

Definitions

NPI	New Product Introduction. The logarithm of total firm sales revenues that derived from the sales of new products introduced (i.e., new to the market, new to the firm, and significantly improved) in the past three years.
INNOVABAN	Abandoned innovation activities. Binary variable: 0 when a firm has no innovation activities that were abandoned in the past three years; and 1 when it has innovation activities that were abandoned.
SEARCH	External search breadth. Whether external knowledge was obtained from suppliers, clients or customers, competitors, consultants (includes commercial labs, private R&D institutes), universities or other high education institutes, government or public research institutes. Each source is coded as 1 when the firm reports that it uses the source and 0 when it does not. We sum of number of types of external knowledge sources used, ranging from 0 to 6 sources, and then divided the sum by all types of external knowledge sources used (6). SEARCH ranges from 0 to 1.
COLLAB	Formal external collaboration breadth. Whether external cooperation was engaged with the same 6 types of external organizations as those used in SEARCH. Each organization type is coded as 1 when the firm reports that it collaborates with the type of organization and 0 when it does not. We sum the number of types of external collaborators, ranging from value 0 to 6, and then divide the sum by all types of external collaborators engaged (6). COLLAB ranges from 0 to 1.
INNOVABAN*SEARCH	Interaction term of INNOVABAN and SEARCH
INNOVABAN*COLLAB	Interaction term of INNOVABAN and COLLAB
Control variables	

INTKNOW	Internal knowledge investment. Logarithm of in-house R&D investment/Sales
EXTKNOW	External knowledge investment. Logarithm of external R&D investment/Sales.
LABOR	Firms' turnover per employee
EMPLOYMENT	Employment size. Logarithm of number of employment.
REGION	Regional dummy variable representative of the following UK regions: East Midlands, Eastern England, London, Northeast England, Northwest England, Northern Ireland, Scotland, Southeast England, Southwest England, Wales, West Midlands, Yorkshire and Humber
INDUSTRY	Industry dummy variable representative of 7 standardized industry code, including manufacture, mining, electricity & water supply, construction, hotel &accommodation, transportation and other.
YEAR	Time dummy variable representative of 4 survey periods
ε_{it}	Random error term
$\beta_0 ... \beta_5$	Model coefficients, where β_0 measures the constants; β_1 measures the relationship between abandoned innovation activities and NPI; β_2 measures the relationship between external knowledge acquisition and NPI; β_3 measures the moderating effects of external knowledge acquisition on the relationship between abandoned innovation activities and NPI.

Table 2: Descriptive Statistics and Correlation Coefficients

	Variable	1	2	3	4	5	6	7	8	9	10	Mean	SD	VIF
1	NPI											2.36	3.55	
2	INNOVABAN	0.25*										0.08	0.28	1.14
3	SEARCH	0.47*	0.25*									0.40	0.40	1.61
4	COLLAB	0.41*	0.25*	0.49*								0.13	0.25	1.50
5	INTKNOW	0.51*	0.30*	0.46*	0.40*							1.06	2.06	1.63
6	EXTKNOW	0.29*	0.20*	0.28*	0.30*	0.46*						0.32	1.17	1.30
7	LABOR	0.09*	0.01	0.00	0.03*	0.05*	0.06*					143.96	208.13	1.03
8	EMPLOYMENT	0.18*	0.05*	0.11*	0.09*	0.18*	0.14*	0.10*				4.17	1.46	1.06
9	INDUSTRY	-0.15*	-0.09*	-0.14*	-0.06*	-0.17*	-0.07*	0.05*	0.01*			4.08	2.54	1.08
10	REGION	-0.01*	-0.01	0.01	-0.01*	0.01	0.01	0.01	-0.03*	0.00		6.50	3.23	1.00
11	YEAR	-0.01	-0.03*	-0.24*	0.05*	-0.05*	-0.06*	0.11*	0.02*	0.15*	0.01	2010	3.35	1.15

*Correlation is significant at 0.05 levels. N=41,877

Table 3: Innovation Activity Abandoning Effect on Logarithms of Product Sales Revenues from New Product Innovation

	GEE†									
	Model 1		**Model 2**		**Model 3**		**Model 4**		**Model 5**	
Dependent variable: NPI					**Full Sample**					
	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
INNOVABAN	0.486***	(17.68)	0.227***	(6.45)	0.224***	(6.24)	0.427***	(7.81)	0.256***	(6.32)
SEARCH			0.764***	(52.13)	0.916***	(38.28)	0.920***	(38.06)	0.921***	(37.39)
COLLAB			0.198***	(17.34)	0.442***	(14.97)	0.449***	(15.25)	0.484***	(15.35)
$SEARCH^2$					-0.524***	(-28.09)	-0.511***	(-26.95)	-0.524***	(-26.31)
$COLLAB^2$					-0.118***	(-11.65)	-0.110***	(-11.05)	-0.126***	(-11.13)
INNOVABAN *SEARCH							-0.196***	(-3.75)	-0.326***	(-4.48)
INNOVABAN *COLLAB							-0.138***	(-5.80)	-0.376***	(-7.39)
INNOVABAN *$SEARCH^2$									0.180***	(3.73)
INNOVABAN *$COLLAB^2$									0.093***	(5.29)
Controls										
INTKNOW	0.248***	(56.31)	0.160***	(27.54)	0.151***	(25.24)	0.151***	(25.54)	0.151***	(25.53)
EXTKNOW	0.061***	(8.53)	-0.007	(-0.74)	0.006	(0.68)	0.012	(1.33)	0.011	(1.30)
LABOR	0.000***	(9.84)	0.000***	(7.03)	0.001***	(7.26)	0.000***	(7.13)	0.000***	(7.10)
EMPLOYMENT	0.074***	(9.30)	0.028***	(2.72)	0.032***	(2.82)	0.034***	(3.04)	0.034***	(2.99)
Manufacture (as base)										
Mining	-0.500***	(-3.17)	-0.425**	(-2.26)	-0.429**	(-2.20)	-0.426**	(-2.16)	-0.427**	(-2.15)
Electricity	-0.492**	(-2.19)	-0.470	(-1.44)	-0.456	(-1.31)	-0.455	(-1.30)	-0.459	(-1.30)
Construction	-0.480***	(-8.96)	-0.514***	(-7.53)	-0.497***	(-6.52)	-0.494***	(-6.48)	-0.495***	(-6.47)
Accommodation	-0.433***	(-8.10)	-0.349***	(-5.22)	-0.354***	(-4.75)	-0.355***	(-4.74)	-0.357***	(-4.75)
Transportation	-0.273***	(-5.65)	-0.193***	(-3.25)	-0.209***	(-3.06)	-0.208***	(-3.03)	-0.209***	(-3.03)
Other	-0.252***	(-10.62)	-0.225***	(-7.28)	-0.217***	(-6.26)	-0.214***	(-6.15)	-0.213***	(-6.11)
Regional dummies	Included		Included		Included		Included		Included	
Year dummies	Included		Included		Included		Included		Included	
No. of observation	41877		41877		41877		41877		41877	
Wald Chi Square	16969.053		18299.732		14780.104		14766.170		14736.184	
Prob>chi2	0.000		0.000		0.000		0.000		0.000	

† Panel effect model ; * p<0.05 ** p<0.01 *** p<0.001

Table 4: Robustness Check for Innovation Activity Abandoning Effect on New Product Innovation: Alternative DV

	Model 6		Model 7		Model 8		Model 9		Model 10		Model 11	
	NEWWORLD†		NEWBUSI†		NEW†		Ratio NPI†		Ordered NPI		Restricted sample‡	
Dependent variable: NPI									Simulated estimate			
	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
INNOVABAN	0.541***	(7.22)	0.319***	(6.24)	0.266***	(4.09)	0.271***	(4.23)	0.215***	(6.16)	0.274***	(3.88)
SEARCH	1.003***	(20.81)	0.905***	(30.22)	1.095***	(26.50)	0.982***	(26.04)	0.543***	(50.31)	0.878***	(20.44)
COLLAB	0.654***	(10.67)	0.483***	(12.21)	0.604***	(11.08)	0.571***	(10.99)	0.322***	(20.68)	0.484***	(8.73)
$SEARCH^2$	-0.489***	(-12.22)	-0.494***	(-20.17)	-0.607***	(-18.50)	-0.554***	(-17.87)	-0.267***	(-25.03)	-0.466***	(-13.20)
$COLLAB^2$	-0.144***	(-6.64)	-0.130***	(-9.16)	-0.147***	(-7.69)	-0.136***	(-7.65)	-0.081***	(-13.61)	-0.129***	(-6.30)
INNOVABAN *SEARCH	-0.328***	(-2.80)	-0.321***	(-3.51)	-0.320***	(-2.73)	-0.473***	(-3.69)	-0.223***	(-6.00)	-0.403***	(-3.18)
INNOVABAN *COLLAB	-0.504***	(-5.81)	-0.373***	(-5.75)	-0.359***	(-4.12)	-0.423***	(-4.80)	-0.088**	(-2.08)	-0.321***	(-3.60)
INNOVABAN *$SEARCH^2$	0.102	(1.24)	0.158***	(2.63)	0.235***	(3.07)	0.325***	(3.95)	0.067***	(5.07)	0.196**	(2.29)
INNOVABAN *$COLLAB^2$	0.121***	(3.96)	0.106***	(4.81)	0.075**	(2.52)	0.106***	(3.49)	0.075**	(2.20)	0.082**	(2.56)
Controls												
INTKNOW	0.223***	(18.13)	0.122***	(16.86)	0.195***	(19.76)	0.173***	(20.43)	0.132***	(38.32)	0.144***	(13.34)
EXTKNOW	0.023	(1.21)	0.027**	(2.55)	0.032**	(2.14)	0.032***	(2.65)	0.025***	(4.83)	0.022	(1.48)
LABOR	0.001***	(8.00)	0.001***	(6.18)	0.000***	(2.96)	-0.000	(-0.89)	0.001***	(19.97)	0.000***	(4.18)
EMPLOYMENT	-0.020	(-0.84)	0.050***	(3.69)	0.019	(1.07)	-0.187***	(-9.84)	0.114***	(24.06)	0.047**	(2.36)
Manufacture (as base)												
Mining	-0.879***	(-2.71)	-0.408*	(-1.69)	-0.334	(-0.94)	-0.584**	(-2.57)	0.668***	(5.36)	-0.946*	(-1.87)
Electricity	0.081	(0.11)	-0.991***	(-3.63)	-0.634*	(-1.87)	-0.340	(-1.09)	0.267*	(1.75)	-0.568*	(-1.68)
Construction	-0.944***	(-6.57)	-0.505***	(-5.52)	-0.215*	(-1.64)	-0.360***	(-3.49)	0.387***	(3.04)	-0.613***	(-4.82)
Accommodation	-0.509***	(-3.35)	-0.433***	(-4.72)	-0.045	(-0.40)	0.020	(0.20)	0.452***	(3.53)	-0.409***	(-3.13)
Transportation	-0.558***	(-4.48)	-0.212**	(-2.45)	-0.149	(-1.39)	-0.074	(-0.76)	0.526***	(4.14)	-0.287***	(-2.59)
Other	-0.242***	(-3.61)	-0.276***	(-6.41)	-0.077	(-1.46)	0.023	(0.50)	0.467***	(3.75)	-0.212***	(-3.53)
Regional dummies	Included		Included		Included		Included		Included		Included	
Year dummies	Included		Included		Included		Included		Included		Included	
No. of observation	41877		41877		41877		41877		41877		12972	
Wald Chi Square	6901.864		9669.575		8997.589		7913.117		22142.98		5479.187	
Prob>chi2	0.000		0.000		0.000		0.000		0.000		0.000	

† Panel effect GEE model; ‡ Sample with at least two observations
* p<0.05 ** p<0.01 *** p<0.001

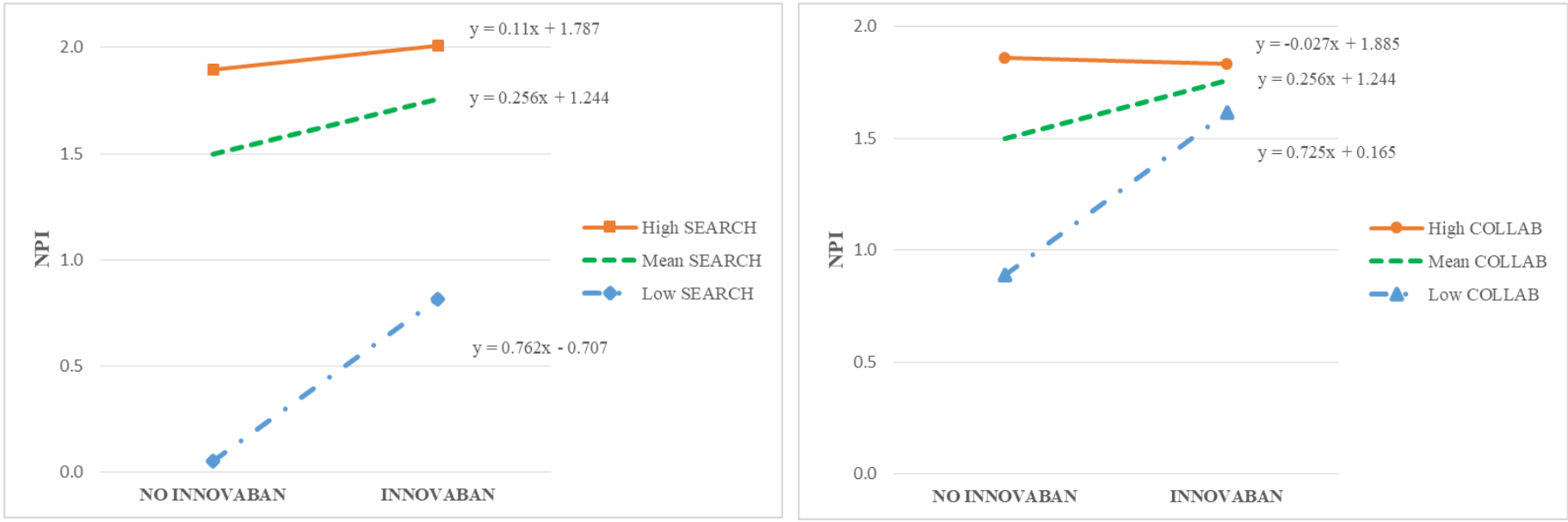
Table 5: Robustness Check for Innovation Activity Abandoning Effect on New Product Innovation: Alternative Estimate Strategy

Dependent variable: NPI	Model 12 OLS		Model 13 GLM		Model 14 Tobit†		Model 15 Wooldridge		Model 16 Matching	
	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value	Coefficient	z-value
NPI_{t-1}							0.083***	(15.76)		
INNOVABAN	0.610***	(7.47)	0.252***	(6.35)	1.589***	(8.17)	0.360***	(5.89)	0.368***	(7.20)
SEARCH	0.831***	(43.19)	0.926***	(42.58)	3.318***	(53.83)	0.757***	(19.42)	1.016***	(9.93)
COLLAB	0.972***	(27.69)	0.487***	(18.72)	1.967***	(22.54)	0.304***	(7.40)	0.354***	(8.74)
$SEARCH^2$	-0.297***	(-13.60)	-0.527***	(-27.87)	-1.656***	(-27.68)	-0.405***	(-13.10)	-0.517***	(-8.21)
$COLLAB^2$	-0.253***	(-18.54)	-0.127***	(-13.30)	-0.512***	(-15.46)	-0.074***	(-5.12)	-0.089***	(-6.86)
INNOVABAN *SEARCH	0.380***	(4.51)	-0.328***	(-4.60)	-0.513**	(-2.19)	-0.331***	(-2.99)	-0.430***	(-3.64)
INNOVABAN *COLLAB	-0.514***	(-5.83)	-0.381***	(-8.59)	-1.482***	(-7.21)	-0.413***	(-6.15)	-0.131***	(-2.67)
INNOVABAN *$SEARCH^2$	-0.169**	(-2.28)	0.182***	(3.71)	0.240	(1.28)	0.140*	(1.91)	0.216***	(2.93)
INNOVABAN *$COLLAB^2$	0.165***	(5.20)	0.096***	(6.16)	0.419***	(5.71)	0.100***	(4.43)	0.032**	(2.02)
Controls										
INTKNOW	0.388***	(48.83)	0.151***	(27.98)	0.676***	(34.78)	0.101***	(13.96)	0.090***	(15.06)
EXTKNOW	0.074***	(5.99)	0.011	(1.23)	0.050*	(1.72)	-0.007	(-0.76)	-0.011*	(-1.69)
LABOR	0.001***	(16.53)	0.000***	(5.77)	0.002***	(8.52)	0.000***	(3.22)	0.001***	(5.37)
EMPLOYMENT	0.154***	(17.06)	0.034***	(3.01)	0.086***	(3.19)	0.046***	(3.22)	0.039***	(3.79)
Manufacture (as base)										
Mining	-0.824***	(-5.05)	-0.423**	(-2.17)	-1.952***	(-3.76)	-0.468*	(-1.94)	-0.295*	(-1.68)
Electricity	-1.226***	(-5.30)	-0.467	(-1.34)	-2.827***	(-3.91)	-0.050	(-0.09)	-1.038***	(-2.71)
Construction	-0.595***	(-10.45)	-0.495***	(-6.58)	-1.834***	(-10.25)	-0.380***	(-3.27)	-0.232**	(-2.42)
Accommodation	-0.482***	(-7.93)	-0.355***	(-4.81)	-1.139***	(-6.03)	-0.324**	(-2.54)	-0.220**	(-2.13)
Transportation	-0.349***	(-6.01)	-0.204***	(-3.00)	-0.921***	(-5.26)	-0.059	(-0.66)	-0.225***	(-2.84)
Other	-0.460***	(-14.35)	-0.213***	(-6.40)	-1.031***	(-11.47)	-0.222***	(-5.17)	-0.147***	(-5.08)
Regional Dummies	Included		Included		Included		Included		Included	
Year Dummies	Included		Included		Included		Included		Included	
No. of observations	41877		41877		41877		13472		6970	
AIC	198592.763		94034.710		108232.775		N/A		33465.529	
BIC	198895.250		94337.197		108552.547		N/A		33705.257	
Wald Chi Square	F-statistics 1088.248		6562.961		15676.456		6086.838		1308.943	

Prob>chi2	0.000	0.000	0.000	0.000	0.000

† Panel effect model.
* p<0.05 ** p<0.01 *** p<0.001

Figure 1 The moderating effect of SEARCH and COLLAB on the relationship between INNOVABAN and NPI



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